University of Brighton

School of Health Sciences

An analysis of the kinematics of the elbow and wrist joints, and the muscle activity of the arm when using three different computer mice

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Abstract

Overall Aim: To investigate the effect of mouse design on static posture and movement of the elbow and wrist joint, and muscle activity of the arm, overall body posture, and mouse usability when using three different computer mice.

Search Strategy: Computerized databases and books were searched (1993-2017).

Methods: This research study has been carried out with the aim to understand how the design of a computer mouse influences the biomechanics of the upper limb. A large-scale study was carried out to investigate the posture and range of movement of elbow and wrist, and the activity of muscles in the arm (biceps, triceps, brachioradialis, wrist flexors and wrist extensors) when using a computer mouse. Three different designs of computer mouse (Standard, Penguin and Evoluent) were tested during a variety of standardised computer activities. Preliminary work was carried out to ensure the validity and reliability of the tools used.

Sample: Convenience sampling was used; healthy male and female participants aged 18 to 70 years old, who were either right or left handed.

Results: The measurement tools from preliminary studies were shown to be valid. The accuracy of Electrogoniometer was found to be good, with random errors of less than 0.2° at rest, and 0.5° during movement; the data were also found to be reliable.

The main study showed that wrist extension was significantly greater with the Evoluent mouse at rest (Evoluent 37.6˚ $\pm$12.7˚, Penguin 24.2˚ $\pm$ 11.8˚, Standard 28.1˚ $\pm$ 9.34˚) and during movement (Evoluent 43.0˚$\pm$ 11.9˚, Penguin 35.4˚$\pm$ 13.8˚, Standard 35.5˚$\pm$ 8.67˚) when compared to the Standard and Penguin mice. The wrist posture was significantly different with the Standard mouse, since it was the only mouse design that positioned the wrist into ulnar deviation when at rest (Standard 1.33˚$\pm$ 8.81˚, Penguin 8.92˚$\pm$ 9.81˚, Evoluent 5.02˚$\pm$ 9.88˚) and during movement (Standard 0.507˚ $\pm$14.5˚, Penguin 3.95˚$\pm$14.0˚, Evoluent 5.17˚$\pm$13.4˚). The Penguin mouse was significantly associated with a more relaxed and neutral wrist posture whilst performing a computer task ($p < 0.001$). When considering the EMG data, the mean voltage and maximum voltage of wrist extensors was greatest when using the Standard mouse; mean voltage (Standard 0.0334 $\mu V \pm 0.0191 \mu V$, Penguin $0.0260 \mu V \pm 0.0139\ \mu V$, Evoluent 0.0286 $\mu V \pm 0.0185\ \mu V$) and maximum voltage (Standard 0.0843 $\mu V \pm 0.0484\ \mu V$, Penguin $0.0703\ \mu V \pm$ 0.0406 μV, Evoluent 0.0697 $\mu V \pm 0.0389\ \mu V$). Looking at the overall posture, the Penguin mouse was the one that maintained the overall and forearm posture closest to the neutral position (mean grand score = 2, mean in each body part = 1). The Evoluent mouse was the most comfortable (56% respondents) and the most preferred mouse (58% respondents) from the usability questionnaire.

Conclusion: This study found a significant difference in the posture, movement and muscle activity of the arm and the overall body posture between the three different mice used. The vertical mouse allows a more relaxed posture whilst performing a computer task compared with a Standard mouse, reducing the potential for musculoskeletal injury.

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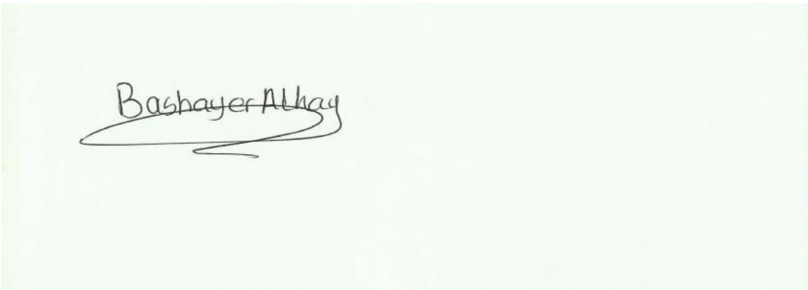
Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree and does not incorporate any material already submitted for a degree.

Signed



Dated

29/05/2018

1 Chapter 1: Introduction

1.1 Introduction

Work-related musculoskeletal disorders (WRMSD) have been commonly observed in office workers and an increase of about 40% in the frequency of musculoskeletal symptoms through the years has been observed with the rapid development of computer technologies and the increased usage of computers (Ardahan and Simsek, 2016). WRMSDs are defined as “any injury, damage or disorders of the joint or other tissue in the upper/lower limbs or the back” (Health and Safety Executive, 2011, online).

In the literature, a direct relationship between computer usage and musculoskeletal disorders with computer users has been found (Blatter and Bongers, 2002; Cook et al., 2000; Fagarasanu and Kumar, 2003; Flodgren et al., 2007; Ortiz-Hernandez et al., 2003; Jensen et al., 2002; Ming and Zaproudina, 2003; Muller et al., 2010; Kaliniene et al., 2013; Ardahan and Simsek, 2016). This is because computer users tend to spend long working hours in front of a computer (Blatter and Bongers, 2002; Cook et al., 2000; Fagarasanu and Kumar, 2003; Flodgren et al., 2007; Ortiz-Hernandez et al., 2003; Jensen et al., 2002; Ming and Zaproudina, 2003; Muller et al., 2010; Kaliniene et al., 2013; Ardahan and Simsek, 2016). Long-term usage of computers for 7 hours per day, working at a desk and sitting for a long time in a chair in the workplace for 3 hours without rest are the main reasons playing a role in the WRMSD with computer users (Kaliniene et al., 2016; Ardahan and Simsek, 2016). The purpose of these studies has also been to find the risk factors of WRMSD.

Mouse design is likely to be an important factor in modifying the joint position whilst performing a computer task, as suggested by several authors (Aarås et al., 2002; Burgess-Limerick et al., 1999; Gustafsson and Hagberg, 2003; Keir et al., 1999; Won et al., 2009) , as well as in muscle activity (Chen and Leung, 2007; Dennerlein et al., 2002; Fagarasanu, Kumar and Naryan, 2004; Houwink and Hengel, 2009; Sanfeld and Jensen, 2005; Tittiranonda, Martin and Burastero, 2002; Won et al., 2003). The use of the mouse, the pointing device for the computer user interface, has increased with the increasing use of personal computers and is now used in many leisure applications such as computer games (Cook et al., 2000). The Health and Safety Executive (HSE, 2017, online) found

97% of computer users use a mouse with desktop computers, while 64% use a mouse with laptops according to their annual statistics report. In addition, the HSE found that 20% of computer users use trackballs with a desktop computer as a non-keyboard input device (NKID). Also, 28-30% of laptops were used with touchpad and trackball touchpads (HSE, 2017, online). These statistics support the findings from studies by Cook et al. (2000), Fagarasanu and Kumar (2003), Flodgren et al. (2007), Jensen et al. (2002) and Muller et al. (2010), identifying the mouse as the most common NKID adopted by computer users.

Gustafsson and Hagberg (2013) examined the effect of using a standard mouse (non-slanted mouse) with a neutral mouse which keeps the hands in a more neutral position, whilst performing an editing task for 15 minutes each. An electrogoniometer was used to measure the wrist range of motion, and a modified Borg scale to measure the level of exertion. This study showed that using a standard mouse tends to cause musculoskeletal symptoms such as pain and discomfort in the forearm. Also, wrist extension and ulnar deviation were increased when working with a standard mouse.

A standard mouse also tends to create repetitive movements, a fixed posture and a static load on the forearm, all of which have been found to be risk factors for musculoskeletal problems (Flodgren et al., 2007). Karlqvist et al. (1999) found that working with a standard mouse entailed higher shoulder elevation compared to using a trackball.

Ergonomics is a science of equipment design such as for the workplace, with the intention to minimise physical effort and discomfort and maximise productivity and efficiency to promote musculoskeletal health (Westgaard and Winkel, 1997). The aim of ergonomics is in how to improve people’s efficiency in the workplace, as well as improving working conditions, and the work tools for optimum results to be achieved from the work and the person at work (Shariat et al., 2017; Westgaard and Winkel, 1997). Ergonomics has helped to reduce work related discomfort and musculoskeletal disorders and increase productivity and job satisfaction (Westgaard and Winkel, 1997). Therefore, ergonomics is important for the preventative field of industrial health and safety (Westgaard and Winkel, 1997).

Several ergonomic and comparative studies have demonstrated ways to minimise the risk of musculoskeletal problems (Aarås et al., 2002; Chen and Leung, 2007;

Cook et al., 2000; Delisle et al., 2004; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). The aforementioned studies have shown that an effective way of minimising such risks includes adopting a more neutral position of the forearm. A neutral position helps to ease the pain on the body and improve work comfort (Aarås et al., 2002; Chen and Leung, 2007; Cook et al., 2000; Delisle et al., 2004; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). The neutral position is when the shoulder girdle is relaxed and not into elevation and the forearm should be in the mid pronated position. Furthermore, the elbow joint should be flexed to 90° and the wrist should be in neutral, not into radial and ulnar deviation, and not flexed to more than 15° (Aarås et al., 2002; Karlqvist et al. 1999).

The application of Ergonomics may help to reduce the risk of injury whilst using a computer with the right computer tools, better overall posture and good working habits (Shariat et al., 2017; Tepper et al., 2017; Westgaard and Winkel, 1997). Many computer users with a standard working day being 7 hours long and this could develop bad working habits and poor posture, which then lead to short-term pain and discomfort that can turn into long-term injuries (Shariat et al., 2017; Tepper et al., 2017; Westgaard and Winkel, 1997). Long-term injuries could occur due to repetitive movements (Greene et al., 2017) and awkward posture of the forearm, when the position of the body deviates significantly from the neutral position (Sharita et al., 2017). Symptoms of these injuries include pain, discomfort, swelling, joint stiffness, muscle weakness and numbness (Greene et al., 2017; Shariat et al., 2017).

The field of ergonomics will help computer users to become more aware of their overall posture and their workstation adjustments during computer work to avoid pain, discomfort and potential injury (Shariat et al., 2017). Ergonomics provides a number of useful tips that every computer user should follow to avoid WRMSD and to promote musculoskeletal health (Shariat et al., 2017). Those tips are: head should be in a balanced position, not leaning forward; arms relaxed at the side; forearm should be parallel to desk, screen at approximately arm’s length and the height of the screen according to the eye level (Shariat et al., 2017). Also, the feet should be flat on the floor or on a footrest (Shariat et al., 2017). Following these tips will ensure comfort during computer use by having a good posture. Furthermore, it will allow the forearm to be relaxed and in a neutral position, whereby the arms can move in the neutral reach zone without having to be raised up or down.

An extensive literature search that looked at computer mouse design and WRMSD, using different databases, was carried out: Science Direct, SAGE Journals Online, Web of Science and PubMed, and with different search terms: computer mouse and musculoskeletal disorders, computer user and musculoskeletal disorders, work related musculoskeletal disorders, elbow posture and computer mouse, wrist posture and computer mouse, forearm posture and computer mouse, and mouse design and musculoskeletal disorders. The literature considering the influence of computer mouse design on working posture and muscle activity and how it relates to WRMSD was limited, as was the literature considering the elbow and wrist joint ranges of movement when operating a computer mouse. This resulted in only six studies proposing an association between computer mouse use and WRMSD through their experimental study designs being found. Those six studies are considered the key studies in this research study, the details of which are set out in the literature review.

The aims of this study were:

1. To have a background knowledge from the literature review of how computer mouse design could increase risk of work-related musculoskeletal disorders (WRMSD).
2. To design a methodology to investigate risk factors for musculoskeletal pain when using a computer mouse.
3. To investigate the effect of mouse design on static posture and movement of wrist flexion, extension, radial deviation and ulnar deviation, and elbow flexion and extension.
4. To investigate the effect of mouse design on muscle activity of biceps, triceps, brachioradialis, wrist flexors and wrist extensors.
5. To investigate the effect of mouse design on overall body posture using Rapid upper limb assessment tool (RULA).
6. To investigate the usability of mouse design during typical use by using a usability questionnaire.

This research study has been carried out to fill the gap in the literature with the aim to understand how the design of a computer mouse influences the posture and biomechanics of the elbow and wrist as well as to look at whether there is a significant difference between mouse designs used on the posture and muscle activity of the elbow and wrist joint. To this end, four questions were raised in this research study:

1. How does the design of a computer mouse affect the posture and movement of the elbow and wrist during typical use?

2. How does the design of the computer mouse influence the muscle activity of the forearm during typical use?

3. How does the design of the computer mouse affect the overall posture during typical use?

4. How does the design of a computer mouse affect the usability during typical use?

In summary, there is a need for further studies to establish the association between computer mouse use and WRMSD, and to investigate the influence of computer mouse design on posture and muscle activity.

1.2 Potential impact of the research study

This study may help the physiotherapists working with patients with WRMSD, and physiotherapists and physical therapy students who are interested in mouse design, WRMSD and ergonomics, as well as clinicians working in ergonomics to gain more information about mouse design and how it affects the posture and muscle activity of the elbow and wrist joint. Furthermore, it could help computer mouse designers learn how mouse design could affect the posture and biomechanics of the elbow and wrist joint. This might help the mouse designers in how to improve future mouse design. In summary, there is a need for further studies to establish the association between computer mouse use and WRMSD, and to investigate the influence of computer mouse design on posture and muscle activity.

1.3 Outline of the thesis

This thesis is divided into six chapters. Chapter One has presented a literature review of computer use and its relationship to WRMSD together with a brief background. Chapter Two presents the first phase of the preliminary experimental work in this study: the validity pilot study (Artificial rig study) together with a review of the method and the results. Chapter Three presents the second phase of the preliminary studies, with preliminary findings discussed in this chapter. Chapter Four discusses the Reliability study with the methods and results and Chapter Five discusses the final study concerning computer mice comparison, with the methods and results discussed in this chapter. Chapter Six discusses the overall doctoral study.

1.4 Literature Review

1.4.1 Overview of WRMSD, Computer use, and Computer mouse design

1.4.1.1 A review of the pathophysiology and anatomy of work-related musculoskeletal disorders (WRMSD)

Elbow and wrist symptoms and signs were found to be prevalent with workers performing a repetitive task and have been classified as an occupational injury (Zetterberg and Ofverholm, 1999). It is important to understand what this injury means: the causes and the physiological process associated with the injury and have a brief background about the anatomy of the site of injury.

Repetitive Strain Injury (RSI) is a general term that is used to describe an injury in the musculoskeletal and nervous systems caused by repetitive movements, vibrations or a static working position (Reilly, 1995; Zetterberg and Ofverholm, 1999). The pathophysiology of this injury is based on the soft and nervous tissues adapting to the stresses placed on them over time and these stresses include tension, compression, impingement and vibration. This then leads to fatigue within tendons, ligaments, neural tissue, and other soft tissues (O'Neil et al., 2001; Zetterberg and Ofverholm, 1999).

It was found that individuals who perform repetitive stereotypical movements at work are at high risk of developing WRMSD (Cappell, 2006). This is due to mechanical stress at specific joints or tendons (Cappell, 2006), which could lead to Carpal tunnel syndrome (CTS), Tennis elbow or lateral epicondylitis and DeQuervain's syndrome. In particular, DeQuervain's syndrome has been shown to be related with occupational risk factors and is an inflammation in the synovial sheath of the thumb tendons, the tendons of extensor pollicis brevis and abductor pollicis longus muscles (Cappell, 2006). These two muscles run adjacent to each other and function to move the thumb away from the hand; the extensor pollicis brevis extends and abducts the thumb, and the abductor pollicis longus abducts the thumb. DeQuervain's syndrome occurs due to frequent and repetitive thumb movements that could lead to thumb tendon injury (Cappell, 2006). When inflammation in the synovial sheath of the thumb tendons occurs due to repetitive thumb movements, thickening of the tendons and mucoid degeneration occur consistently with a chronic degenerative process. This will then develop to a DeQuervain's syndrome (Cappell, 2006).

CTS has been discussed commonly as an occupational injury (Lublin, Rojer and Barron, 1998; Zetterberg and Ofverholm, 1999). It is a medical condition that occurs due compression of the median nerve and is a common disorder of the hand (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). CTS can be associated with any condition that causes pressure on the median nerve at the wrist (Lublin et al., 1998; Zetterberg and Ofverholm, 1999).

The carpal tunnel is located at the base of the palm and is an anatomical compartment through which nine flexor tendons and a median nerve pass (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). The median nerve provides sensation to the thumb, index finger, long finger, and half of the ring finger. Thus, numbness, pain and sensory loss are the main symptoms of this disorder (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). The median nerve supplies the muscles at the base of the thumb, the flexor pollicis brevis, which flex the thumb; the abductor pollicis brevis, which abducts the thumb; and opponens pollicis, which opposes the thumb (Lublin et al., 1998). Because of that, any compression to the median nerve could cause atrophy, weakness in these muscles, and sensory loss in the fingers supplied by this nerve.

Mainly, it has been associated with workers using highly repetitive hand movements (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). Repetitive hand movements could stress the tendons that attach the hand and arm muscles to the bone. When tendons are overworked, micro-trauma and inflammation could occur and could cause tendinitis. In the long run, tendinitis could progress to CTS. This is because the swelling from tendinitis can end up causing carpel tunnel problems, since the swelling can put pressure on the medial nerve. Then persistent tissue edema will occur with the obstruction of venous outflow, resulting in sensory loss, muscle atrophy and ischemia in the nerve.

Tennis elbow is a condition in which the lateral part of the elbow becomes sore and the forearm tendons and muscles become damaged from repetitive use

(McMurtrie and Watts, 2012; Waugh, 2005). It affects the muscles that responsible for forearm supination, wrist extension and extension of the fingers. This condition leads to pain and tenderness of the elbow. Also, the pain is increased by increased wrist extension (Waugh 2005).

Many cases of tennis elbow have been found to be associated with WRMSD (Waugh 2005). For example, computer users could find that their mouse use causes their forearm to be held in a tensed or in an uncomfortable posture for long periods (Waugh 2005). As the forearm is held in a tensed posture, it may increase tension in the tendon and therefore mechanical stress could lead to micro-trauma and inflammation (Waugh 2005). This could lead to muscle and tendon damage because of inflammation of the radial humeral bursa, the fluid filled sac, and the ligaments. This then leads to microscopic tearing with scar formation at the origin of the Extensor Carpi Radialis Brevis (ECRB) muscle tendon, in turn leading to mucoid degeneration, fibrinoid necrosis in tendons and proliferation of fibroblasts. It has been found that the best action or solution to take is to adopt a more relaxed posture of the forearm whilst performing a computer task (Waugh 2005).

In summary, repetitive movements and a tensed static posture could play an important role in initiating musculoskeletal symptoms or disorders. Understanding the underlying causes and the anatomy of the injury could help to understand the meaning of the injury and assist in finding simple preventative manoeuvres to minimise the risk of WRMSD. The next section discusses WRMSD and computer use more specifically.

1.4.1.2 WRMSD and Computer Use

Studies have shown that musculoskeletal disorders are widely prevalent among employees working with a computer (Blatter and Bongers 2002; Cook et al., 2000; Ortiz-Hernandez et al., 2003; Jensen et al., 2002). Various assessments of WRMSD have tried to determine any association between them and computer usage (Blatter and Bongers 2002; Cook et al., 2000; Ortiz-Hernandez et al., 2003; Jensen et al., 2002).

According to the HSE (2017, online), the prevalence of WRMSD in the United Kingdom (UK) has increased particularly in full-time workers (2.2%) compared to part-timers (1.6%), with the greatest rise in WRMSD occurring mostly between 2006 and 2007 in the UK when compared to 2008-2011, the rate then remaining flat until 2013/2014. The prevalence of WRMSD cases in the UK was 508,000 by the end of 2011; nonetheless, the prevalence of WRMSD cases in 2015/2016 increased and was 539,000 cases, and then decreased to 507,000 cases in 2016/2017 (HSE, 2017, online).

The Labour Force Survey (LFS), an annual survey of 38,000 households in the UK that found the prevalence of WRMSD by causative factors, discovered that manual handling and carrying were the main factors in the development of WRMSD in approximately 800 cases per 100,000 people (HSE ,2017, online). Additionally, repetitive movements such as keyboard or mouse work or repetitive action (about 200 cases per 100,000) or being in an awkward fatiguing position (about 400 cases per 100,000 people) were the other main reported factors in the development of WRMSD (HSE, 2017, online).

Furthermore, a survey of occupationally trained General Practitioners (GPs) across the UK, a health and occupation network of general practitioners (THOR-GP), carried out between 2005 and 2016 recorded WRMSD in their patients in their local surgeries. This survey found that the majority of patients suffered with back pain in approximately 1,000 cases, or disorders in the elbow or wrist in approximately 800 cases. This could be due to repetitive movements as addressed by the GPs and most likely reflected what was suggested in the LFS.

Fagarasanu and Kumar (2003), and Ming and Zaproudina (2003), reported that personal, occupational and data entry risk factors could increase the likelihood of developing WRMSD. Personal risk factors could be, for example, being aged between 30 and 50, having previously had a wrist fracture and pre-existing joint hypermobility; occupational risk factors could include the time spent on the task and the force applied on the upper limb; and data entry risk factors could be typing speed; higher typing speeds a greater risk of injury, and the use of a particular group of fingers.

WRMSD can be divided into WRMSD related to computers generally due to poor posture, and WRMSD related specifically to the use of the computer mouse and that arises from arm and hand movements such as holding, gripping, twisting and the continual repetition of these movements that could lead to WRMSD (Cook et al., 2000). The most common example of WRMSD frequently affected by computer mouse use is CTS, as stated by Cook et al. (2000).

Two studies found a relationship between the duration of computer and mouse use with increased risk WRMSD. First, Blatter and Bongers (2002) examined the link between WRMSD for the upper limb and duration of mouse use between different genders with musculoskeletal symptoms in a cross-sectional study design, using a questionnaire distributed to all office employees with WRMSD. The results showed that mouse use for more than 6 hours per day would increase the symptoms of WRMSD by more than 30%. Also, there was a significant difference between the duration of mouse use and WRMSD in the neck, shoulder and wrist ($p < 0.05$). The value of this study was limited since its design might have resulted in a selective response in that only those employees with poor working conditions or with health problems might have participated in the study rather than those in good health.

Second, in their cross-sectional study, Jensen et al. (2002) distributed a questionnaire to 3,475 respondents with WRMSD who worked full time with a computer between 32 and 41 hours per week. The results found that a prolonged duration of computer and mouse use could increase the risk of WRMSD. Jensen et al. (2002) also found significant differences between the duration of computer and mouse use with WRMSD in the neck, shoulder and wrist ($p < 0.05$). This finding was consistent with the finding from the Blatter and Bongers (2002) study. It could be reported that this study was also limited as it showed only the relationship between the duration of computer and mouse use and participants with WRMSD; it did not show how prolonged use of computers could really affect healthy participants to indicate the real influence of prolonged exposure to computer and mouse use with WRMSD.

Additionally, two studies looked at the association between computer and mouse use and WRMSD: Cook et al. (2000) used a questionnaire in their cross-sectional study, with healthy participants divided into intensive and non-intensive mouse users; and Ortiz-Hernandez et al. (2003) distributed a questionnaire among newspaper office workers. The questionnaires in each study concerned the duration of computer and mouse use at work and at home, and the frequency of breaks and exercise.

These studies (Cook et al., 2000; Ortiz-Hernandez et al., 2003) found a greater risk of WRMSD with those involved in a specific task requiring repetitive movements such as a painting task and with those adopting an uncomfortable position of the forearm; adopt a particular working posture of wrist pronation, extension and ulnar deviation whilst performing a computer task could lead to musculoskeletal disorders such as CTS and repetitive strain injury (RSI). The latter is a condition whereby prolonged performance of repetitive actions causes deficiency of function in the involved tendons and muscles, and pain. Ortiz-Hernandez et al. (2003) found that prolonged duration of computer mouse use might increase the risk of WRMSD. However, Cook et al. (2000) found no significant results in the duration of mouse use and musculoskeletal symptoms, contradicting the findings of Blatter and Bongers (2002), Ortiz-Hernandez et al. (2003), and Jensen et al. (2002). However, a significant relationship was found with other variables such as shoulder abduction when using the mouse, and with non-mouse risk factors such as the screen height above or below eye level and shoulder elevation.

From the Cook et al. (2000) and Ortiz-Hernandez et al. (2003) studies, a relationship between computer mouse use and increased risk of WRMSD due to several risk factors can be seen. One of the real strengths of these cross-sectional studies was in their sampling technique (using healthy participants) to investigate possible correlations between computer mouse use and WRMSD. Using healthy participants will help to reach the aim of these studies more quickly than using population of patients.

Thus, the findings from the above studies (Blatter and Bongers, 2002; Cook et al., 2000; Ortiz-Hernandez et al., 2003; Jensen et al. 2002) could indicate a rise in the incidence rate of WRMSD following the increase in computer and mouse use, and the symptoms could be greater in those spending more time working at the computer and in those with a history of WRMSD. These surveys indicated the co-existence of computer use and musculoskeletal symptoms, but there is a lack of research looking at how and why these might be linked.

After becoming familiar with the term WRMSD and the prevalence of WRMSD, the next section discusses the most common input device that is used mainly in any computer setting and an overview of the computer mouse design. Table 1.1 below summarises the results of the literature discussed in this section.

Table 1.1 *Summary results of the studies discussed about WRMSD and computer use.*

Authors	Method	Population	Outcome
Jensen et al. (2002) Cook et al. (2000) Ortiz-Hernandez et al. (2003) Blatter and Bongers (2002)	Examined the link between WRMSD for the upper limb and the duration of computer mouse use by distributing a questionnaire.	Jensen et al. (2002) used 3,475 respondents with WRMSD (full-time with computer use between 32 and 41 hours/week). Cook et al. (2000) used healthy participants, divided into intensive and non-intensive mouse users. Ortiz-Hernandez et al. (2003) used healthy newspaper office workers. Blatter and Bongers (2002) used office employees with WRMSD.	-Prolonged duration of computer mouse use could increase the risk of WRMSD (Jensen et al., 2002; Ortiz-Hernandez et al., 2003; Blatter and Bongers, 2002). -Significant difference between the duration of mouse use and WRMSD in the neck, shoulder and wrist ($p < 0.05$). -Cook et al. (2000) found no significant difference between the duration of mouse use and WRMSD. -Mouse use > 6 hours/day would increase the symptoms of WRMSD (Blatter and Bongers, 2002).

1.4.1.3 Overview of Computer Mouse Designs

There are numerous mouse designs on the market which may have the description “ergonomic”, but to be ergonomic, a mouse design should ease performance and reduce risk of injury (Hedge et al., 2010). A good mouse design can be determined by increased productivity, user satisfaction and well-being at the time of performing the task (Karlqvist et al., 1999). A recent trend in ergonomic mouse design is for the mouse to be vertical or slanted (Hedge et al., 2010). There is limited literature discussing how to consider the design of a computer mouse regarding its suitability as well as its effect on posture (Hedge et al., 2010;

Karlqvist et al., 1999; Lee and Su, 2008; Woods et al., 2003). These studies assessed NKIDs to identify factors for good design related to performance (ease of use), comfort (hand and finger positioning), operation (adequate control and good interaction with software), and time required to carry out the task.

Karlqvist et al. (1999) compared the standard Apple mouse with the standard Trackball in a 15-minute text editing exercise with healthy visual display unit (VDU) workers and observed that working with a trackball could lead to more wrist extension than with a mouse. This is thought to be due to the biomechanical demands differing between different input devices; joint position depends on the shape and size of the input device and users' anthropometry. Participants preferred the mouse because it was more precise, and easy to control. The trackball was comfortable as it did not need significant arm movement. The limitation in this study was the use of only one standard mouse with a standard trackball; there are different input devices on the market, as seen in the above studies. If different input devices had been used in this study, their similarities and differences and their effect on upper limb posture could have been ascertained to learn which design is effective for posture.

Woods et al. (2003) assessed 8 devices (D1 - D8) comprising standard and vertical mice, joystick mouse and trackball (each input device is explained in Figure 1.1). The participants carried out three computer tasks: answering a questionnaire, editing, and drag and drop. This study found the standard mouse was the most desirable one to use as well as the 3-button mouse (D1) and the 3-button curved mouse (D8). Furthermore, to help determine a good input device, Woods et al. (2003) made a device checklist which included how well it fit the user's hand, whether the user should have a trial before purchase, whether it was easy to use, and whether it was compatible for all software applications.

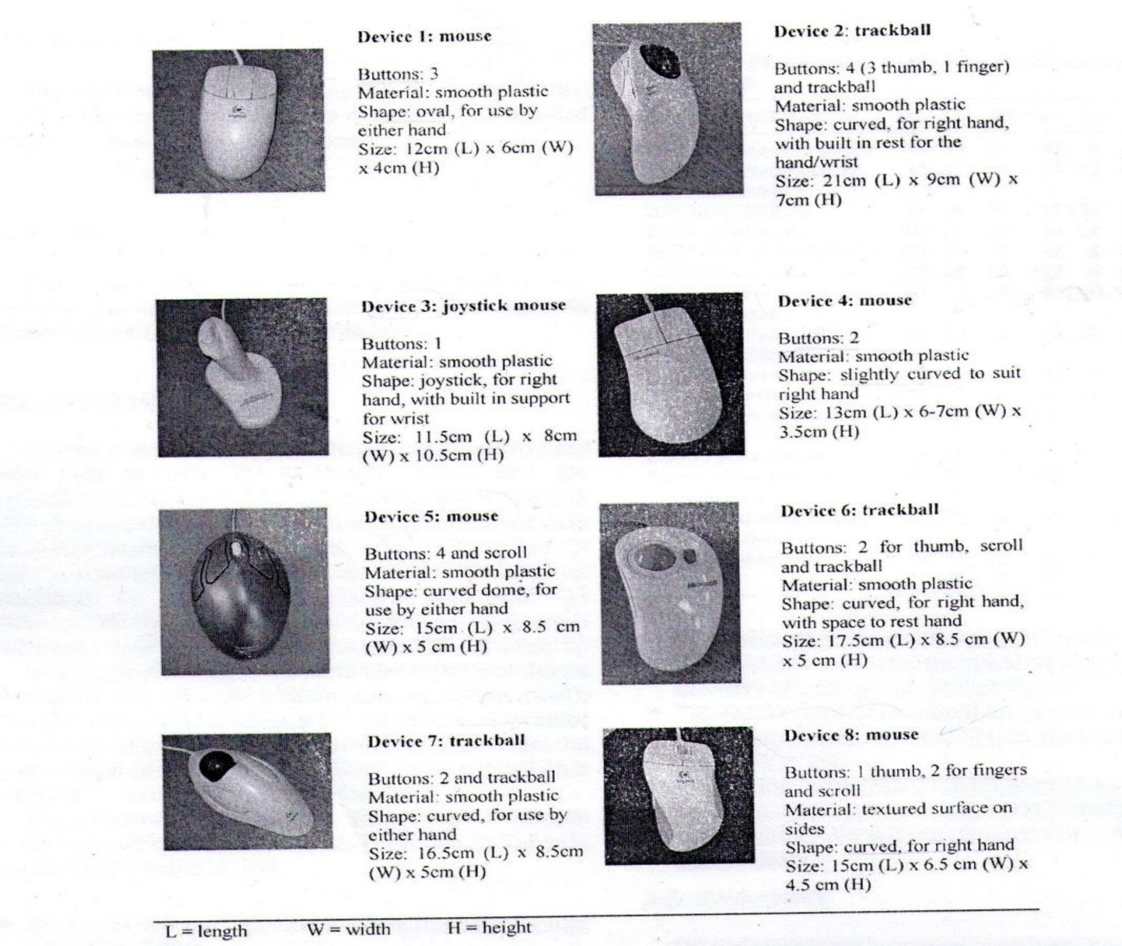
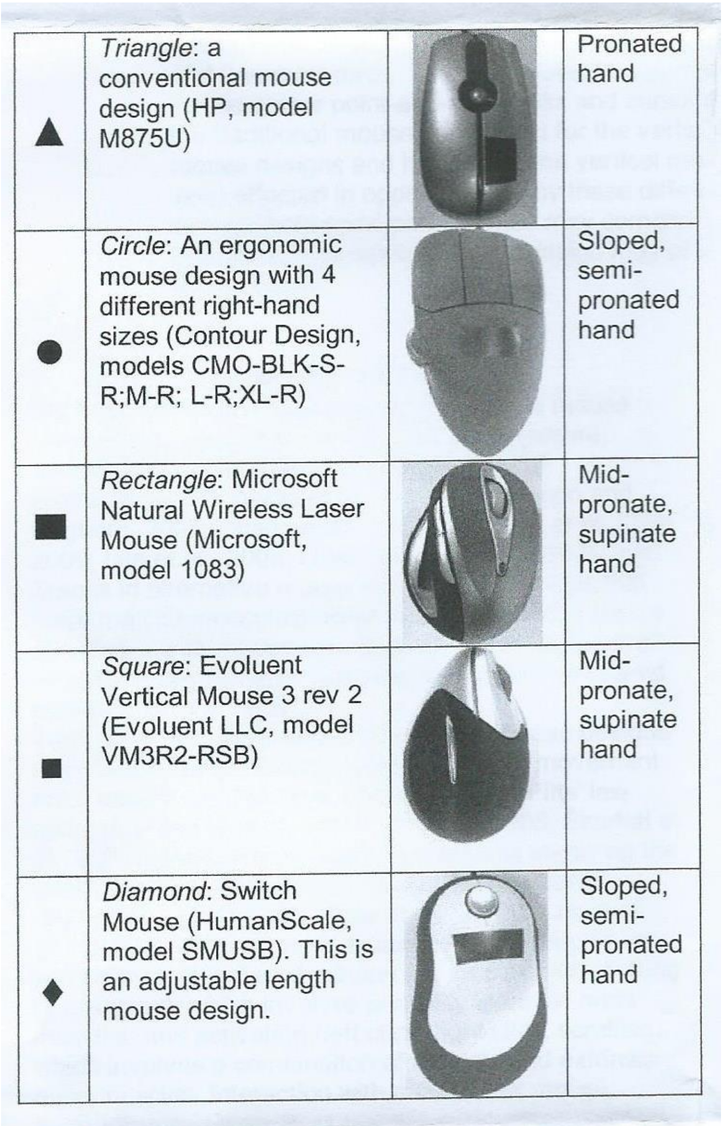


Figure 1.1 *Different Input Devices in Woods et al. (2003)*

Hedge et al. (2010) examined the effect of five different optical mice on wrist posture during a cursor positioning task (Figure 1.2), comprising: a traditional mouse; two slanted mice (contour mouse design and switch mouse that keep the hand in a semi-pronated position); and two vertical mice (a Microsoft wireless laser mouse and the Evoluent mouse that position the hand into half-way between pronation and supination). This study found task performance to be fastest with both the vertical mice and the contour mouse, and slowest with the traditional mouse. Less wrist extension, less than 20˚, was found with the switch mouse design where the hand was semi-pronated, but highest with the vertical mice, exceeding 30° wrist extension, and considered extreme for the vertical mouse as reported by Hedge et al. (2010). Less ulnar deviation was found with both vertical mice compared to the other mice in this study; the ulnar surface of the hand is close to the work surface when using these mice, giving little opportunity for ulnar deviation, which could keep the hand in a more neutral position. This study indicated that user performance and posture were affected by mouse design in opposing ways and that mouse design features promoting good wrist posture and good performance could be considered a good design.

The Woods et al. (2003) and Hedge et al. (2010) studies were ergonomically useful as they highlighted good design factors and checklists that are potentially useful in many areas such as for equipment manufacturers responsible for setting up the workstation and for people who would like to buy an NKID.



▲	*Triangle*: a conventional mouse design (HP, model M875U)		Pronated hand
●	*Circle*: An ergonomic mouse design with 4 different right-hand sizes (Contour Design, models CMO-BLK-S-R;M-R; L-R;XL-R)		Sloped, semi-pronated hand
■	*Rectangle*: Microsoft Natural Wireless Laser Mouse (Microsoft, model 1083)		Mid-pronate, supinate hand
■	*Square*: Evoluent Vertical Mouse 3 rev 2 (Evoluent LLC, model VM3R2-RSB)		Mid-pronate, supinate hand
◆	*Diamond*: Switch Mouse (HumanScale, model SMUSB). This is an adjustable length mouse design.		Sloped, semi-pronated hand

Figure 1.2 *Five different optical mice evaluated in Hedge et al. (2010)*

Finally, a study by Lee and Su (2008) discussed the effectiveness of using the multiple mouse wheels by performing three experimental tasks on the computer such as toolbar clicks using the conventional mouse and multiple mouse wheels. The multiple mouse wheels are defined as a mouse that provides multiple manipulation positions for scrolling by the finger; scrolling from the middle, from the left side and from the right side of the wheel through a sensing device. For example, when the user scrolls the wheel at one of the manipulation positions, the sensing device senses the position of the finger and then issues a signal to differentiate between different manipulation positions.

This study measured only the time to perform the task and found that the time was shorter when using the multiple mouse wheels ($p < 0.001$). Moreover, this mouse design enhanced the operating efficiency of software functions. The results in this study could illustrate the advantages or the effectiveness of using the multiple mouse wheels to reduce the operation time of the software. In this study, it might have been better to compare different mouse designs, for example, using a vertical mouse alongside a standard mouse and multiple mouse wheels to ensure the findings that multiple mouse wheels help to perform the task in a shorter time.

In brief, there seems to be no literature discussing whether any input device is inappropriate or has difficulties for usability; rather, only factors that may enable the device to be a good design. It seems that the mouse is the most favourable input device with computer users. If a product design reaches its specific goal by giving user satisfaction, being effective in its performance and offering a comfortable hand position, then this product can be considered a good design. Productivity could also be a good measure to ascertain whether a mouse or other input device is an efficient tool (Karlqvist et al., 1999). In contrast, a product which causes any discomfort, difficulty in its use and a lack of control for the user can be considered inappropriate.

Table 1.2 summarises the studies discussed in this section. After reviewing some of the computer mouse designs available in the market, the next section demonstrates the relationship between computer mouse design and WRMSD.

Table 1.2 *Summary of studies discussed in the overview of computer mouse designs.*

Authors	Method	Population	Outcome
Karlqvist et al. (1999)	Compared the standard Apple mouse with the standard Trackball in a 15-minute text editing task.	Healthy VDU workers.	Participants preferred the mouse because it was more precise, and easy to control.
Woods et al. (2003)	Assessed 8 devices (D1-D8) comprising standard and vertical mice, joystick mouse and trackball during three computer tasks.	27 NKI users working in health and safety.	This study found the standard mouse was the most desirable to use as well as the 3-button mouse (D1) and the 3-button curved mouse (D8).
Hedge et al. (2010)	Examined the effect of five different optical mice on the wrist posture during a cursor positioning task.	24 healthy right-handed university students (12 males,12 females).	Task performance fastest with both the vertical mice and the contour mouse, and slowest with the traditional mouse. Less wrist extension was found with the switch mouse design, but highest with the vertical mice. Less ulnar deviation was found with both vertical mice compared to the other mice.
Lee and Su (2008)	Discussed the effectiveness of using the multiple mouse wheels by performing three experimental tasks on the computer. This study measured only the time to perform the task.	Healthy participants (11 males, 9 females).	The time was shorter when using the multiple mouse wheels ($p < 0.001$).

1.4.1.4 Computer mouse design and WRMSD

The most common input device used during computer work nowadays is the computer mouse (Gustafsson and Hagberg, 2003). This common input device becomes an important factor in increasing the risk of musculoskeletal symptoms in today's workplace. Musculoskeletal symptoms in the upper extremity are common with computer mouse users, according to several studies (Aarås et al., 2002; Delisle et al., 2004; Flodgren et al., 2007; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). This is because of the non-neutral postures of the forearm, repetitive movements of the forearm and prolonged duration of computer and mouse use (Aarås et al., 2002; Delisle et al., 2004; Flodgren et al., 2007; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999).

However, unlike the keyboard, the number of studies that have tested the impact of mouse use on musculoskeletal health is limited. Only six experimental studies were found that discussed the association between computer mouse design and WRMSD. An extensive literature search that looked at computer mouse design and WRMSD, using different databases, was carried out: Science Direct, SAGE Journals Online, Web of Science and PubMed, and with different search terms: computer mouse and musculoskeletal disorders, computer user and musculoskeletal disorders, work related musculoskeletal disorders, elbow posture and computer mouse, wrist posture and computer mouse, forearm posture and computer mouse, and mouse design and musculoskeletal disorders. A PRISMA flow diagram illustrates how the researcher searched for these studies and these studies were considered the key studies in this research. A PRISMA flow diagram and a summary table of the key studies will be illustrated at the end of this section.

Flodgren et al. (2007) assessed wrist movements (flexion/extension and ulnar/radial deviation) and elbow movements (supination/pronation) using FASTRAK, an electromagnetic tracking system used to measure the range of movement in humans, while performing a painting task on the computer with healthy right-handed participants using a standard mouse. This study found that a painting task required repetitive movements in the wrist. This study also found that during computer mouse use, the mean range of motion in wrist flexion/extension was 14.8° with SD = 10.6°, the mean range for radial/ulnar deviation was 14.9° with SD = 5.5°, and the mean range of motion in pronation/supination was 12.7°

with SD = 4.2°. Moreover, the study found the prolonged period of computer and mouse use and the repetitive movements from doing the task for at least 3 or 4 hours of the working day could cause musculoskeletal symptoms such as pain and numbness to develop, as well as muscle fatigue.

Flodgren et al. (2007) tested the effect of a standardised painting task on wrist and elbow movements and it appears from their findings that this task could be suitable to study the relevant risk factors of WRMSD. This study also offers the potential to examine the pathophysiological mechanisms related to musculoskeletal disorders due to computer mouse use. However, it would be better to test several computer tasks on the posture of the wrist and elbow joint to generalize the findings of this study. Also, it would better to test different computer mouse designs using the same task used in the Flodgren et al. (2002) study to see the real effect of mouse design on the posture of the forearm and compare the range of motion results with the findings found related to the use of the standard mouse and check which mouse design could allow a relaxed posture whilst performing the same computer task.

Gustafsson and Hagberg (2003) compared the traditional mouse with the neutral mouse, a vertical mouse that keeps the hands in a more neutral position, for 15 minutes each (Figure 1.3). Wrist movements were recorded using an Electrogoniometer, with the modified Borg scale used to measure exertion levels.

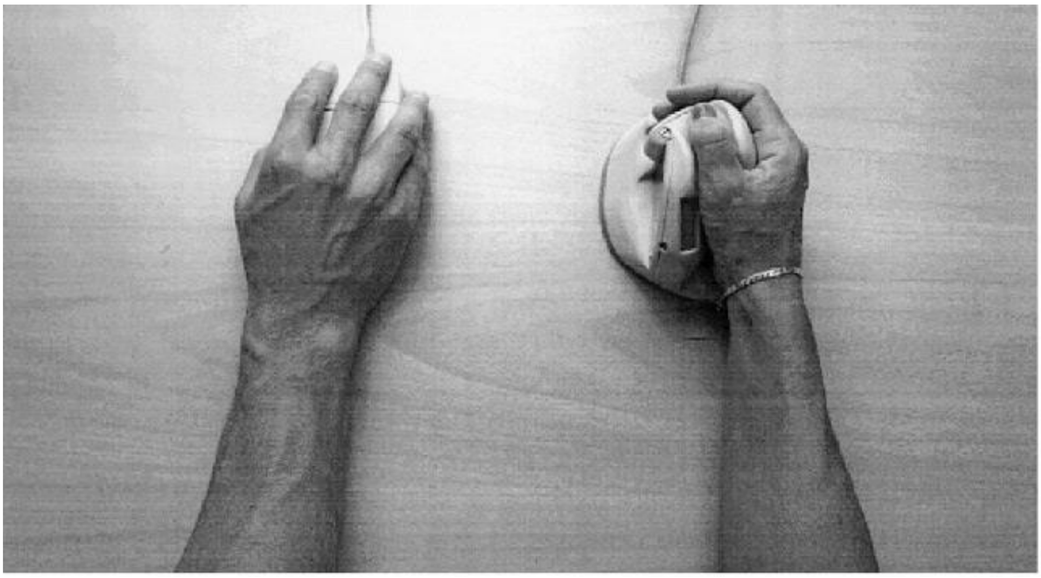


***Figure 1.3** The two hand positions. The pronated hand position to the left with the traditional mouse and the neutral hand position to the right with the neutral mouse (Gustafsson and Hagberg, 2003).*

This study indicated a decrease in wrist extension and ulnar deviation when working with a neutral mouse. The median value for wrist extension = 23° and for wrist ulnar deviation = 4° with the neutral mouse compared to a traditional mouse with the median value = 31° for wrist extension and = 11° for wrist ulnar deviation. However, level of exertion increased when using the traditional mouse and the results were statistically significant ($p < 0.05$). It was found that forearm supination/pronation affects wrist goniometer measurement accuracy. This was because of the crosstalk and off-set error with the Electrogoniometer system. It was found that the effect of forearm supination/pronation in pronated hand position (90° pronation) would be + 1° in flexion/extension and + 4° in deviation positions. However, in neutral hand position (0° supination, 0° pronation), the effect of supination/pronation would be 9° in flexion/extension, and 5° in deviations.

The study by Gustafsson and Hagberg, (2003) used a standardised task which is an editing task, and only one task was used, as with Flodgren et al. (2007). Because of that, the results could be valid only for this kind of computer task. It would have been better to test different computer tasks to be able to generalize the findings from this study. The Gustafsson and Hagberg (2003) study showed that a vertical mouse could have a better effect on the posture of the forearm when compared to the posture of the forearm when using a standard mouse as seen in their findings and that could promote musculoskeletal health.

One study was found that tested the effect of using an ergonomic mouse on wrist posture: Keir et al. (1999) investigated whether any differences in the design of a computer mouse influenced wrist posture and carpal tunnel pressure with healthy participants aged between 22 and 45 years. The participants used 3 mice (Figure 1.4): mouse A was the prototype of the Contour mouse (vertical mouse); mouse B was the Apple II ADM mouse; and mouse C was the Microsoft serial mouse (traditional mouse) (Keir et al., 1999). Participants carried out a dragging task with each mouse. The workstation was adjusted so that the mouse was almost at seated height of the elbow so as to not cause shoulder flexion. An electrogoniometer was used to measure wrist flexion/extension and radial/ulnar deviation. Carpal tunnel pressure was measured by means of a saline-filled catheter, which was inserted in the carpal tunnel of the right hand and connected to a pressure transducer. This study found a significant difference with mouse designs and wrist posture ($p < 0.05$). Mouse A led to a more neutral position of the wrist during the task, and a more radial posture in the static position ($p < 0.05$). However, there was no significant difference between mouse designs and carpal tunnel pressure.

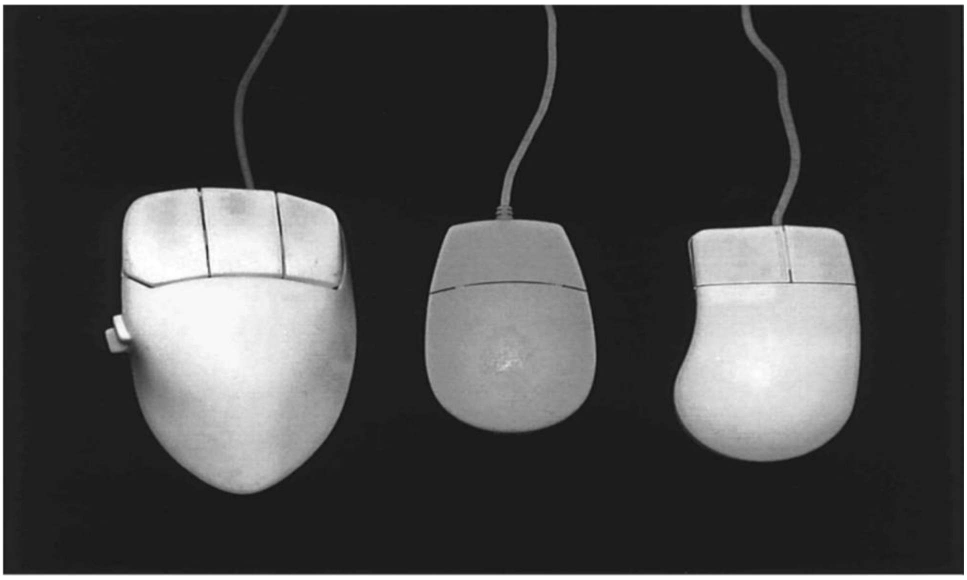


Figure 1.4 *The three mice designs evaluated in Keir et al. (1999). From left to right: vertical mouse, Apple II ADM mouse and traditional mouse.*

A parallel study designed by Aarås et al. (2002) for use with a visual analogue scale (VAS) investigated whether subjects with existing musculoskeletal pain could experience a reduction in pain over 6 months when using an Anir mouse (Figure 1.5), a vertical mouse designed to keep the wrist in a more neutral position, at their workstation. A VAS is a horizontal line, 100 mm in length, anchored by word descriptors at each end, where 0 mm means no pain, and 100 mm means very severe pain (Aarås, et al., 2002). The patient marks on the line to the point that best represents their perception of their current state (Aarås et al., 2002). The participants were split into an intervention group and a control group, the latter using a traditional mouse. The study indicated a significant reduction in pain level in the upper limb for the intervention group ($p < 0.001$) and no significant changes in pain level with the control group. The intervention group means VAS values were from 48.9 mm to 33.9 mm in the neck; shoulder (54.1 mm to 31.8 mm); forearm (52.9 mm to 32.8 mm) and wrist/hand (42.5 mm to 22.3 mm). This finding showed that a significant pain reduction will be generated when using a vertical computer mouse and this is an important source of reducing pain in the upper part of the body.

Figure 1.5 *The Anir mouse (Aarås et al., 2002)*

Both the Aarås et al. (2002) and Keir et al. (1999) studies were meaningful for several reasons. First, they compared different types of mouse with the subjects to show the real influence of mouse design on wrist position and movement. Second, their significant results indicate a more neutral position of the forearm could be an important source of pain reduction in the upper extremity.

Two studies were also found that discussed the influence of mouse design on the posture of the forearm (Delisle et al., 2004; Houwink et al., 2009). These studies examined the effect of using a standard mouse (Delisle et al., 2004) or using a standard and a vertical mouse (Houwink et al., 2009) as well as the impact of ergonomic training on the posture of the upper limb.

First, Delisle et al. (2004) discussed the impact of using the traditional mouse on the left side of the standard keyboard on the posture of the upper extremity of healthy participants before and after a month of ergonomic intervention. Participants performed several computer tasks in a laboratory setting (pointing, dragging and clicking, text editing and data entry). An optoelectronic system was used to determine shoulder, elbow and wrist joint movements. This study showed that after a month of ergonomic intervention, the time required to perform the same task was reduced from 307.2 seconds to 283.3 seconds, but it was longer than when using the mouse on the right side. Also, this study found that discomfort and the perceived difficulty were improved, measured by using the Borg scale, and shoulder flexion, abduction, elbow flexion and wrist extension decreased after a month of left-hand mouse use.

Second, Houwink et al. (2009) compared two different mouse designs, the standard mouse and the vertical mouse (Microsoft Neutral Wireless Laser Mouse 6000) (Figure 1.6), to determine whether ergonomic training and using an alternative mouse design could promote a more neutral position of the forearm and decrease the muscle activity of the forearm muscles. A computer task was performed by the participants (dragging, steering and pointing task) and measurements were taken for the muscle activity (extensor carpi radialis, extensor carpi ulnaris and extensor digitorum communis) using Surface Electromyography (EMG), and wrist and forearm posture were measured using electromagnetic motion analysis. The participants were divided into two groups: one group with ergonomic training (trained group), and one group without ergonomic training (untrained group), and both groups used both mice. This study resulted in reduced forearm pronation, wrist extension and ulnar deviation in both the trained and untrained groups but was least when using the vertical mouse with the trained group when compared with the untrained group. The differences in the muscle activity were found to be fewer with the trained group than the untrained group and using the vertical mouse ($p < 0.05$).

Figure 1.6 *The two mouse designs used in Houwink et al. (2009). Standard mouse on the left side and Microsoft Neutral Wireless Laser Mouse 6000 on the right side.*

Both studies showed that an alternative mouse design (Delisle et al. 2004; Houwink et al., 2009), combined with ergonomic intervention, could affect the posture of the upper extremity more efficiently to prevent or minimise the risk of WRMSD. It should be mentioned that in both studies the experiment was only in a laboratory setting and it would have been better to do the experiment in another setting because that might have given different results since computer users mainly use the computer at work or at home and that type of setting has a different office configuration. Also, the Houwink et al. (2009) study was the only study located that measured both the muscle activity and the posture of the elbow and wrist joint. The evidence in this area is very limited and there is little literature covering this field.

The six studies above show how mouse design could influence the position of the forearm whilst performing a computer task, meaning the design of computer mouse could allow a comfortable posture or an uncomfortable position of the forearm. These six studies were significant because of the appropriate methodology enabling each participant to examine the influence of mouse design on wrist or elbow posture, thus helping them to learn which might lead to discomfort and increased symptoms of musculoskeletal disorders. Also, the key studies might have been enhanced by including subjects with a history of musculoskeletal pain or injury, similar to the Aarås et al. (2002) study, to investigate whether a vertical mouse decreases the risks or symptoms of musculoskeletal disorders. Furthermore, those studies showed the association between mouse design and WRMSD.

Further investigations need to be done in this area, however, as only six studies were found; three studies assessed wrist posture only, two studies assessed wrist and elbow posture, and one study looked at pain reduction only while using a vertical mouse. This will help to show how the design of a computer mouse affects the forearm posture whilst performing a computer task and how it could lead to WRMSD. Thus, the researcher aimed to cover the gap in the literature to show whether mouse design could influence the posture and biomechanics of the elbow and wrist joint whilst performing a computer task. Table 1.3 summarises the findings for the studies discussed in this section.

Following the association between mouse design and WRMSD, the next section shows the individual differences presented while using the same input device.

Table 1.3 *Summary of the key studies related to mouse design and WRMSD.*

Authors	Method	Population	Outcome
Flodgren et al. (2007)	Assessed wrist flexion/extension, radial/ulnar deviation and supination/pronation during painting task on the computer. FASTRAK was used to measure wrist ROM.	Healthy right-handed participants.	-Mean range in flexion/extension was 14.8° with SD = 10.6°. -Mean range for radial/ulnar deviation was 14.9° with SD = 5.5°. -Mean range for supination/pronation was 12.7° with SD = 4.2°. -Computer, mouse use and repetitive movements could increase pain and numbness.
Gustafsson and Hagberg (2003)	Examined wrist position while performing editing task using traditional and neutral mouse for 15 minutes each. Electrogoniometer was used to measure wrist movement and a modified Borg scale to measure exertion levels.	19 experienced VDU workers.	-Decreased wrist extension and ulnar deviation when working with neutral mouse compared to a traditional mouse. -Increased level of exertion when working with traditional mouse and was statistically significant.
Keir et al. (1999)	Keir et al. (1999) investigated whether any difference in the mouse design influenced wrist posture during a dragging task.	14 healthy participants aged between 22 and 45 years.	-Sig. difference between mouse design and wrist posture ($p < 0.05$) in the radio-ulnar angle. -No sig. difference between mouse design and wrist flexion/extension between static posture or while using the mouse.
Aarås et al. (2002)	Aarås et al. (2002) investigated if subjects with existing musculoskeletal pain could experience a reduction in the pain level (using VAS) when using Anir mouse for 6 months.	Participants with existing musculoskeletal pain.	-A sig. reduction in the pain level in the upper limb ($p < 0.001$) in the intervention group and no significant changes in the pain level with the control group.

Authors	Method	Population	Outcome
Delisle et al. (2004)	The effect of ergonomic intervention (1 month) while using a traditional mouse on the upper arm using optoelectronic system (Delisle et al., 2004).	Both studies used healthy participants.	-Delisle et al. (2004) found that after one month of ergonomic training, shoulder flexion and abduction, elbow flexion, wrist flexion angle decreased. -Discomfort and perceived difficulty were improved (using Borg scale). -The time required to perform the task was reduced.
Houwink et al. (2009)	The effect of ergonomic training and using 2 different mouse designs on the upper arm using electromagnetic motion analysis (Houwink et al., 2009).		-Houwink et al. (2009) found that forearm pronation, wrist extension and ulnar deviation were the least when using the vertical mouse with the trained group. -Less muscle activity was found with the trained group while using the vertical mouse (p < 0.05).

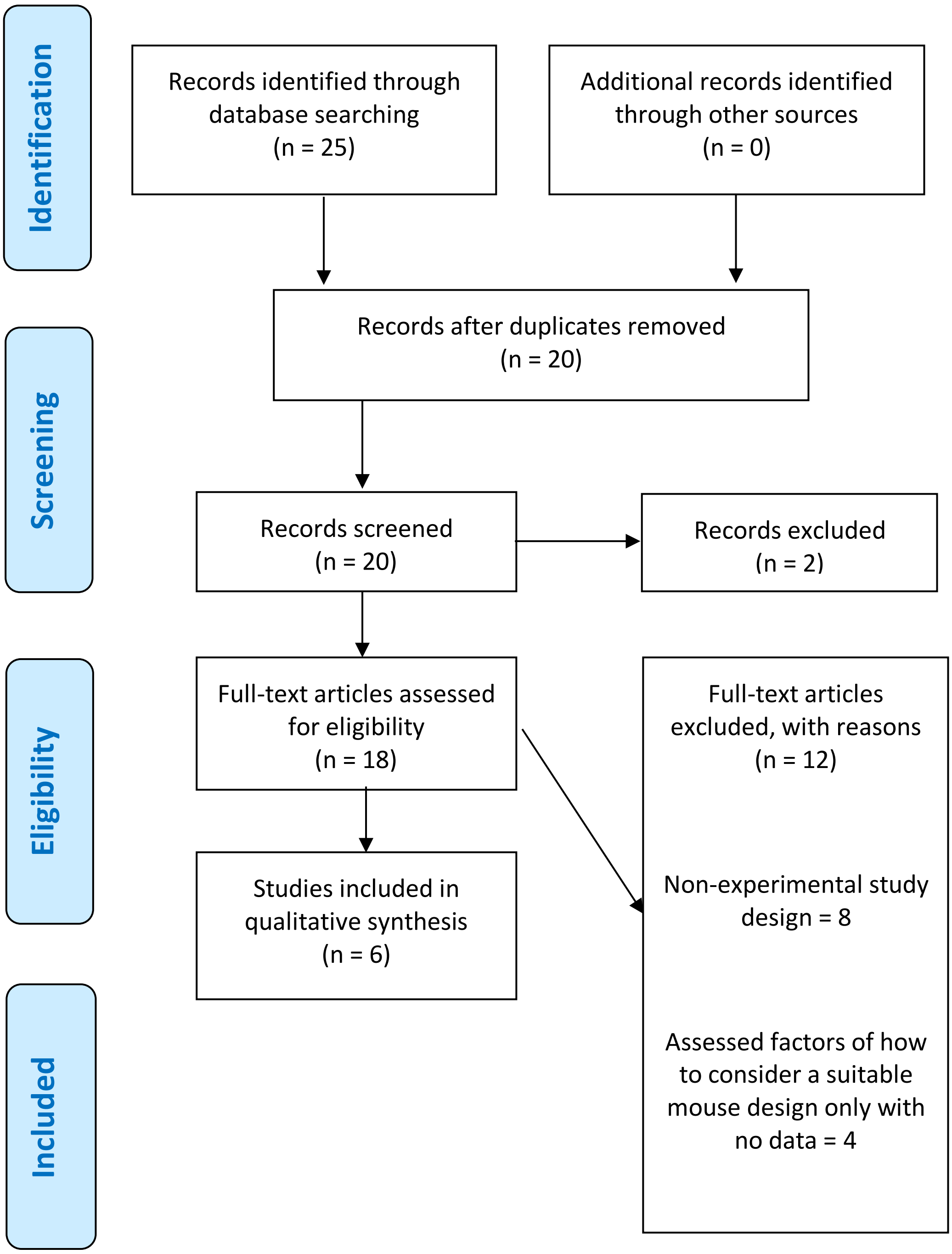


Figure 1.7 *Flow Diagram PRISMA. Source: Moher et al. (2009)*

1.4.1.5 *Elbow, wrist joints posture and WRMSD*

Computer tasks have been commonly linked to the development of WRMSD (Donoghue et al., 2003). The position and the movement of the elbow and wrist joints could play an important role in the development of upper extremity disorders (Nordander et al., 2013). To understand the effects of computer use on the upper limb posture, it is important to identify the movements involved while participants perform a computer task (Donoghue et al., 2003).

Two studies were found that examined the relationship between wrist posture and WRMSD (Nordander et al., 2013; You et al., 2014). First, the study by Nordander et al. (2013) explored the relationship between wrist joint posture and WRMSD. A group of female and male workers were participants and measurements were taken to measure the posture and movements of the right wrist joint (flexion and extension), using a biaxial flexible Electrogoniometer, whilst performing their occupational work. Also, the participants were physically examined to check whether there were any signs or symptoms of lateral and medial epicondylitis and CTS.

This study results showed that the increase risk of musculoskeletal disorders was associated with increasing wrist angular velocity. Also, this study found that increased wrist flexion showed a positive association with musculoskeletal disorders such as CTS. Working with wrist flexion increased the pressure in the carpal tunnel and provoked the development of CTS. This could indicate that a reduction in wrist flexion could have a considerable preventive effect in reducing the risk of WRMSD.

It could be seen that the study by Nordander et al. (2013) indicated a relationship between wrist posture and WRMSD in that increased wrist flexion showed a relationship with several disorders such as CTS and lateral epicondylitis. In this study, it would have been useful to measure all wrist movements, not only flexion/extension, to check whether other wrist postures could lead to WRMSD. Also, the study measured wrist movements while participants performed their occupational work and each participant had a different work task from the others; thus, it would be beneficial to mention which work task could lead to a specific disorder and why, rather than mentioning it in general. This would help to understand which task could lead to WRMSD and what the causes are, and then that could help the clinicians with how to minimise the risk of WRMSD

The second study is a systematic review by You et al. (2014) which evaluated the evidence of the relationship between wrist posture at work and the risk of CTS from existing studies between 1980 and 2012. PubMed and Google Scholar were used for the systematic review searches and the search terms were CTS, wrist posture, work related and epidemiology. Nine studies were found, and these showed that the relative risk of work-related CTS increased with increasing hours of exposure to wrist deviation either in extension or flexion, $p < 0.01$, compared to low hours of exposure. Furthermore, CTS occurs due to repetitive hand movements, leading to an increased pressure in the carpal tunnel, persisted tissue edema and nerve compression. It could be seen that the You et al. (2014) study indicated the risk factors or the causes that increase the risk of work-related CTS.

You et al. (2014) carried out a systematic review and a systematic review is often considered the first and essential step in the research process. To conduct a thorough literature review, researchers should determine what is already known in the research topic and identify the research gaps to generate new evidence to fill the gap. Because of this, researchers need to ensure that the research area is covered properly by using different and appropriate databases; however, You et al. (2014) used only PubMed and Google Scholar, just two databases, which can be considered as insufficient to cover the research proposed topic properly. More databases should be used to cover the area carefully and to do a rigorously conducted literature review.

Two other studies were found that measured wrist posture in one or two planes of motion and examined their effect on WRMSD (Carey and Gallwey, 2002; Donoghue et al., 2003). Firstly, the study by Carey and Gallwey (2002) showed the effect of wrist posture on discomfort whilst performing the task. Sixteen healthy male participants performed four sessions, and, in each session, the participants performed one movement in a neutral position and 16 in a non-neutral position, for example, flexion with UD, flexion with RD, extension with UD and extension with RD. Wrist angle was measured using a twin-axis Electrogoniometer, and the VAS was used to measure the level of discomfort, whereby 0 means no discomfort and 10 means maximum discomfort.

This result was that extreme flexion position (flexion with UD and flexion with RD) caused higher discomfort (asymptomatic) (mean discomfort level = 5.65) than the other simple type of deviation (flexion or extension only) and the results were statistically significant ($p < 0.01$). Moreover, flexion with UD caused higher discomfort (asymptomatic) than the other type of combined deviation (mean discomfort level = 5) and the results were significant ($p < 0.01$). This study (Carey and Gallwey, 2002) indicated a strong association between wrist posture and the level of discomfort whilst performing the task. If the wrist was either in an extreme position of one plane of motion or two planes of motion, this would increase the level of discomfort and that could lead to fatigue. Fatigue could then be a sign of increased risk of WRMSD.

This study would seem to help clinicians with how to minimise the risks of WRMSD and might also help computer users to eliminate any stressful tasks. Moreover, it will help ergonomists in designing an NKID that could reduce such risk and allow the forearm to be in a neutral position. The study also used an Electrogoniometer and because of that, it would have been ideal for the authors to give some measurements of wrist angle in one plane of motion and two planes of motion to check the range that leads to discomfort; there were no measurements written specifically in the Carey and Gallwey (2002) study.

Next, a study by Donoghue et al. (2003) measured wrist posture during a typing task. Healthy participants performed a typing task using both a standard mouse and a standard keyboard. A motion analysis technique (Hawk Digital Real Time System) was used to measure wrist posture (flexion, extension, radial deviation and ulnar deviation). The results for a motion in one plane showed that the position of extension and ulnar deviation were the most common; the peak amount of extension was at 20° and the peak amount of ulnar deviation was at 15°. Moreover, flexion was the least movement done by all participants. No statistical significance was found between right and left hand for any wrist postures.

The results for two planes of motion showed that the most frequented position was in an extension of 20° with ulnar deviation of 20°, followed by extension of 20° with 10° of ulnar deviation, and then an extension of 30° with 20° of ulnar deviation. However, flexion with ulnar deviation and flexion with radial deviation account for only 4% of the entire task, which indicated that the typing task required a minimal amount of such wrist movement.

This study indicated that wrist posture can vary during a typing task or any other computer task and this could be from participants' habit or preference. In this study, it would have been ideal for the authors to study several computer tasks and check their relationship with the posture of elbow and wrist joints because that would help the computer users to know which task might increase the risk factors of WRMSD. Also, this would help the ergonomist and the clinicians to know how to minimise these risks.

To sum up, the above studies showed that there is a strong association between wrist posture and WRMSD and that wrist posture can vary whilst performing the task. Also, wrist posture in two planes of motion could increase the risk of WRMSD, as discussed above. It should be reported that no literature examined the relationship between elbow posture and WRMSD. Also, only four studies were found that examined the association between wrist posture and WRMSD. Further research needs to be done in this area as it is important to know the posture of the forearm when performing a computer task and how the position of the elbow and wrist joints could lead to WRMSD.

A summary table (Table 1.4) below presents the results from this section. The next section 1.4.1.6 discusses the relationship between joint posture and muscle activity of the forearm to check the influence of joint posture on muscle activity.

Table 1.4 *Summary results of the studies discussed elbow, wrist joint posture and WRMSD.*

Authors	**Method**	**Population**	**Outcome**
Nordander et al. (2013)	Explored the relationship between wrist joint posture and WRMSD using biaxial flexible Electrogoniometer. -Participants were physically examined to check for any sign or symptom of lateral and medial epicondylitis, and CTS.	Groups of female and male workers.	-Increased risk of musculoskeletal disorders was associated with increasing wrist angular velocity. -Increased wrist flexion showed a positive association with musculoskeletal disorders such as CTS.

Authors	Method	Population	Outcome
You et al. (2014)	A systematic review which evaluated the evidence of the relationship between wrist posture at work and the risk of CTS from existing studies between 1980 and 2012.	Not applicable.	-Nine studies were found, and these showed that the relative risk of work-related CTS increased with increasing hours of exposure to wrist deviation either in extension or flexion ($p < 0.01$). -CTS occurs due to forceful hand intensive work, leading to an increased pressure in the carpal tunnel, persisted tissue edema and nerve compression.
Carey and Gallwey (2002)	Measured the effect of wrist posture in discomfort.	16 healthy male participants.	-Carey and Gallwey, 2002 resulted in: -extreme flexion position caused higher discomfort (mean discomfort level = 5.65) than the other simple type of deviation (flexion or extension only) and the results were statistically significant ($p < 0.01$). -Flexion with UD caused higher discomfort than the other type of combined deviation (mean discomfort level = 5) and the results were significant ($p < 0.01$).

Authors	Method	Population	Outcome
Donoghue et al. (2013)	Measured wrist posture during a typing task using motion analysis technique.	20 healthy participants	-The results for a motion in one plane showed that the position of extension and ulnar deviation were the most common. Flexion was the least movement done by all participants. -The results for two planes of motion showed that the most frequented position was in an extension of 20° with ulnar deviation of 20°, followed by extension of 20° with 10° of ulnar deviation, and then an extension of 30° with 20° of ulnar deviation.

1.4.1.6 *Joint posture and Muscle Activity of the Elbow and Wrist Joints*

Several studies were found that looked at the relationship between joint posture and muscle activity of the elbow and wrist joints (Dennerlein et al., 2002; Fagarasanu et al., 2004; Sanfeld and Jensen, 2005; Tittiranonda et al., 2002; Won et al., 2003).

A study by Fagarasanu et al. (2004) examined the forearm muscle activity for 20 healthy participants in different wrist deviated positions (45° flexion, 45° extension, 30° ulnar deviation and at the end of range of motion for radial deviation) and in wrist neutral zone. Forearm muscles (flexor carpi ulnaris (FCU), flexor carpi radialis (FCR), extensor carpi radialis (ECR), and extensor carpi ulnaris (ECU)) were measured using electromyography (EMG). The participants were seated in an upright position, the forearm resting and being fully pronated. Then, they performed a five-second maximum isometric contraction against fixed resistance by the examiner. This study found that EMG activity was significantly higher for each forearm muscle in all the deviated wrist postures when compared to the neutral position ($p < 0.001$). The deviated joints cause muscle to overstretch. For ulnar deviation, maximum muscle activity was found in ECU then FCU. For wrist flexion, higher muscle activity was found in FCR, followed by FCU; and for wrist extension, higher muscle activity was found in ECR, followed by ECU. Also, ECR had higher muscle activity than FCR for radial deviation.

This study showed the relationship between forearm muscle activity and wrist deviation. A significant finding was that lower muscle activity was generated with the wrist in neutral position compared to muscle activity in all wrist deviated postures, which could increase the muscle load; deviated joint posture causes the muscle to be overused and overstretched. The results of this study could help the manufacturer to design a mouse that allows the wrist to be in a neutral position. In this study, an increased sample size would have been better to generalize the findings. A larger sample size is essential to develop a better understanding of the research results and will make the results more representative of an entire population.

A study by Sandfeld and Jensen (2005) examined the effect of several motor and visual demands on performance and muscle activity with young and elderly computer mouse users. Participants were seated in an adjustable chair and at a high adjustable table; the right upper arm was placed vertical and with 10° of arm abduction, with the forearm in a horizontal position. The participants then performed three sessions of a multi-directional pointing task, using three target sizes: small, medium and large. It should be noted that the three sessions were performed with a computer mouse gain (MG) of 1:2, 1:4 and 1:8 (MG is the ratio representing mouse movement relative to screen cursor movement) (Sandfeld and Jensen, 2005).

EMG was used to measure ECR, ECU, FCR, extensor digitorum superficialis (ED), right and left trapezius and right neck extensors (upper part of trapezius and splenius capitis). It was found from this study that performance speed was affected by the motor demands in that higher working speed was found in the large and medium target size for both groups. However, a significant reduction in working speed was found for both groups with a small target size because more motor demand needed with a small target size. It was also found that when motor demand increased, higher muscle activity was observed in all measured muscles and in both groups.

It should be reported from this study that when visual demands increased (using small target size), the computer mouse users' performance decreased and led to a higher EMG level. It can be seen that this study was a comparative study in that it used two different age groups to highlight the differences between both groups regarding the performance and muscle activity when different visual and motor demands were used.

Two studies were found that compared posture and muscle activity of the wrist joint by performing five different tasks in a random order: typing, text editing, graphics, completing a web-based form, and internet web-page surfing on an adjustable workstation (Won et al., 2003; Dennerlein et al., 2002). Furthermore, Won et al. (2003) looked at gender differences when performing standardised computer tasks and used 30 participants; Dennerlein et al. (2002) used 15 participants.

In both studies, EMG measured muscle activity of the wrist (ECR, ECU, FCU, FCR). Wrist posture was measured using Electrogoniometer (Won et al., 2003) and using a biaxial glove wrist system whilst participants performed a typing task (Dennerlein et al., 2002). In addition, EMG was measured while participants performed a 5-second maximum isometric contraction. The results of the Won et al. (2003) study showed that female computer users had higher EMG values in all muscles and in all tasks and this was statistically significant ($p < 0.05$). Furthermore, the study found that there were no postural differences in the wrist joint between males and females. The Dennerlein et al. (2002) study results found that muscle activity of the wrist was highest during a typing task in that more extension and ulnar deviation were observed. Also, muscle activity of the wrist decreased when the work changed from keyboard to mouse use.

It can be seen that both studies compared posture and muscle activity simultaneously and when performing several computer tasks. This could give a better understanding of the relationship between posture, computer use, and muscle activity. Also, Won et al. (2003) looked at gender differences whilst performing standardised computer tasks, and the results suggest there are biomechanical and physiological differences in exposure to physical risk factors between males and females even when performing a standard computer task and when workstations are adjusted to each participant's anthropometry. The study by Dennerlein et al. (2002) also showed how muscle activity and posture differ across several tasks, which could give an idea of how to reduce the WRMSD risk factors associated with computer use.

One further study was found that looked at muscle activity and posture of the forearm and wrist joint by using four different input devices: traditional mouse, trackball, joystick mouse and an experimental mouse (Patent pending mouse) (Tittiranonda et al., 2000).

The study by Tittiranonda et al. (2000) compared muscle activity during the use of four different computer pointing devices among computer aided design (CAD) operators. The participants worked with their forearm supported and performed three different tasks: CAD, tracking and multi-directional pointing. EMG was used to measure flexor digitorum superficialis (FDS), extensor carpi ulnaris (ECU), extensor indicis prorius (EIP) and upper trapezius (UT) muscles. These muscles were chosen in this study because of previous experiments by Jacobson (1998, cited in Tittiranonda et al., 2000). The study showed an increase in muscle activity of the FDS, ECU, EIP and UT when using the traditional mouse compared to other input devices in the study. Besides, it showed a significant difference in the muscle load of the EIP, ECU and upper trapezius across the four different pointing devices. It found the standard mouse tends to create higher loads on the upper trapezius and ECU, leading to increased shoulder elevation and wrist ulnar deviation. However, a trackball creates less load on ECU and upper trapezius compared to the traditional mouse.

The Tittiranonda et al. (2000) study showed how important the type of pointing device is and how it affects posture and muscle activity. Also, using an ergonomic mouse design could promote a more neutral posture of the forearm whilst performing a computer task and that could be through the mouse shape and the location of the buttons, the thumb and fingers.

In conclusion, it seems that muscle activity could depend on the type of mouse design and the type of computer task. Training in how to use a computer mouse correctly will also have an effect on reducing muscle activity, which could decrease the risk of WRMSD.

Table 1.5 demonstrates the results summary of the studies discussed in this section. After reviewing the association between joint posture and muscle activity, the next section will link the association between muscle activity and WRMSD more.

Table 1.5 *Results of the studies discussed joint posture and muscle activity of the elbow and wrist joint.*

Authors	**Method**	**Population**	**Outcome**
Fagarasanu et al. (2004)	Examined the forearm muscle activity in different wrist deviated positions using EMG.	20 healthy participants.	EMG activity was significantly higher for each forearm muscle in all the deviated wrist postures when compared to the neutral position ($p < 0.001$).
Sandfeld and Jensen (2005)	Examined the effect of several motor and visual demands on performance and muscle activity. Participants performed three sessions of a multi-directional pointing task using three target sizes: small, medium and large.	Young and elderly computer mouse users.	-Performance speed was affected by the motor demands in that higher working speed was found in the large and medium target size for both groups. -A significant reduction in working speed was found for both groups with a small target size. -When motor demand increased, higher muscle activity was observed in all measured muscles and in both groups.

Authors	Method	Population	Outcome
Won et al. (2003); Dennerlein et al. (2002)	-Compared posture and muscle activity of the wrist joint by performing five different tasks in a random order. Also, looked at gender differences when performing standardised computer tasks. -EMG measured muscle activity of the wrist. Wrist posture was measured using Electrogoniometer	-Won et al. (2003) used 30 participants. -Dennerlein et al. (2002) used 15 participants.	-Won et al. (2003) showed that female computer users had higher EMG values in all muscles and in all tasks and this was statistically significant ($p < 0.05$). -The study found that there were no postural differences in the wrist joint between males and females. -Dennerlein et al. (2002) found that muscle activity of the wrist was highest during a typing task in that more extension and ulnar deviation were observed. Also, muscle activity of the wrist decreased when the work changed from keyboard to mouse use.
Tittiranonda et al. (2000)	Looked at muscle activity of the forearm by using different input devices.	Tittiranonda et al. (2000) used CAD workers.	-Tittiranonda et al. (2000) results: -An increase in muscle activity of the FDS, ECU, EIP and UT when using the traditional mouse. -Standard mouse tends to create higher loads on the upper trapezius and ECU. A trackball creates less load on ECU and upper trapezius

1.4.1.7 Muscle Activity and WRMSD

Intensive computer use has been linked to increased risk factors of WRMSD and increased risk of developing musculoskeletal symptoms of the hand, wrist and arm (Qin et al., 2013). These symptoms, including numbness, pain and stiffness, increase the internal loading on the muscles and joints, and disorders such as CTS and tendinitis (Qin et al., 2013). Three studies were found that discussed the relationship between higher muscle activity and increased risk of WRMSD (Chen and Leung 2007; Szeto and Lin, 2011; Qin et al., 2013).

First, a case control study design by Szeto and Lin (2011) examined the muscle activity of the wrist extensors and flexors during four different mouse clicking tasks at different speeds. Seventeen healthy participants and nine participants with symptoms (symptomatic group) related to mouse use such as pain and numbness were allocated in the study. EMG was used to measure the muscle activity of ECU, ECR, FCU and FCR, and a biaxial Electrogoniometer was used to measure wrist radial/ulnar deviation angles of the right wrist joint.

Also, in this study, a subjective discomfort rating scale was used; the scale was from 0 to 10, where 0 indicates no discomfort and 10 indicate extreme discomfort. The study resulted in both groups placing their wrist in the direction of ulnar deviation whilst performing the task but there was no significant difference between groups. Furthermore, a mouse task at a higher speed produced a significant increase in the muscle activity of ECR and FCU ($p = 0.01$) in the symptomatic group and increased the level of discomfort.

This study showed that there is an association between higher muscle activity and the level of discomfort; when muscle activity increased, the level of discomfort could increase as seen with symptomatic participants and that could lead to muscle fatigue. In addition, the sample size in this study was small and it would have been ideal for the authors to increase the sample size because a larger sample size would help to show any significant difference between both groups regarding posture and muscle activity. Also, it would help to draw a good conclusion and generalize the findings, which is not possible with a small sample size.

The second was a study by Qin et al. (2013) which assessed the muscle activity of the hand and forearm while tapping on a key switch in different wrist postures:

straight (neutral), ulnar deviation, flexed and extended posture. Qin et al. (2013) hypothesised that non-neutral wrist postures will increase muscle tension and will be considered as a risk factor of musculoskeletal disorders among computer users.

Healthy participants were recruited. EMG was used to measure the muscle activity of extensor digitorum, extensor indices, flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), radial interossei (RI), ulnar interossei (UI), ECU, ECR, FCR, FCU and lumbricales (LUM). The results showed that non-neutral wrist postures lead to higher muscle activity than neutral wrist postures and lead to muscle tension and this was more in the extensor muscles in all wrist postures (ECR, ECU and LE). This finding confirmed that the hypothesis was met.

The study by Qin et al. (2013) demonstrated an association between wrist posture and muscle activity; muscle activity of the hand and forearm muscles was higher when the wrist was in a deviated posture (non-neutral posture) and that could lead to muscle tension. It would have been better to test more complicated postures, for example, wrist extension with radial deviation to generate more muscle activity of the hand and forearm. Also, it would have been better to include participants with a history or symptoms of musculoskeletal disorders, as in the study by Szeto and Lin (2011), to look at the effect of non-neutral posture on the muscle activity of the symptomatic group to be able to generalize the findings.

Finally, Chen and Leung (2007) examined the effect of different computer mouse design on the muscle activity of the forearm while performing an editing task on 12 healthy participants. Different types of mouse with different slanted angles, 0° (non-slanted mouse, standard mouse), 10°, 20°, 25° and 30° were used, for 30 minutes each. The angle of slanted surface of a mouse is defined as “the angle between a horizontal plane and the inclined surface of a mouse in the front or rear view” (Chen and Leung, 2007, p.519), as shown in Figure 1.8. EMG was used to measure the muscle activity of the extensor carpi ulnaris (ECU), extensor digitorum (ED) and pronator teres (PT).

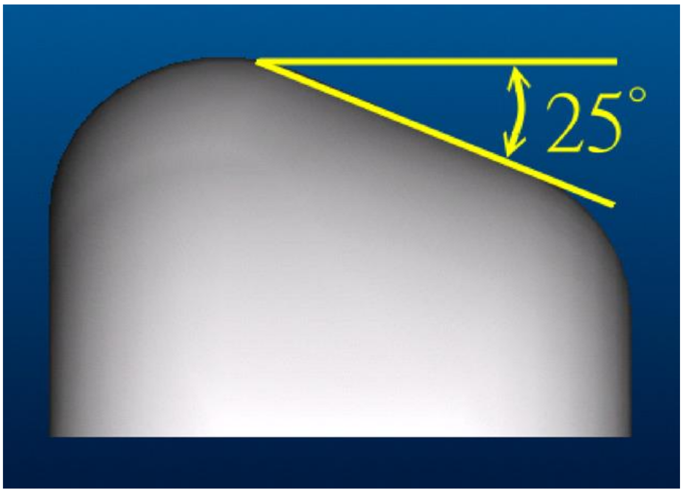


Figure 1.8 *The rear view of the 25° slanted mouse model (Chen and Leung, 2007)*

Chen and Leung (2007) found the muscle activity of the ECU decreased as the slanted angle of the mouse increased and it was significantly lower in using the 30° slanted mouse (p = 0.041) compared with that in using the non-slanted mouse. The PT muscle had a significant lower muscle activity with using the 25° slanted mouse (p = 0.041) when compared with the non-slanted mouse. However, the muscle activity of the ED increased when the slanted angles increased. The lowest muscle activity of the ED was found with the non-slanted mouse (standard mouse).

This study was effective in that it used and compared different computer mouse designs on the muscle activity of the forearm among computer users and showed the influence of different mouse design on the muscle activity whilst performing a computer task. Using a computer mouse with a suitable slanted angle that fits the user's hand will provide a more neutral wrist position in that the wrist will be in a more relaxed or comfortable posture and thereby decrease the risk of musculoskeletal disorders.

In conclusion, it could be seen from the above studies (Chen and Leung, 2007; Szeto and Lin, 2011; Qin et al., 2013) that there is a direct relationship between wrist and hand posture, muscle activity and the level of discomfort. Unfortunately, only one article was found (Chen and Leung, 2007) that had tested or discussed the effect of computer mouse use on muscle activity. Further research needs to be undertaken in this area to understand how and whether higher muscle activity could lead specifically to WRMSD.

Table 1.6 summarises the studies discussed in this section. After the overview on WRMSD, computer use, mouse design, and mouse design and WRMSD, the next section discusses the available measurement approaches and assessment tools that can be used in this research study.

Table 1.6 *Summary of the studies discussed the muscle activity and WRMSD.*

Authors	**Method**	**Population**	**Outcome**
Szeto and Lin (2011)	-Case control study design examined the muscle activity of the wrist extensors and flexors during four different mouse clicking tasks with different speeds. -EMG and Electrogoniometer and a subjective discomfort rating scale were used.	17 healthy participants and nine participants with symptoms.	-Both groups placing their wrist in the direction of ulnar deviation whilst performing the task but there was no significant difference. -Mouse task at a higher speed produced a significant increase in the muscle activity ($p = 0.01$) in the symptomatic group and increased the level of discomfort. -There is an association between higher muscle activity and the level of discomfort.
Qin et al. (2013)	Assessed the muscle activity of the hand and forearm while tapping on a key switch in different wrist postures.	10 healthy participants.	-Non-neutral postures lead to higher muscle activity than neutral wrist postures and this was more in the extensor muscles in all wrist postures (ECR, ECU and LE).

Authors	Method	Population	Outcome
Chen and Leung, (2007)	Examined the effect of different computer mouse design on the muscle activity of the forearm during an editing task.	12 healthy participants.	-Muscle activity of the ECU decreased as the slanted angle of the mouse increased. -Muscle activity of the ED increased as the slanted angle of the mouse increased. The lowest muscle activity with ED was found with standard mouse.

1.4.2 Measurements Approaches and Assessment tools

1.4.2.1 Elbow and Wrist Measurement Approaches

The position and movement of the elbow and wrist joint could be important in the development of upper extremity disorders (Johnson et al., 2002; Maciel dos Santos et al, 2012). Wrist movements could also be important in characterising wrist activity, especially in the clinical setting (Johnson et al., 2002). A number of instruments have been used to measure elbow movements (Maciel dos Santos et al., 2012; Packer et al.,1993) and wrist movements (Biryukova et al., 2000; Johnson et al. 2002; Small et al., 1996). These studies discussed the validity and reliability of the instrument used to measure range of motion of the elbow and wrist joints. Validity was defined as the accuracy of the measurements in that the measurements obtained should be close enough to the reference value (Small et al., 1996). In addition, reliability was defined as the repeatability of the measurements, such that they remain the same under unchanged condition (Packer et al.,1993). It was found from these studies that to determine which measurement tools should be used, the measurement tools should be reliable and valid to be used in clinical setting. These studies will be discussed below.

Limited literature was found discussing the available measurement tools for the wrist joint movements. First, by using a test-retest design, Small et al. (1996) determined the validity of the non-invasive optoelectronic 3D tracking system in measuring wrist movements. The subjects performed four wrist motions: neutral, from neutral to extension, from neutral to flexion, and from flexion to extension. The 3D optoelectronic system results matched those calculated from bone landmarks in the hand and forearm using a radiographic method. It was found that all sources of experimental errors were, on average, of less than 6°. This amount of uncertainty was found to be acceptable within a given range due to the difficulty in determining specific landmarks in the hand.

This study found the 3D optoelectronic system to be a reliable tool with the potential to be useful in the clinical setting; intraclass correlation coefficients indicated good agreement between the measurements of wrist range of motion (ICC = 0.98). Good correlation among the measurements showed that the surface markers accurately reflect the alignment and motion of the underlying bone segments.

Moreover, this study found low test-retest differences in all parameters, indicating the reliability of the marker placement protocol of the 3D optoelectronic system. Alignment differences had means of $\pm 2°$ with an SD less than 3°, and the motion differences had a mean of $\pm 3°$ with a SD less than 3°. However, the markers on the wrist were not removed or reapplied after each movement, which could have influenced the reliability of the data. If the markers were reapplied after each movement, this would show whether the experimenter had the ability to repeat the test and placed the markers on the same reference position with confidence at each repetition to ensure the reliability of the instrument used and the reliability of the experimental set-up. Also, after reviewing this study, it was found that there were not enough details mentioned concerning the analysis and the results such as measurement error. For a validity study, those details are very important to make a decision in whether to use this measurement tool or not.

Second, Biryukova et al. (2000) calculated the joint angles of the human arm movements using FASTRAK and checked the validity of this equipment on healthy participants. The participants performed passive movements carried out by the experimenter for elbow flexion/extension and supination/pronation, and wrist flexion/extension and radial/ulnar deviation. Also, they were asked to do reaching movements into six different directions and performed five movements in each direction. It was found that the variations during wrist radial/ulnar deviation were approximately 3-5° and 1-2° during wrist flexion/extension, according to the direct kinematics error. This could be due to the carpal bone movements. In addition, the variations during elbow flexion/extension were between 3-8° and did not exceed 2° for supination/pronation. This suggests that these variations could be due to the anatomical structure of the articulating surfaces and ligament constraints in the elbow joint.

The study found FASTRAK to be valid as the joint angle values from FASTRAK obtained in this study matched the results with other validated experimental data enabling FASTRAK to be used in analysing multi-joint movement. The authors concluded (Biryukova et al., 2000) that the amount of variabilities found to be acceptably small considering the simplifications of the anatomical structures of the joints. For the validity study, the authors should provide the reader with sufficient details about the type of analysis chosen to determine the accuracy of FASTRAK and sufficient details on the validity results. It was difficult to follow what was done exactly and what types of analysis were made.

Third, Johnson et al. (2002) compared two wrist goniometer systems with eight healthy subjects: a biaxial single transducer wrist goniometer (System A) and a biaxial two-transducer wrist goniometer (System B), one transducer to measure flexion/extension (F/E) and the other to measure radial/ulnar deviation (R/U). The participants moved their wrist into four different pronation and supination (P/S) positions: 90° pronation, 45° pronation, 0° neutral, and 45° supination. This study showed that both Electrogoniometers were prone to measurement error: crosstalk and offset. The former could happen due to twisting the transducer during forearm rotation, defined by Johnson et al. (2002, p.413) as "a phenomenon where movement in one wrist plane (flexion, extension) causes a false reading in the other wrist plane (radial/ulnar deviation)". The latter is when the signals of the goniometer move away from the reference position due to supination/pronation (S/P) movements.

System A was also prone to radial/ulnar crosstalk more than System B, while F/E crosstalk was the same in both goniometers. Offset error was more prone with System B. As System B is still not available in the market, System A is the only available Electrogoniometer that could be used. It was difficult to measure P/S with both the Electrogoniometers. This type of movement could twist the sensors and affect the measurement accuracy. Both systems showed that they underestimated the range of motion in both flexion/extension and radial/ulnar deviation. This could be due to the possible sources of measurement error in the equipment and/or method used, as suggested by Johnson et al. (2002).

This research used a small sample size of 8 participants and it could be beneficial to increase this because experimental results should be generalized with caution. One way to enhance the experiment's results is to perform it with a large sample size to make the results more representative.

Two studies were found that measured the kinematics of the elbow joint and discussed the reliability of the instrument used (Maciel dos Sandos et al., 2012; Packer et al.,1993). First, Maciel dos Santos et al. (2012) assessed the intra and inter-rater reliability and measurement error of the universal goniometer and a digital inclinometer in the knee and elbow flexion and extension of healthy participants. A digital inclinometer is defined as an engineering instrument to measure surface inclination (in degrees) with respect to gravity. It should be reported that the ROM measurements with the inclinometer do not depend on the anatomic references.

In this study (Maciel dos Santos et al., 2012), reliability was measured by ICC and measurement standard error (MSE). This study set the range of motion (ROM) measurements as having high ICC ranging between 0.70 and 0.89 and above 0.90 and a measurement error below 2° to be reliable and appropriate for clinical use. This study resulted in the inclinometer presenting higher inter and intra-rater reliability and MSE below 2° for the ROM of knee and elbow joint when compared with the goniometer.

In Maciel dos Santos et al. (2012), the ICC and MSE were used, which could give good evidence about the reliability of each instrument and the ability to use that instrument in the clinical setting as it is not suitable to use an instrument that has good reliability, according to ICC, and with high measurement error, higher variability in the data, above 2°, because higher variability indicated that the measurements taken were less reliable. From this study, it could be seen that the inclinometer could be used in measuring elbow ROM because it is a reliable instrument, as discussed above. Also, it could be the reason that this instrument does not depend on the anatomic references when measuring the ROM when compared with the goniometer, since the static and the mobile handles of the goniometer need to be specifically aligned on anatomic references.

Second, a study by Packer et al. (1993) assessed the reliability of the non-invasive optoelectronic 3D tracking system to measure elbow kinematics (flexion, extension, supination and pronation) using a test-retest design. Each participant's elbow joint was placed into nine flexion/extension angles and five rotation (pronation/supination) angles and each angle was held for 5-10 seconds. The results from the optoelectronic system were compared with the results from the universal goniometer. The mean difference between both instruments averaged from -2.3° to 1°. The least significant difference (LSD) was calculated to indicate the reliability of the system and should be below 4.9° to be reliable. This study resulted in that the mean range of the LSD values for both instruments ranged from 4.9° - 13.2° for flexion angles and ranged from 10.7° - 19.4° for rotation angles, indicating less reliability for both instruments.

In Packer et al. (1993), it was found that the optoelectronic system that measured elbow kinematics was less reliable, which was not consistent with the results from Maciel dos Santos et al. (2012). It would have been better in this study to compare the results from the optoelectronic system with other reliable instruments to determine the reliability of that system because the universal goniometer appears to be less reliable, as shown in Maciel dos Santos et al. (2012).

To sum up, the validity and reliability of the measurement tools that measure the posture and movements of the elbow and wrist joints could assist the clinician in decision-making in how they assess patients, how they select the appropriate treatment techniques and goal setting with patients. After reviewing the literature, it could be considered that the amount of literature presented was inadequate as only five studies were addressed. However, this has given an indication of the available options that could be used to measure the range of motion of the elbow and wrist in this research study. Table 1.7 summarises the results of the studies discussed in this section. The next section reviews the validity of the Electrogoniometer to ensure its appropriateness for the purpose of the study.

Table 1.7 *Summary of results on the studies discussed concerning elbow and wrist measurement approaches.*

Authors	**Method**	**Population**	**Outcome**
Small et al. (1996)	Test-retest design determined the validity of the non-invasive optoelectronic 3D tracking system in measuring wrist movements.	24 asymptomatic participants.	The 3D optoelectronic system to be a reliable tool with the potential to be useful in the clinical setting. -Low test-retest differences in all parameters were found, indicating the reliability of the marker placement protocol of the 3D optoelectronic system.
Biryukova et al. (2000)	Checked the validity of using FASTRAK.	7 healthy participants (5 males, 2 females)	-FASTRAK to be valid as the joint angle values from FASTRAK matched the results from other validated experimental data.
Johnson et al. (2002)	Compared two wrist goniometer systems, a biaxial single transducer wrist goniometer (System A) and a biaxial two-transducer wrist goniometer (System B).	8 healthy participants.	-Both Electrogoniometers were prone to measurement error: crosstalk and offset. -System A was also prone to radial/ulnar crosstalk more than System B, while F/E crosstalk was the same in both goniometers. Offset error was more prone with System B. -System B is not available in the market. -Difficult to measure P/S with both the Electrogoniometers.

Authors	Method	Population	Outcome
Maciel dos Santos et al. (2012)	-Assessed the intra and inter-rater reliability and measurement error of the universal goniometer and a digital inclinometer in the knee and elbow flexion and extension.	Healthy participants.	The inclinometer presenting higher inter and intra-rater reliability and MSE below 2° for the ROM of knee and elbow joint when compared with the goniometer.
Packer et al. (1993)	-Assessed the reliability of the non-invasive optoelectronic 3D tracking system to measure elbow kinematics (flexion, extension, supination and pronation) using a test-retest design.	Healthy participants.	-The results from the optoelectronic system were compared with the results from the universal goniometer. -The mean difference between both instruments averaged from -2.3° to 1°. -The mean range of the LSD values for both instruments ranged from 4.9° - 13.2° for flexion angles and ranged from 10.7° - 19.4° for rotation angles, indicating less reliability for both instruments.

1.4.2.2 <u>Validity of Flexible Electrogoniometer</u>

The repeatability and the accuracy of the measurements using an Electrogoniometer should be tested first to determine whether this instrument is reliable and valid, and to ensure its suitability for the purpose of any study. There are two types of validity that can be used: internal and external (Hicks, 2009). Internal validity tests the research tool to check it measures the correct parameters, and external validity tests the findings to check it can be applied to a large population (Hicks, 2009).

Several studies have examined the reliability of Electrogoniometer to consider the consistency, reproducibility and repeatability of the instrument (Christensen, 1999). The validity of the Electrogoniometer should be assessed as well to ensure the results are close to the true value. Several studies have discussed the reliability and validity of the Electrogoniometer and their findings will be discussed below.

First, a study by Camassuti et al. (2015) assessed the inter-rater, intra-rater and inter-instrument reliability of the Electrogoniometer in the measurement of wrist range of motion (flexion, extension, radial and ulnar deviation) with 24 healthy participants. The participants were instructed to actively perform all the wrist movements and in random order. The wrist movements were measured by both the Electrogoniometer and the universal goniometer. All measurements were taken when the participants were in a seated position. Two examiners carried out three trials with each movement. Also, one of the examiners performed repeated measures after one week to assess the intra-rater (test-retest) reliability.

The inter-correlation coefficient (ICC), standard error of measurement (SEM) and Bland and Altman test were used for data analysis. The results showed excellent intra and inter-rater reliability for all wrist movements with the Electrogoniometer (ICC > 0.90). The inter-rater reliability with wrist flexion was ICC of 0.89. A lower SEM was found with all wrist movements using the Electrogoniometer compared to the universal goniometer. It was the lowest with ulnar deviation in inter-rater reliability ($\pm$1.93 SEM) and in test-retest reliability ($\pm$1.41 SEM). The Bland and Altman test showed some dispersed data for radial and ulnar deviation with intra-rater reliability, and with inter-instruments in all movements. However, based on their sample, the results of this study suggested that the Electrogoniometer is a reliable tool in terms of intra and inter-rater reliability and can be used for clinical applications. This study was seen to look at the reliability from different aspects in terms of inter-rater, intra-rater and inter-device reliability.

It was helpful to see the degree of reliability, according to SEM, on a test was carried out with more than one examiner and with only one examiner performing a repeated measure. This would ensure whether the Electrogoniometer is able to give stable and consistent results on repeated trials. The results from this study suggested that the Electrogoniometer is a reliable tool and is capable to be used clinically in measuring wrist joint kinematics. The study used the Bland and Altman test for inter-rater and inter-device reliability, but it would have been better to include more detail in the study about the test interpretations and their understanding about the level of agreement. This would help the reader to have a clear picture about the test results. Usually the Bland and Altman test results are interpreted by looking to the bias and the limits of agreement. The bias should be small enough not to cause a problem in the experiment. Also, the size of movement by looking to the limits of agreement should be narrow in the context of their range. Those details were missing. The only interpretation was found on some outliers in their data and this was unlikely to be enough to generate a better understanding of the level of agreement in their reliability analysis.

Second, a systematic review by Priyaprasarth et al. (2008) evaluated the literature that looked at the reliability of the measurement tools that quantify knee joint movements and knee joint angles. Their search was an electronic search, using seven medical databases; Cochrane library, Medline@OVID, CINAHL, Embase, PsyInfo and Pubmed; and one engineering database, the IEEE Xplore. The keywords used in their search were: knee joint measurements and reliability. Their inclusion criteria were studies published in English, to measure knee movements or position in the sagittal plane, and to report the psychometric properties of the measurement procedures or tools. The exclusion criteria were any studies conducted on animals and cadavers. This resulted in 43 studies relating to the reliability and validity of the measurements tools. Inter-tester and intra-tester reliability were reported, and the inter-tester was between 2-14 testers. The ICC and SEM were used to analyse reliability. To be considered a reliable instrument, it should have a larger ICC and less SEM. A larger ICC indicates higher association, and a larger angle of SEM indicates a greater error of measurement or higher variations between the measurements. This systematic review found several tools considered to be reliable and valid to measure knee movements and position. For sagittal knee joint position, hand held goniometers, gravity-based goniometers, 2D motion analysis, and MRI can be used with confidence.

For static joint angle measurements, MRI and 2D motion analysis had lower SEM and high ICC. For dynamic measurements, the Electrogoniometer and 3D analysis had similar levels of SEM (lower SEM). Also, this study showed that intra-tester reliability was higher than inter-tester reliability; ICC ranged from 0.51° to 1.00° for intra-tester and from 0.43˚-0.99˚ for inter-tester. The reasons are that a different testing position could influence the inter and intra-tester reliability in that it was higher ICC and less SEM during sitting. Also, a different time between testing could affect the inter and intra-tester reliability. From the findings of this study, it can be considered that an Electrogoniometer is a reliable instrument and can be used clinically because of the lower variations being found in the measurements.

It could be reported that the reason why the intra-tester reliability was higher is that the measurement performed by one tester could be highly repeatable and that tester could accurately position the Electrogoniometer at the same zero position (the reference) more than if it were different testers. Unfortunately, in this systematic review, some of the results were mentioned in general, such as high ICC and low SEM, without giving the exact number for each to generate better understanding of the results. However, this review addressed all the points that should be mentioned in every systematic review such as their search strategy, quality of review article, participants' and testers' details, and the statistical analysis used. This helps researchers who are looking at similar fields to have more reliable findings to inform their decision-making because a systematic review is designed to provide complete and thorough summary of the literature relevant to research questions.

Third, a study by Henrick and Christensen (1999) evaluated the accuracy and the precision of the Electrogoniometer in cervical spine movements and compared the results with two manual protractors. Accuracy was defined as the closeness of a measured value to its true value. Precision is the closeness of repeated measurements of the same quantity to each other. A series of tests was performed on a rig that simulated the movements of spine flexion, extension, left lateral flexion, right lateral flexion, left rotation and right rotation at 10^o, 20^o, 40^o, 60^o and 80^o to determine the precision of the Electrogoniometer. Twenty measurements were taken for each set of angles and directions. For measurement accuracy, the mean, standard deviation (SD) and mean difference were calculated, and a comparison of the Electrogoniometer measurements and the preset value of the protractor were made by calculating the agreement as mean $\pm 2SD$. The Electrogoniometer would be considered accurate if agreement between this and the two protractors is achieved when the protractor preset value is within the calculated range of the Electrogoniometer (mean $\pm 2SD$). Both protractors and the Electrogoniometer were placed on non-gliding material to prevent accidental gliding of the protractors and to ensure that the measurements would be taken correctly. Both protractors were precision protractors, according to the manufacturer's claim, and both protractors had a resolution of 1°. The results showed that the Electrogoniometer is a precise tool and the precision was found to be $\pm 0.1^{\circ}$ for angles at 10˚, 20˚,40˚ and 60˚ for all cervical spine movements.

Measurements taken at 80˚ were excluded because the construction of the Electrogoniometer made it impossible to take measurements beyond 70˚. Moreover, one data set (at 10˚ of extension) had an agreement between the preset value of the protractors and the Electrogoniometer. However, the remaining datasets were found to have substantial agreement between 2.0% and 11.5%. Although one data set had an agreement, Henrik and Christensen (1999) stated that the measurements obtained were accurate, according to several studies found with similar experiment setups stating that Electrogoniometer is accurate and the accuracy was within 0.1˚.

The results from this study showed that Electrogoniometer is a valid tool and can be used for a movement measurement. The reasons why their results showed substantial agreement could be due to limitations in their study. Possible explanations could be: faults within the software program calculating the angle measurements; faults in the Electrogoniometer physical calculations of angular movements, causing inconsistencies with the precision of the protractors. Also, 20 measurements were taken at each angle and in each direction; this could develop a fatigue factor for the observer, which could be the most likely explanation for the inaccuracy.

Two further studies were found that tested the validity of the flexible Electrogoniometer (FG) (Rowe et al., 2001; Tesio et al., 1995). The first, Tesio et al. (1995), hypothesised that the FG provides valid measurements in measuring knee and ankle movements with healthy participants. This is by comparing an FG with a conventional potentiometric goniometer (PG) in a set of 5-10 times measuring ankle dorsiflexion and plantar flexion, and in a set of six times measuring knee flexion and extension. Both sets of equipment were used simultaneously. Ankle and knee measurements were taken when participants were sat on a high chair, allowing the legs to hang freely with the knee flexed at 90˚. Ankle measurements were taken at three different positions: neutral, full supination from dorsiflexion, and full pronation from dorsiflexion. Knee measurements were taken from extension to flexion: 90˚ to 0˚. The results showed that the FG allowed greater ankle movements in neutral and pronated positions by 19-40%, and it was smaller by 10-21% in supinated position. In addition, the FG signalled greater knee flexion by 24-32% with respect to the PG. However, it was found that PGs underestimate the measurements of the ankle and knee joints. This could be due to PGs consisting of rigid arms that could limit the joint movements.

Interestingly, this study showed that the findings from the FG were consistent with the known joint biomechanics in both knee and ankle joints, and this finding allows the FG to be a valid instrument. In addition, for measurements of angles between adjacent body segments, the FG should be preferred to PGs because FGs are more practical and provide a valid measure of relative orientations in one plane of motion, regardless of the number of different concurrent motions of the underlying joints.

Second, Rowe et al. (2001) assessed the validity of the biometric FG as a measure of joint kinematics. This study was divided into three parts. Part one, assessed the accuracy, precision and hysteresis of the Electrogoniometer when attached to a protractor. The Electrogoniometer was manipulated through a range of angles, from -120˚ to 120˚ in 10-degree increments, and 10 readings in each position were taken. The mean and SD were calculated in each position. It was found that the Electrogoniometer had a high level of precision with a maximum SD of less than 0.1% (0.24˚), and a small hysteretic effect of about 1˚ or 2˚ at an angle around 0˚.

For part two, the Electrogoniometer was exposed to different environmental pollutants such as temperature changes from 15˚ to 25˚, mechanical shock by hammer and hand to the test table, and electrical noise from a computer screen, software machine, and electric drill. The results showed no significant effects in any of these tests on measurements taken with the Electrogoniometer.

Part three evaluated the Electrogoniometer in measuring knee movements (flexion, extension) and compared the results with the findings from a ‘gold standard’ Vicon system (television (TV) motion analysis system). Five participants walked around 10m, performing five free speed walks; then the measurements were taken: the mean range of motion, mean maximum angle, mean minimum angle and mean difference in the ROM. The results showed that the measurements obtained from the Electrogoniometer were similar to those from the Vicon system. The differences between the two measuring tools were between 1.5˚ to 2.8˚. Those small differences found were considered acceptable for a clinical evaluation with patients with musculoskeletal injuries regardless of the cause of errors.

It could be seen that the findings of this study indicated the Electrogoniometer is precise, accurate and repeatable in measuring joint kinematics because the findings from the Electrogoniometer were shown to be as accurate and precise as those from the gold standard 'Vicon system'. Also, this system was not affected by any environmental changes. This made the Electrogoniometer system capable of giving meaningful data in any setting. Both studies (Rowe et al., 2001; Tesio et al., 1995) were well designed because their findings supported their hypothesis in that an Electrogoniometer is a valid instrument and because they were testing the validity from different aspects such as in terms of error and hysteresis.

In conclusion, from the above studies, it could be reported that a biometric flexible Electrogoniometer is a valid and reliable instrument to be used in kinematics measurements and can be used in any setting. The next section reviews the applicable postural assessment tools that can be used in this research study as part of ergonomic assessment while the computer users perform the task.

Table 1.8 *Summary results of the studies discussing the validity of the flexible Electrogoniometer.*

Authors	Method	Population	Outcome
Camassuti et al. (2015)	Assessed the inter-rater, intra-rater and inter-instrument reliability of the Electrogoniometer in wrist range of motion.	Healthy participants.	-The Electrogoniometer is a reliable tool in terms of intra and inter-rater reliability.
Priyaprasarth et al. (2008)	Systematic review using an electronic search. Keywords: knee joint measurements, reliability	NA	- 43 studies related to reliability and validity of the measurement tools.

Authors	Method	Population	Outcome
Henrick and Christensen (1999)	Evaluated the validity of the Electrogoniometer in cervical spinal movements and compared the results with 2 manual protractors.	On a rig that simulated the cervical spine movements.	-The Electrogoniometer is a precise tool and the precision was found to be $\pm 0.1^\circ$ for angles at 10˚,20˚,40˚ and 60˚.
Tesio et al. (1995)	Tested the validity of the Electrogoniometer on knee and ankle movements. It compared the Electrogoniometer with a PG in a set of repeated measures.	Healthy participants.	-The Electrogoniometer had greater ankle movements in neutral and pronated position by 19-40%, and smaller by 10-21% in supinated position. Also, greater knee flexion by 24-32%. -PG underestimates the measurements of the ankle and knee joints. -The Electrogoniometer is a reliable and valid tool.
Rowe et al. (2001)	Consisted of three parts: Part one: assessed the accuracy, precision and hysteresis of the Electrogoniometer. Part two: the Electrgniometer was exposed to a different environmental pollutant.	On artificial rig.	-The Electrogoniometer had a high level of precision with a maximum SD of less than 0.1% (0.24˚), and a small hysteretic effect of about 1˚ or 2˚ at angle around 0˚. -No significant effect between different environmental pollutants on the Electrogoniometer.

Authors	Method	Population	Outcome
	Part three: evaluated the Electrogoniometer in measuring knee movements and compared the results with the findings from a ‘gold standard’ Vicon system.		-The Electrogoniometer is precise, accurate and repeatable in measuring joint kinematics.

1.4.2.3 Postural Assessment Tools

Postural changes could be an area of concern with clinicians because postural deviation could produce musculoskeletal disorders (Kee and Karwowski, 2007). In addition, poor posture and a static working position are both related to the development of musculoskeletal disorders (Kee and Karwowski 2007; Meksawi, Tangtrakulwanich and Chongsuvivatwong, 2012). An assessment of an overall postural behaviour whilst performing a task requires suitable assessment tools and scales and those scales should be reliable (Kee and Karwowski 2007; Meksawi et al., 2012). Inadequate evidence of reliability testing of work-related assessments is a major concern in the field of ergonomics (Kee and Karwowski 2007; Meksawi et al., 2012). Objectivity, the ability of a scale to be used by more than one rater and draw the same conclusion when investigating the same issue is one type of reliability (Meksawi et al., 2012). The available postural assessment tools found in the literature and found to be applicable for use in this research study are the rapid upper limb assessment (RULA), and the sitting position classification matrix (Kee and Karwowski 2007; Meksawi et al., 2012).

The study by Meksawi et al. (2012) evaluated the prevalence of WRMSD and ergonomic risk factors related to low back pain (LBP) in the posture of rubber tappers using the Rapid Upper Limb Assessment (RULA). This study aimed to show the ability of RULA to be used in clinical setting. RULA is a commonly used tool for assessing ergonomic risk of WRMSD due to work posture, muscle use and forces exerted on the upper arm, lower arm, neck, trunk and legs, which is linked to job characteristics. This study was a cross-sectional survey using face to face interviews, direct observation of rubber tapping work and a video analysis of the work posture using RULA which was scored from 1 to 4, where 1 indicates the best or the most neutral posture and higher scores show a more unbalanced posture. In addition, a grand score for RULA is produced by a combination of risk scores in the upper arms, lower arms, wrists, neck, trunk and legs, and ranges from 1 to 7. The grand score details can be found in Appendix 1. RULA was used as an indication of any risk factor associated with the any job activities such as musculoskeletal pain.

According to the RULA score, the mean upper arm score of the rubber tappers was 3.3; this meant an average degree of shoulder flexion of more than 90°. The average lower arm score was 2.8, indicating elbow flexion less than 60° and up to 100°. The average wrist score was 1.9, which indicated that the wrists were placed in an extension position with an angle less than 15°. It was found that the mean neck score was 2.9 and the mean trunk score was 2.8, indicating that the neck and trunk of the participants were either in flexion, rotation, side bending or in combination. This study resulted in a grand RULA score of 5.25, indicating that the workers needed to change their work habit soon due to major postural deviations being found through RULA score.

It can be seen from Meksawi et al. (2012) that RULA can be considered a useful tool to assess different body parts. It appears that RULA could show any ergonomic risk factors related to work posture by allocating a RULA score to each body part, and by using a RULA grand score, it has the ability to show whether the work habits of each worker need to be changed immediately or not. RULA could be a good example to assess work posture, as seen in this study. The results from this study recommended the need for the implementation of a postural tool using ergonomic concepts to reduce the risk of WRMSD. Although this study recommended using RULA as part of ergonomic intervention, it would be better to include the reliability of RULA because it would be better to assess the posture or to use a postural assessment tool that is reliable to ensure the findings from this study.

A study by Kee and Karwowski (2007) compared three different observational tools for assessing posture in 301 manufacturing industry workers (electronics, iron and steel, automotive, chemical industries, and the service industry of a general hospital). These tools were RULA, Ovako Working Posture Analysis System (OWAS) and Rapid Entire Body Assessment (REBA). The study aimed to compare the three observational tools in assessing working posture and check the inter-rater reliability for each tool. OWAS is a tool based on rating working postures and has four working postures in the back, three postures for the arms, seven for the lower limbs and three categories for the amount of force used (Appendix 2) (Kee and Karwowski, 2007). Furthermore, this tool has four action levels that indicate the requirement or the urgency for changing the workplace intervention (Appendix 2) (Kee and Karwowski, 2007).

REBA is an assessment tool used to analyse posture and can give an indication of any postural or musculoskeletal risk (Appendix 3), and its posture classification system includes the upper arms, lower arms, wrist, trunk, neck and legs, and is based on a body part diagram (Kee and Karwowski, 2007). However, the tool has five action levels, unlike RULA and OWAS. This study resulted in OWAS and REBA appearing to underestimate the risk level with working posture slightly ($p < 0.0001$) in that the posture had been mostly evaluated with action level 3 or 4. In OWAS, action level 3 indicates that postures need consideration in the near future, whereas action level 4 indicates postures need immediate consideration. In REBA, action level 3 indicates that corrective action including further assessment is necessary soon, whereas action level 4 indicates that corrective action including further assessment is necessary now. Also, this study showed that the percentage agreement between OWAS and RULA was 29.2%; the agreement between RULA and REBA was 48.2% and between OWAS and REBA was 54.8%. This showed that OWAS and REBA underestimated postural loads when compared with RULA, regardless of work type and whether the body posture was a balanced posture or not.

It can be seen from Kee and Karwowski (2007) that it would be more advantageous to use RULA to assess working posture because it tends to overestimate the potential risks factors of WRMSD, unlike OWAS and REBA which tend to underestimate the postural risks. This is consistent with the findings of the Meksawi et al. (2012) study which showed that RULA can be used to assess posture and can give an indication of any ergonomic risk. As this study assessed posture in a variety of work types and in different locations to compare three different observational techniques to show the similarities and differences, and the advantages and disadvantages of each tool, this can help with regard to the most applicable assessment tool for use in assessing work posture.

To sum up, it can be seen that ergonomic assessment tools that assess work posture involve the evaluation of WRMSD risks in different body parts. Also, these ergonomic tools have been developed to assess exposure to known risk factors and that could help the ergonomist to develop a programme that reduces the risk of WRMSD. Ergonomic assessment tools also identify body parts at risk and allow differentiation of high risk jobs from low risk jobs, seen specifically in RULA. RULA has a grand score that could help in indicating whether the working posture is acceptable or requires immediate change (Kee and Karwowski, 2007; Meksawi et al., 2012).

More comparative research in this area will help to identify which postural tool may be a good or the best example for use in assessing posture and showing any ergonomic risk of WRMSD. In considering the existing literature, the balance of evidence confirms RULA as the most appropriate tool for assessing risk regarding WRMSD when sitting at a desk. Table 1.9 summarises the studies discussed in this section. The next section reviews the reliability of RULA to be confident in the use of this assessment tool in this research study.

Table 1.9 *Summary of the studies discussing postural assessment tools.*

Authors	Method	Population	Outcome
Meksawi et al. (2012)	Cross-sectional survey evaluated the prevalence of WRMSD and ergonomic risk factors related to low back pain (LBP) using RULA.	Rubber tapper workers.	-The grand score of RULA was 5.25, indicating that the workers needed to change their work habit soon.
Kee and Karwowski (2007)	Compared three different observational tools for assessing posture, RULA, OWAS and REBA. Also, checked the inter-rater reliability for each tool.	301 manufacturing industry workers (electronics, iron and steel, automotive, chemical industries, and the service industry of a general hospital).	-OWAS and REBA appearing to underestimate the risk level with working posture slightly ($p < 0.0001$). -The agreement between OWAS and RULA was 29.2%; the agreement between RULA and REBA was 48.2% and between OWAS and REBA was 54.8%.

1.4.2.4 Reliability of Rapid Upper Limb Assessment (RULA)

This section will show how the assessment tool RULA was developed and whether the level of experience in using RULA could affect the reliability and validity of that tool. Hixson (2006, p.1442) defines the objectivity of RULA as "the ability of a scale or test to be used by raters to come to the same conclusion when examining the same thing, which is one type of reliability". Cronbach's alpha is the most common tool used to test the internal consistency of RULA. Inadequate evidence of reliability testing of postural assessment tools is a major concern in the ergonomic field (Hixson, 2006). With increasing numbers of people using computers daily, it is important to assess the impact of using a computer on people's posture as they might be at risk of WRMSD (Dockrell et al., 2012). RULA can be used to identify musculoskeletal risks in work tasks that are carried out by workers (Hixson, 2006). In addition, RULA was designed to be carried out easily with minimal changes to the working environment and with minimal disruption to those under observation (Dockrell et al., 2012).

Two studies were found that investigated the level of experience of using RULA and how it affects the reliability of RULA. First, a study by Hixson (2006) testing the objectivity of RULA used five raters with different work experience levels ranging from novice to intermediate and experienced. All raters attended a RULA training session for one hour. Then, the raters were instructed to view four different video tasks in a specific manner. All raters were allowed to view each video as many times as needed, but they could not to return to any video task once they had started the next rating.

In this study, the objectivity of RULA was measured using Cronbach's alpha and was set at 0.7 to be acceptable. Hixson (2006) assumed there were two essential issues with the measurements and RULA: first, the reliability of the evaluation tool; second, the experience and background of the evaluator regarding RULA so that the tool could be interpreted in a correct or reliable manner. The study showed the reliability of RULA ranged between -0.395 and 0.68. Also, there was a significant difference between the novice and experienced raters ($p \le 0.05$); no significant difference was found for the intermediate level raters. The study found that RULA cannot be used as an objective measure.

It can be seen from this study that the reliability of RULA did not reach 0.7 to be acceptable, as set by Hixson (2006) and, according to Hixson, RULA is not recommended for use as an objective measure. The raters' background, experience, knowledge and skills in how to use RULA appeared necessary to be able to use the tool correctly and reliably, which will help to produce raters who produce consistent results, and ultimately ensuring the reliability of RULA.

The second study, by Chen et al. (2013), evaluated the impact of experience when using RULA. The purpose of this study was to determine the differences between experienced and novice assessors in their RULA scores and action levels. Sixteen occupational therapy students (novice) and experienced occupational therapists (OT) assessed a 12-year old female via a video scenario to perform several activities around the home. Furthermore, both novice and experienced assessors had not previously used RULA and prior to the experiment, they were trained in its use.

The study showed no significant difference in the mean grand RULA score and action level between novice and experienced assessors and this finding contradicts the finding from Hixson's (2006) study. The mean grand RULA score for the novices ranged between 4.56 and 6.88, and for the experienced OTs, it ranged between 5.06 and 6.81. The mean action level for the novices ranged between 2.50 and 3.63, and for the experienced OTs, it ranged between 2.75 and 3.69. Since there were no significant differences between both groups, this study (Chen et al., 2013) could suggest that RULA can be used regardless of the assessor's experience, knowledge and skills in postural risk assessment. Prior to this study, none of the participants had any experience in using RULA, but both groups achieved similar scores, which suggests that RULA is simple to use and minimal training is required. Although this study found that RULA can be used regardless of the assessor's experience, it did not show whether RULA is a reliable tool or not. For a reliability study, reliability analysis should be performed to know whether this assessment tool is reliable or not. However, it seems that the major concern was to look at the impact of experience on the RULA scoring system rather than a reliability study.

Two other studies were found that tested the reliability of RULA (Dockrell et al., 2012; McAtamney and Corlett, 1993). The first, Dockrell et al. (2012), investigated the inter and intra-rater reliability of RULA when assessing 24 school children aged from 8 to 12 years old. Three physiotherapy students and three physiotherapists assessed 24 video recordings of school children. The required number of video clips was 24 to achieve a level of significance $p < 0.05$ and to detect an ICC of 0.6 or greater, a moderate level of reliability. Prior to the experiment, all raters attended a 45-minute training session in how to use RULA.

This study (Dockrell et al., 2012) resulted in both inter and intra-rater reliability being moderate to good. Inter-rater reliability for the action level for the three physiotherapists was between 0.54 and 0.58, and for the three students was between 0.58 and 0.67. The intra-rater reliability by the type of rater for the action level was: 0.66 for student 1; 0.62 for student two; 0.52 for student three; 0.27 for physiotherapist one; 0.69 for physiotherapist two; and 0.86 for physiotherapist three. Also, the intra-rater reliability by the type of rater for the RULA grand score was: 0.83 for student one; 0.64 for student two; 0.47 for student three; 0.55 for physiotherapist one; 0.75 for physiotherapist two; and 0.84 for physiotherapist three. The intra-rater reliability was slightly higher than inter-rater reliability since the measurements performed by one rater could be highly repeatable compared with the measurements performed by more than one rater.

This study (Dockrell et al., 2012) showed that RULA can be used as a postural risk assessment tool because it was found to be a reliable tool; it also showed that RULA requires no previous knowledge or skills in observation techniques and is easy to learn and use. This finding is consistent with the finding of Chen et al. (2013). However, the finding was inconsistent with the finding from Hixson's (2006) study in terms of reliability.

Second, the McAtamney and Corlett (1993) study was by the team who developed RULA. They evaluated the development of RULA and investigated the validity and the reliability of RULA. RULA was developed for several reasons: first, to provide a method of screening a working population's posture quickly; second, to give outcomes about working postures regarding whether the postures could be a risk or not, and that could help in ergonomic assessments. In addition, RULA was developed without the need for special equipment, which provides the opportunity for a number of investigators to use RULA and to be trained, as the investigators need only a clipboard and pen. Also, those who are trained to use RULA do not need any previous skills and knowledge and this could be an advantage. RULA involves allocating a numerical rating to the posture of the neck, trunk, upper limbs and legs; then another numerical rating for additional factors which strain the musculoskeletal system such as repetitive movements; and then all these scores are combined to generate a grand score from 1 to 7. The grand score will help to know the required action level that should be taken, action levels ranging from 1 to 4.

In McAtamney and Corlett (1993), the validity and reliability of RULA were also assessed. In the validity study, 16 experienced operators performed VDU data entry tasks for 40 minutes in each of two working postures. The participants were seated and adjusted to a posture that gave RULA a score of 1. Also, they were seated and adjusted into a posture that caused 20° or more of neck flexion, forearm flexion of more than 90°, and the right wrist was extended and in ulnar deviation. The results showed that there was a significant difference between both posture scores, A and B, and reported pain or discomfort in the relevant body regions. This finding could show the RULA scoring system is sensitive to the changes from acceptable to unacceptable postures.

Moreover, testing the reliability of RULA was by training over 120 physiotherapists who observed a videotape of operators performing screen-based keyboard operations, sewing and packing. This study found that there was a high consistency of scoring amongst participants and that RULA is a reliable tool.

This study (McAtamney and Corlett, 1993) showed how RULA was developed and how it is a reliable and valid tool that can be used to assess working postures. It also showed what RULA could provide and how it could assist ergonomists in their assessment. It showed that the use of RULA could give a priority order for jobs that need to be investigated and the RULA action list will give a more detailed investigation of the working posture in whether it needs to be changed or not to minimise or prevent the risk of WRMSD. RULA achieves the role of providing a “method” for screening a large population quickly, and the developed scoring system provides an indication of the level of muscular loading in each body part. It can be seen that RULA is used without the need for any additional equipment and without the need of training, and this finding is consistent with the findings from Chen et al. (2013) and Dockrell et al. (2012).

In conclusion, it could be reported that investigating the reliability of RULA was highly limited as only four studies were found. From the available studies discussed above and the balance of evidence, it can be stated that RULA is a reliable tool that can be used as an objective measure. Table 1.10 summarises the findings from the studies discussed in this section.

Table 1.10 *Summary of the studies discussing the reliability of RULA.*

Authors	**Methods**	**Population**	**Outcome**
Hixson (2006)	-Both studies investigated the level of experience of using RULA and how it affects the reliability of RULA. -Hixson (2006) measured the objectivity of RULA using Cronbach's alpha and was set at 0.7 to be acceptable.	Five raters with different work experience levels.	-Hixson (2006) results: the reliability of RULA ranged between -0.395 and 0.68. A significant difference between the novice and experienced raters ($p \leq 0.05$); no significant difference was found for the intermediate level raters.
Chen et al. (2013)	-Chen et al. (2013) evaluated the impact of experience when using RULA with a 12-year-old child.	Chen et al. (2013) used 16 occupational therapy students (novice) and experienced occupational therapists (OT).	-Chen et al. (2013) results: -No significant difference in the mean grand RULA score and action level between novice and experienced assessors and this finding contradicts the finding from Hixson's (2006) study.
Dockrell et al. (2012)	-Investigated the inter and intra-rater reliability of RULA.	24 school children (8-12 years old)	-The intra-rater reliability was slightly higher than inter-rater reliability -RULA was found to be a reliable tool.

Authors	Methods	Population	Outcome
McAtamney and Corlett (1993)	-Evaluated the development of RULA and investigated the validity and the reliability of RULA	-Garment-making industry workers. -16 experienced operators (validity study) -120 physiotherapists (reliability study)	-It is a reliable and valid tool. -RULA can be used without the need for any additional equipment and without the need of training.

1.4.3 Conclusions from the Literature Review

After reviewing the literature, there appears to be an association between the computer and mouse users and WRMSD due to several risk factors, for example, greater range of movement whilst performing the task and prolonged use of the computer. In addition, the most important factor that could increase the risk of WRMSD is mouse design. Mouse design influences the forearm position in that the forearm could be in a pronated position, which could increase the risk of musculoskeletal symptoms, or in a neutral position, which could allow a relaxed posture of the forearm and then the WRMSD could be minimised.

The literature also showed how the elbow and wrist posture could affect muscle activity and how it could relate to WRMSD; however, only six studies were found that examined the influence of mouse design on elbow and wrist posture.

It seems appropriate for there to be a focus on mouse design and its effect on the posture and muscle activity, especially as this factor could be the easiest way or the most effective way of minimising the risk of musculoskeletal injuries in the forearm since it can be difficult for computer users to adjust their workstation at home or at work the same as in a laboratory setting. Mouse design is likely to be one of the early applied and less expensive solutions.

The elbow and wrist could be considered the key joints in indicating hand function and play an important role in daily human activity and in the clinical courses with disordered elbow or wrist patients. Therefore, elbow and wrist movements and muscle activity should be measured to assess their association with WRMSD.

The review of measurement approaches that can be used to measure elbow and wrist range of motion could be considered insufficient as only five studies were addressed. However, this has given an indication of the available options that could be used to measure the range of motion of the elbow and wrist in this research study.

Finally, RULA will be used to give the researcher an indication of any postural deviation that could be considered a risk in developing musculoskeletal symptoms or disorders, according to RULA scoring system. It will also give the researcher an insight into which mouse design could maintain the overall posture as a more relaxed posture whilst performing the computer task.

2 Chapter 2: Validity Pilot Study

2.1 Introduction

This chapter outlines the work carried out to analyse the validity of the measurement tools FASTRAK and Electrogoniometer on an artificial rig through a range of known angles. Validity in this instance will be defined in terms of measurement accuracy. Measurement accuracy is defined as the degree of closeness to the reference value (Small et al., 1996). The preliminary work was divided into two phases: phase one considered the validity of the measurements, and phase two focused on the reliability of the measurements. The details of phase one will be discussed in this chapter. Phase two will be discussed in Chapters Three and Four.

The work carried out in the validity pilot study took place prior to implementing the main experiment. It was necessary to investigate practical experimental issues relating to equipment suitability since both pieces of equipment were available in the laboratory and they needed to be checked to ensure they were suitable for the purpose of the study before use. To identify the equipment which was to be used for larger scale experiments, a range of potentially viable equipment was examined to establish their measurement accuracy and the results were evaluated against the experimental requirements. To provide the most controllable measurements, an artificial rig was used which provided simple rotational movements in two directions to simulate the flexion-extension and pronation-supination movements of an arm. The artificial rig was used to provide a simple representation of the elbow joint. This rig consisted of two arms: a fixed arm to represent the upper arm, and a movable arm with two degrees of freedom to represent the forearm, as shown in Figure 2.1, section 2.2. The rig was specifically developed to eliminate the localised movement of sensors placed on a participant's forearm, and because an artificial rig would allow for a truly static test to be carried out.

2.1.1 Aim

The overarching aim for the first phase validity study of the preliminary work was as follows:

1. To investigate the validity of the measurement tools FASTRAK and Electrogoniometer in the measurements taken on the artificial rig at known angles.

2.1.2 Research Questions

1. How can the validity of the potential measurement techniques, FASTRAK and Electrogoniometer, when measuring flexion and extension be investigated?

2. How can the validity of the potential measurement techniques of FASTRAK when measuring supination and pronation be investigated?

3. How can the interference between the Electrogoniometer and FASTRAK systems be checked?

4. How can the interference between FASTRAK and metal objects be checked?

5. How can FASTRAK or Electrogoniometer be identified for use in measuring the range of motion of the elbow and wrist joint for larger scale experiments?

2.1.3 Research Proposal and Ethics Approval

The research plan was approved on 4th April 2013 by the University of Brighton and then followed by the approval of the Faculty of Research Ethics and Governance Committee (FREGC) on 24th October 2013 (for the completed ethics proposal and letter of approval see Appendix 4).

2.2 Equipment used in the pilot study

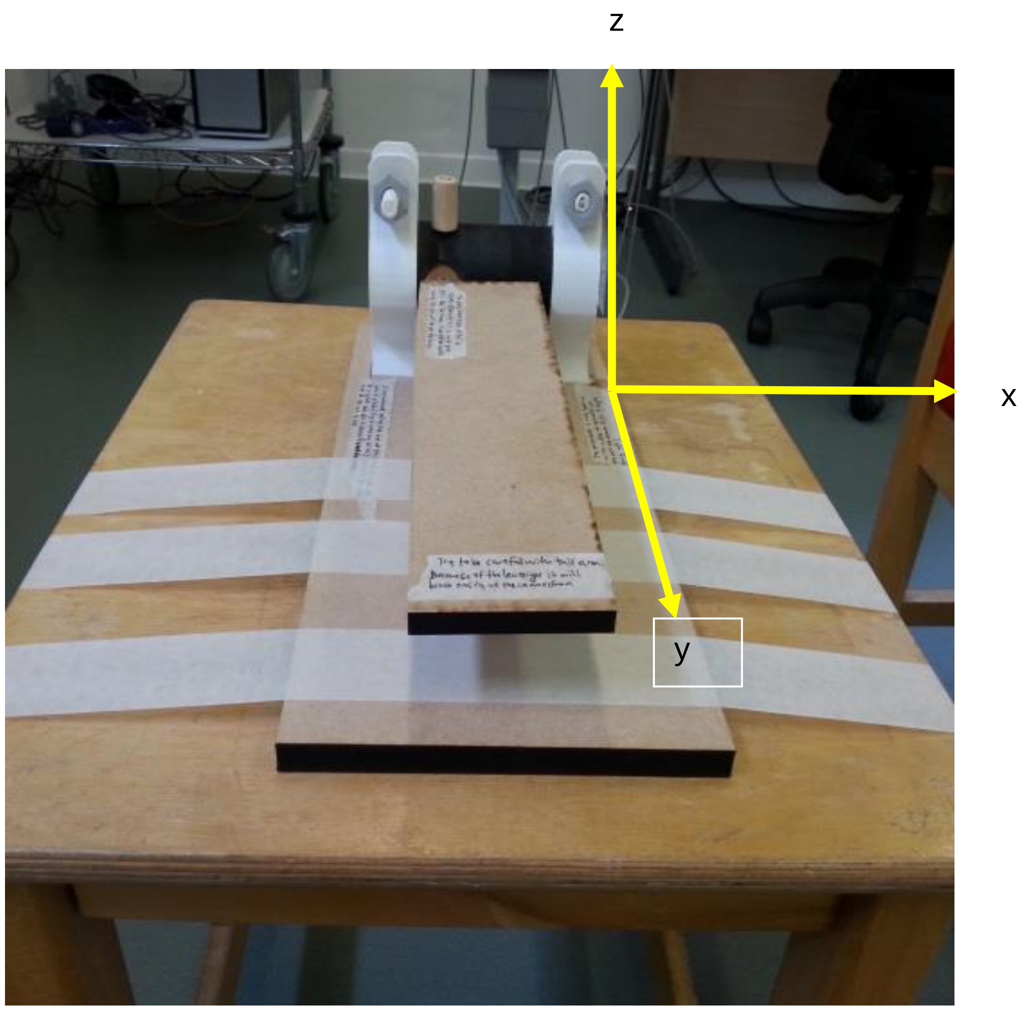


Figure 2.1 *The artificial rig developed specifically for this study to simulate the flexion-extension and pronation-supination movements of elbow joint. The coordinates for the system are also shown.*

In this study, the artificial rig was adjusted between 50° and 70° at intervals of 10° in the vertical y-z plane, to represent elbow flexion and extension movements, with angle readings taken from a simple protractor mounted on the side.

To simulate elbow supination/pronation movements, the rig was adjusted between 0°, 45° and 85° in the vertical x-z plane, to represent elbow supination and pronation movements, using the three preset angles built into the rig.

To know the exact target angle of each of the preset angles built into the rig, the rig had three pre-drilled holes and each hole represented an angle; to align each angle, a digital spirit level was used. The movable arm was rotated to each pre-drilled hole and the digital spirit level was placed on the movable arm of the rig to ensure that the table was stable and ensure the readings would be taken correctly from the digital spirit level. The angles were measured at 0°, 45° and 85°, which were chosen to simulate a small range of the elbow in supination and pronation. These angles were chosen because it anticipates the range the forearm will be using during the mice used. The researcher repeated this process five times to make sure that the readings taken from the digital spirit level were correct.

The angles between the static and movable arms were measured using a 3 SPACE FASTRAK system (Polhemus, S/N M2A50138), as shown in Figure 2.2. FASTRAK is an electromagnetic tracking system suitable for measuring human movement and the presence of any magnetic field or metal objects can lead to measurement errors (Flodgren et al., 2007).

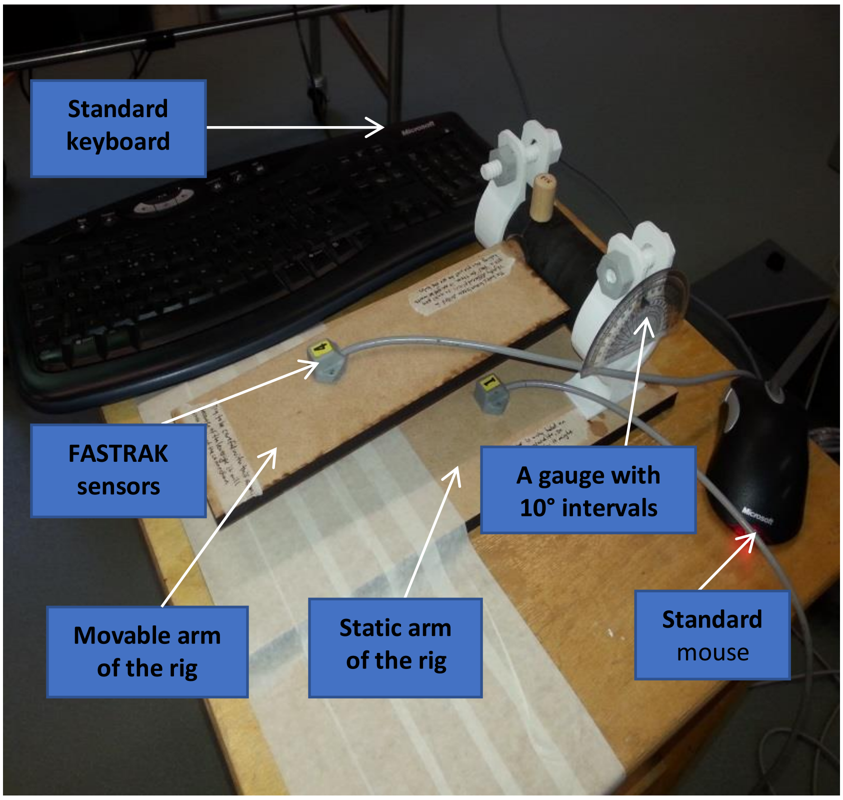


Figure 2.2 *Placement of FASTRAK sensors on an artificial rig; Standard mouse; and standard keyboard*

The angles between the static and movable arms were also measured using a twin axis flexible Electrogoniometer (Biometrics Ltd, model SG 110). SG 110 was used to measure the equivalent of elbow flexion/extension. The instrument and sensors were lightweight (23 g for SG110), which allowed a participant to move freely while activity was recorded (Biometrics Ltd, 2002). The sensors were connected to a small control unit which powered the sensors and converted the input into digital signals (Biometrics Ltd, 2002).

To investigate for interference between the FASTRAK system and metal objects, a standard computer keyboard (Hewlett Packard, 434821-037), a standard computer mouse (Hewlett Packard, 590509-002) and a monitor were used (Figure 2.2).

2.3 Experimental Methods

The test protocol was carried out by a single researcher using the artificial rig in the Human Movement Laboratory at the University of Brighton, School of Health Sciences.

The artificial rig was taped to a wooden table which was secured and taped to the floor to ensure that the rig would not move during data collection. The measurements were taken only for the y-z plane of motion of the rig which was designed to simulate elbow flexion and extension, and for the x-z plane of motion of the rig which was designed to simulate elbow supination and pronation.

2.3.1 Measurements in the direction of flexion/extension in y-z plane of the test rig

The researcher placed two FASTRAK sensors so that they were aligned with the long axis of the rig and attached to the static and mobile arms of the rig using double-sided tape (Figure 2.2). The placement of FASTRAK sensors was in accordance with the guidelines in the Prokopenko et al. (2001) study so that the methods of fixation of the sensors on the participant's arm were chosen in such a way that their displacements would be minimised.

The movable arm of the rig was moved by hand and adjusted to a predetermined angle using the protractor. The baseline starting position of the rig was at 70° (Figure 2.3) and held for approximately 20 seconds before being moved to 60°, then to 50°, and then back to 60° and finally back to 70°, with each angle being held for approximately 20 seconds. These movements were considered a full cycle; 10 cycles of data were recorded in sets of 2 since the FASTRAK could not record more than two minutes of data at a time. The data were recorded with a sampling rate of 60 Hz.

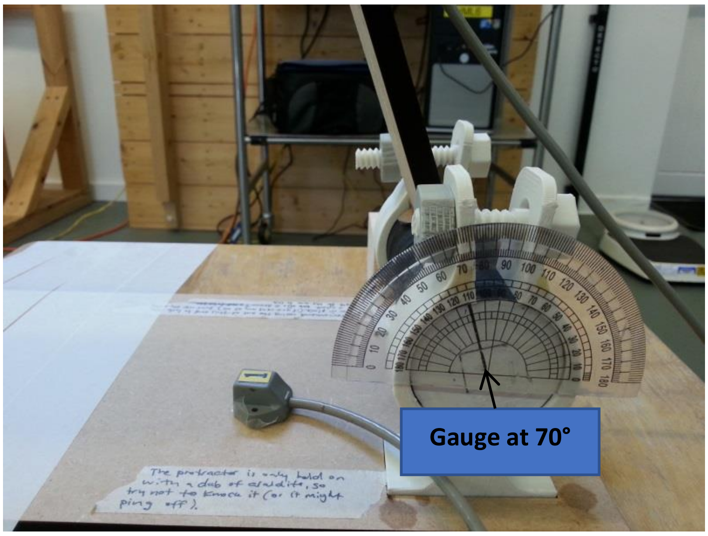


Figure 2.3 *Starting position of the rig at 70° using the gauge*

The same test protocol was repeated with the further inclusion of a computer mouse, a standard keyboard and a computer screen located beside the artificial rig, plugged in and switched on to see whether these input devices interfered with the output of FASTRAK.

After the measurements were taken with FASTRAK, the end blocks of the Electrogoniometer sensors were placed beside the FASTRAK sensors (Figure 2.4) and the experiment was repeated with both systems logging simultaneously. Since there was quite a large gap between the two arms of the artificial rig, a small wooden block (Figure 2.4) was used to lift the Electrogoniometer above the static arm, making it possible to place both ends of the sensors across the joint on both arms. This limited the range of motion of the rig to between 50° and 70°, whereby any further movement risked damaging the sensors.

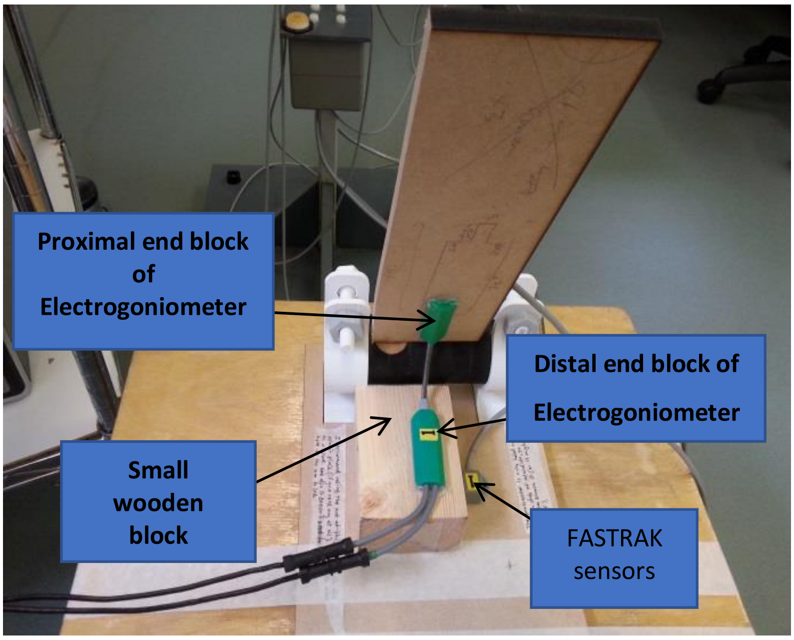


Figure 2.4 *Placement of Electrogoniometer sensors with FASTRAK sensors.*

The sampling rate for the Electrogoniometer was set to 50 Hz since only multiples of 50 Hz were possible in the system's settings and 50 Hz was the closest to that of the FASTRAK (60 Hz).

The end blocks and the wooden block were fixed in place using double-sided adhesive tape. The Electrogoniometer was zeroed at 70° to allow for a simple reference datum to be used in data analysis. While taking the measurements with both pieces of equipment, the FASTRAK sensors were not removed between recordings to maintain the same reference position of the FASTRAK sensors each time the measurements were taken to reduce the measurement error.

The same test protocol was then repeated with the inclusion of a computer mouse, standard keyboard and computer screen positioned beside the artificial rig, plugged in and switched on to check whether these input devices were interfering with the output of FASTRAK when used simultaneously with Electrogoniometer.

Finally, the FASTRAK sensors were removed and were placed away from the experimental setup; then the same test protocol was repeated using only the Electrogoniometer.

2.3.2 Measurements in the direction of supination/pronation in the x-z plane of the test rig

The same test protocol as with the previous experiment in 2.3.1 was used with regards to adjustment of the artificial rig and placement of the sensors. The measurements were then taken using FASTRAK only.

The mobile arm of the rig was moved by hand and positioned in predetermined angles using pre-drilled holes in the rig. The starting position of the rig was at 0°, and this position was held for 20 seconds. Then, the arm was moved between positions, pausing for 20 seconds in each position (Figure 2.5).

Ten cycles of data were recorded in sets of 2. This protocol was then repeated with a computer mouse, a standard keyboard and a computer screen positioned beside the artificial rig, plugged in and switched on to check whether these input devices were interfering with the output of FASTRAK.

At 45 degrees

At 0 degree

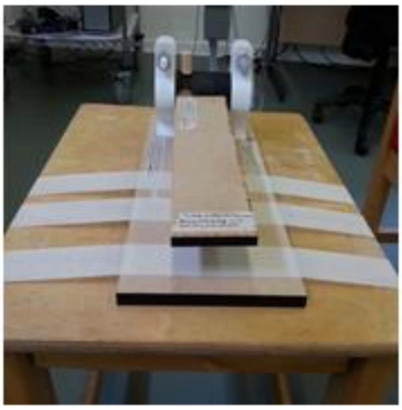


Figure 2.5 *Moving the mobile arm of the rig from 0° to 45°.*

2.4 Data Processing

The data processing was carried out using Microsoft Excel 2010. The results were interpreted in terms of measurement accuracy. The range of motion (ROM) values for both flexion/extension when using Electrogoniometer were converted from binary numbers to degrees; this was calculated as (ROM in binary number ×

180/4096), where 180 is the maximum angle in degrees in the goniometer and 4096 is the maximum number in the binary system, which is 2^{12}.

Mean and standard deviation (SD) were calculated for all data sets for the target angles of 0°, 10°, and 20° in the direction of flexion/extension movements, and similarly for the target angles of 0°, 45 °and 85° in the direction of supination/pronation movements.

For all the FASTRAK and Electrogoniometer measurements, a continuous data subset of 1.7 seconds was selected from the middle of the 20-second period of data collected. This provided a 102-data point sample set which is equal to 1.7 seconds with FASTRAK, and 85-data point sample set with the Electrogoniometer.

The data obtained from FASTRAK and Electrogoniometer were rounded to two decimal places as the acceptable level of accuracy. Therefore, when the SD was calculated, it was rounded to two decimal places.

2.5 Data analysis

2.5.1 Preliminary Analysis

In the preliminary analysis, three questions were raised to know if the readings were accurate at rest and when moved from one position to another and furthermore, to know whether there was hysteresis between the upward and downward direction at target angles 0° and 10° for flexion/extension movements, and at target angles 0˚ and 45˚ for supination/pronation movements. Hysteresis was defined as a systematic error. The three questions were related when moving the rig in the direction of flexion/extension using FASTRAK only and when using Electrogoniometer only, as well as when moving the rig in the direction of supination/pronation using FASTRAK only. The three questions will be discussed below.

2.5.1.1 <u>Are the readings accurate at rest?</u>

To know whether the readings were valid at rest, the researcher needed to know how much random error the FASTRAK and Electrogoniometer systems had. To know that, the researcher looked at the largest standard deviation (SD) within 10 cycles at rest. The largest SD will represent the background system noise which is the level of inaccuracy within the system, the random error. Table 2.1 shows the largest SD within 10 cycles in each system.

Table 2.1 *The largest SD within 10 cycles in FASTRAK during Flexion/Extension and Supination/Pronation and Electrogoniometer during Flexion/Extension*

	FASTRAK	**FASTRAK**	**Electrogoniometer**
	Flexion/extension	**Supination/pronation**	**Flexion/extension**
SD	0.05°	0.09°	0.19°

It was found that the largest SD with FASTRAK in flexion/extension equals 0.05°. This showed the background system noise within the FASTRAK system has an SD = 0.05° and this level of inaccuracy within the system will be considered minimal and acceptable and can be ignored for future analysis.

The largest SD within the FASTRAK system during supination/pronation was found to be 0.09°. This level of inaccuracy within the system is less than one 10^{th} of a degree (0.1°) and will be considered small and acceptable and can be ignored for future purposes.

It was also found that the largest SD within the Electrogoniometer system in flexion/extension = 0.19° and this level of inaccuracy is about one 5^{th} of a degree (0.2°). The level of inaccuracy of 0.19° in the expected range of movement of 20° will be considered small, acceptable and can be ignored for future analysis.

In conclusion, the random errors within the FASTRAK and Electrogoniometer systems have been shown to be acceptably small at less than 0.2° and can be ignored for future analysis. This showed that the readings at rest were valid.

2.5.1.2 Are the readings accurate when moved from one position to another?

To know if the readings were accurate when the rig was moved from one position to another, the researcher needed to establish the meaning of the Mean and SD, which is about a combination of random error by looking at the SD and a systematic error by looking at the mean. Total mean and SD of the mean were calculated at target angle 0°, 10° and 20° for flexion and extension, and at 0°, 45 °and 85° for supination and pronation.

According to Table 2.2, with FASTRAK for flexion/extension, it can be seen that the random error in each position at target angles 0°, 10° and 20° was approximately the same, SD = 0.5°, while using a protractor that has an increment of 1°. This showed effectively that FASTRAK could give a range of data with 2 SD of 1° which equalled the accuracy of the protractor.

Table 2.2 *Mean and SD at target angles 0°, 10° and 20° with FASTRAK for the movement of flexion/extension*

FASTRAK-Flexion/Extension	**0°**	**10°**	**20°**
Mean	-0.05°	10.58°	21.34°
SD	0.40°	0.51°	0.49°

By looking at the means in Table 2.2, there was no systematic error and the readings were accurate when positioning the rig at 0°. At target angle 10°, the mean showed that there was a bias or systematic error of approximately 0.5° over the required target angle. At target angle 20°, the mean showed that there was a systematic error of about 1° overshooting, signifying the trend of the data or systematic errors was increasingly overshooting when the range went further from 0° to 20°.

In Table 2.3, with FASTRAK for supination/pronation, it can be seen that the random error, changing from one position to another, increased from target angle 0° to 45°, and then decreased at target angle 85°. This could be due to a laxity in the movement of the pin locking mechanism.

By looking at the means in Table 2.3, there was no systematic error and the readings were accurate when the rig was positioned at 0°. At target angle 45°, the mean showed that there was a systematic error of approximately 1.36° undershooting. At target angle 85°, the mean showed that there was a systematic error of about 1.70° overshooting. This showed that the systematic errors were undershooting at 45° and overshooting when the range went further to 85°.

Table 2.3 *Mean and SD at target angle 0°, 45° and 85° with FASTRAK for Supination/Pronation*

FASTRAK-Supination/Pronation	**0°**	**45°**	**85°**
Mean	0.01°	43.64°	86.70°
SD	0.73°	1.82°	1.35°

In Table 2.4, with Electrogoniometer for flexion/extension, it can be seen that the random error at target angles 0°, 10° and 20° was approximately the same, SD = 0.5°, while using a protractor with an increment of 1°. This showed effectively that the Electrogoniometer could give a range of data within 2 SD of 1° which equalled the accuracy of the protractor.

Table 2.4 *Mean and SD at target angle 0°, 10° and 20° with Electrogoniometer for Flexion/Extension*

Electrogoniometer-Flexion/Extension	**0°**	**10°**	**20°**
Mean	-3.86°	9.31°	19.70°
SD	0.47°	0.40°	0.25°

By looking at the means in Table 2.4, it showed a systematic error when positioning the rig at 0° of approximately 3.86° undershooting. At target angle 10°, the mean showed that there was a systematic error of approximately 0.69° undershooting. At target angle 20°, the mean showed that there was a systematic error of about 0.3° undershooting. This showed that the trend of the data or systematic errors was undershooting when the range went further from 0° to 20°.

Although both systems showed that they had small differences in the systematic errors, both systems presented that the random errors were similar, and both could be considered usable systems and provide valid readings during movement. However, in supination/pronation, the readings could be less accurate with the FASTRAK system. This may show that FASTRAK may not provide a valid reading at movement for supination/pronation.

2.5.1.3 Is there Hysteresis?

To know whether there was hysteresis, the researcher needed to look at position data in each target angle in the upward and downward directions for flexion and extension, and supination and pronation. All the mean values at target angles 0°, 10° and 20°, and 0°, 45° and 85° were combined in the upward direction and in the downward direction for each target angle. Then the average mean of each target angle was calculated and the differences in the mean at target angles 0° and 10°, and 0° and 45° were calculated. Hysteresis will be presented as a percentage error in a context of a range of 20° for flexion/extension movements at target angles 0° and 10°, and in a context of a range of 85° for supination/pronation at target angles 0° and 45°.

It was found that with FASTRAK for flexion/extension, the difference in the mean between upward and downward direction in the context of a range of 20° at target angle 0° = 0.07˚ (Table 2. 5) and this would be considered acceptable because it was still less than the random error found, SD = 0.40°, and was 0.20˚ at target angle 10° (Table 2.5). This would be considered acceptable still because it was still less than the random error, SD = 0.51°. It was found that the maximum hysteretic effect was 1% at target angle 10˚. Figure 2.6 illustrates whether there was hysteresis in the upward and downward direction.

Table 2.5 *The total mean in the upward direction and downward direction. Differences in the mean and percentage error with FASTRAK in the direction of Flexion/extension*

FASTRAK-Flexion/Extension Angle	Total Mean in Downward Direction	Total Mean in Upward Direction	Difference in the Mean	Percentage error (hysteresis)
0°	-0.11°	-0.04°	0.07°	0.35%
10°	10.44°	10.64°	0.20°	1%
20°	21.32°	21.32°	0.00°	N/A

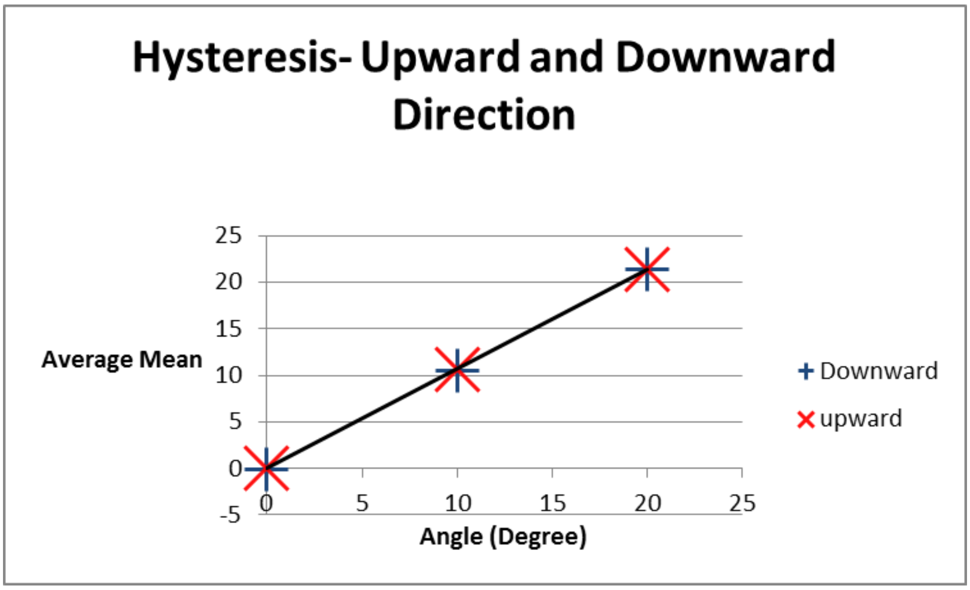


Figure 2.6 *Hysteresis in the upward and downward direction in the movement of flexion/extension using FASTRAK*

In addition, it was found that with FASTRAK for supination/pronation, the difference in the mean between upward and downward direction in the context of a range of 85° at target angle 0° was 0.05˚ (Table 2.6) and this would be considered acceptable because it was less than the random error found, SD = 0.73°; and at target angle 10° was 0.12˚ (Table 2.6) and considered acceptable because it was less than the random error found, SD = 1.82°. The maximum hysteretic effect was

0.14% at target angle 45˚. Figure 2.7 illustrates whether there was hysteresis in the upward and downward directions.

Table 2.6 *Total Mean in the Upward and Downward Direction, Differences in the Mean and Percentage error with FASTRAK in the direction of Supination/Pronation*

FASTRAK-supination/pronation Angle	Total Mean in Upward direction	Total Mean in Downward Direction	Difference in the Mean	Percentage error
0°	-0.10°	-0.05°	0.05°	0.06%
45°	43.58°	43.70°	0.12°	0.14%
85°	86.71°	86.71°	0.00°	N/A

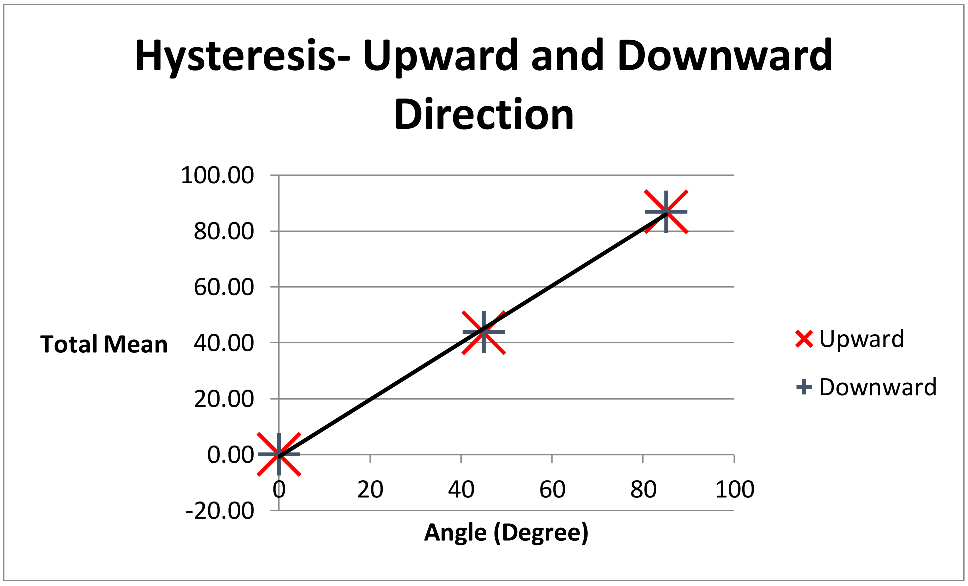


Figure 2.7 *Hysteresis in the Upward and Downward direction with FASTRAK in the movement of Supination/Pronation*

With the Electrogoniometer, it was found that the difference in the mean between upward and downward directions at target angle 0° in the context of a range of 20° = 0.05˚ (Table 2.7); this would be considered acceptable because it was less than the random error found, SD = 0.47°, and was 0.58˚ at target angle 10° (Table 2.7). This comes out with larger position errors, larger than the random error found, SD = 0.40° but any systematic errors would be from the system itself. Also, it is not massively larger than the random error. Because of that, this would be considered acceptable in the context of a range of 20°. The maximum hysteretic effect was 2.92% at target angle10˚. Figure 2.8 illustrates whether there was hysteresis in the upward and downward directions.

Table 2.7 *Total Mean in the Upward and Downward Direction, Differences in the Mean and Percentage error with Electrogoniometer in the Direction of Flexion/Extension*

Electrogoniometer-flexion/extension Angle	**Total Mean in the Upward Direction**	**Total Mean in the Downward Direction**	**Difference in the Mean**	**Percentage error**
0°	-3.76°	-3.81°	0.05°	0.27%
10°	9.60°	9.01°	0.58°	2.92%
20°	19.70°	19.70°	0.00°	N/A

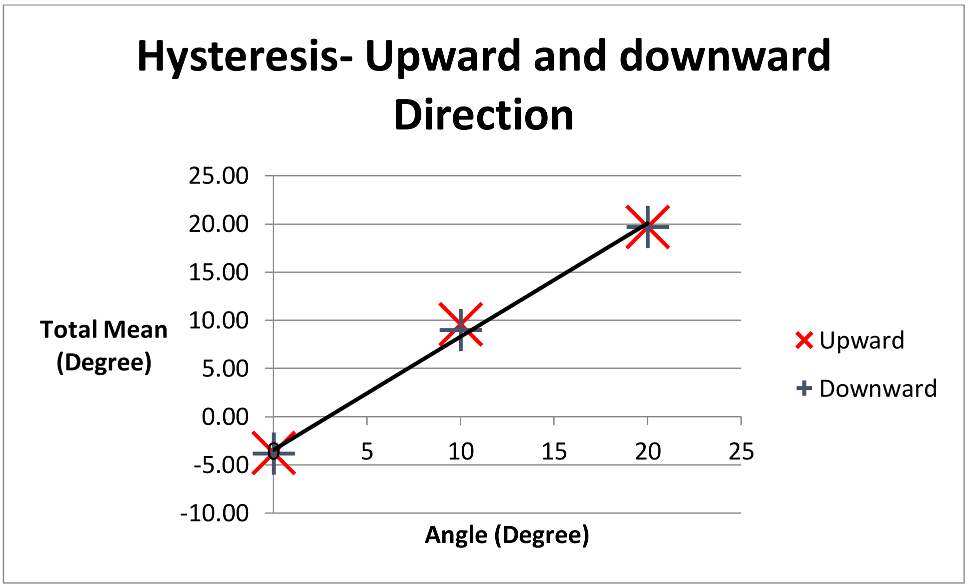


Figure 2.8 *Hysteresis in the Upward and Downward Direction with Electrogoniometer in the Direction of Flexion/Extension*

In conclusion, it could be seen that there were minor differences in terms of hysteretic effect between FASTRAK and Electrogoniometer. FASTRAK showed that it had lower magnitude of the directional error than Electrogoniometer at 10°. This represented different systematic bias between the upward and downward movements with Electrogoniometer at 10°. However, the small hysteretic effect could be considered acceptable in the context of a range of 20° for flexion/extension.

2.5.2 Measuring Agreement

A Bland and Altman (1986) test was carried out to assess the degree of agreement between the FASTRAK and Electrogoniometer measurements to check whether both pieces of equipment could give similar results and be used simultaneously. Moreover, the test was done to check for interference between both pieces of equipment, as well as to check which equipment could be used for the measurements of elbow and wrist range of motion for larger scale experiments.

The difference in the mean of the FASTRAK and Electrogoniometer data was calculated, followed by calculations for the mean difference ($\bar{d}$) and standard deviation of the differences (s). Subsequently, the range between $\bar{d}$- 2s and $\bar{d}$+2s was referred to as the limits of agreement.

The differences between the measurement types gave values that should lie within the limits of agreement for approximately 95% of the time (Bland and Altman, 1986). The differences between the data measured with FASTRAK and Electrogoniometer were calculated and compared to the limits of agreement to determine the agreement between FASTRAK and Electrogoniometer. In addition, the Bland and Altman test would show the size of error by looking to the bias and the limits of agreement.

2.6 Results

The Bland and Altman test was done to all experiments that were done at the same time in the validity pilot study, ensuring that the recordings were taken effectively at the same angle. Those experiments firstly used FASTRAK and the Electrogoniometer simultaneously and secondly used FASTRAK and the Electrogoniometer simultaneously with the inclusion of the computer equipment. The computer equipment consisted of a standard computer mouse (Hewlett Packard, 590509-002) a standard keyboard (Hewlett Packard, 434821-037) and a computer monitor.

The Bland and Altman test results were interpreted by looking to the bias and the limits of agreement. The bias should be small enough to not cause a problem in the experiment. From the published literature, the bias should be approximately close to zero to not cause a problem in the experimental setting (Bland and Altman, 1986, 1992; Myles and Cui, 2007; Giavarina, 2015). Furthermore, the size of movement by looking to the limit of agreement should be narrow in a context of a range of 20° (Bland and Altman, 1986, 1992; Myles and Cui, 2007; Giavarina, 2015). If the limit is wide, the results could be problematic. If the limits are narrow and the bias is small enough, then the two quantitative methods used were sufficiently equivalent (Bland and Altman, 1986, 1992; Myles and Cui, 2007; Giavarina, 2015). Table 2.8 demonstrated the findings from Bland and Altman test.

Table 2.8 *Bland and Altman test results*

Bland and Altman test	Mean Difference (Bias)	$\pm 2SD$
FASTRAK+Electrogoniometer used simultaneously.	0.60°	1.86°
FASTRAK, Electrogoniometer and Computer equipment.	0.39°	1.74°

2.6.1 FASTRAK and Electrogoniometer when both used simultaneously

The scatter graph (Figure 2.9) showed the difference between the FASTRAK and Electrogoniometer measurements on the vertical axis, and the average of the measurements by the two pieces of equipment on the horizontal axis. The bias was found to equal 0.60°, which is close to zero approximately, and the limits of agreement were equal to −1.25° and 2.46°. Thus, FASTRAK tended to give a higher reading, by between −1.25°and 2.46°. Despite this, the limits of agreement (−1.25°and 2.46°) were small enough for the researcher to be confident that both pieces of equipment agreed sufficiently and could give similar results.

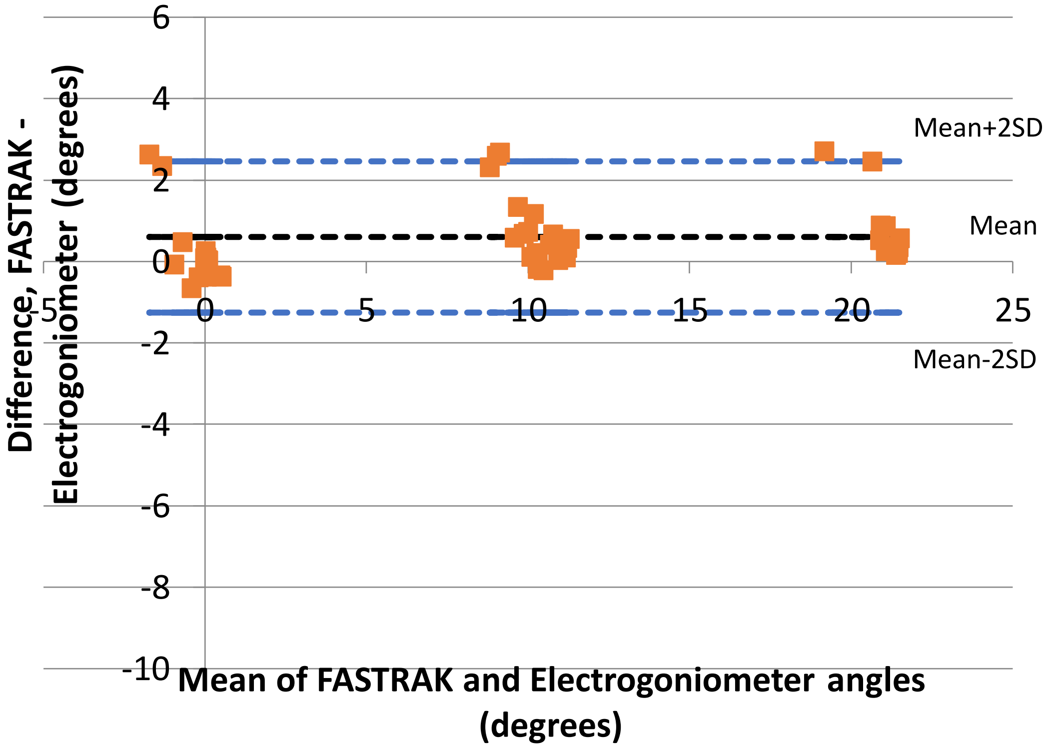


Figure 2.9 *Bland and Altman plot of differences between FASTRAK and Electrogoniometer when used simultaneously, with the representation of the limits of agreement.*

2.6.2 FASTRAK and Electrogoniometer when both used simultaneously with the inclusion of the computer equipment

The scatter graph (Figure 2.10) showed the difference between the FASTRAK and Electrogoniometer measurements during the inclusion of the computer equipment on the vertical axis, and the average of the measurements by the two pieces of equipment on the horizontal axis. The bias was found to equal 0.39°, which is approximately close to zero and the limits of agreements were equal to −1.34°and 2.13°. This meant that FASTRAK tended to give a higher reading, by between −1.34°and 2.13°. Despite this, the limits of agreement (−1.34°and 2.13°) were small enough for the researcher to be confident that both pieces of equipment agreed sufficiently with the inclusion of the computer equipment.

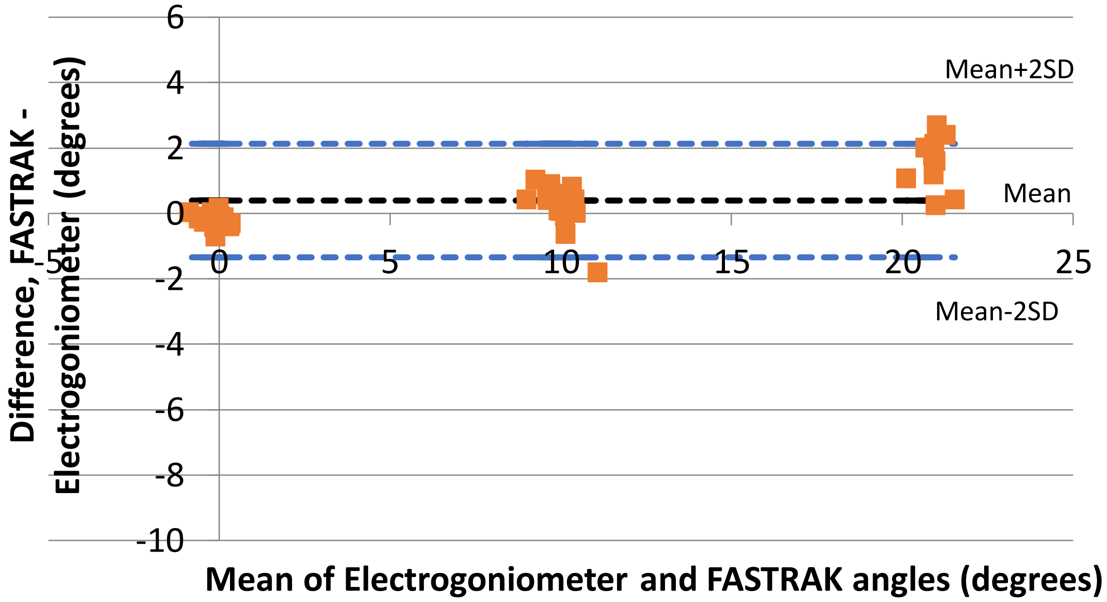


Figure 2.10 *Bland and Altman plot of the differences between FASTRAK and Electrogoniometer when used simultaneously with the inclusion of the computer equipment, with the representation of the limits of agreement.*

In comparison, by looking to the Bland and Altman plot (Figure 2.9 and 2.10), and by looking to Table 2.8, it can be seen that the bias was approximately the same in both experiments, equal to 0.60°, when FASTRAK and Electrogoniometer were both used at the same time, and equal to 0.39° when both pieces of equipment were used at the same time with the inclusion of the computer equipment. Also, the discrepancies within the data ($\pm 2SD$) as shown in Table 2.8 were almost the same in both experiments, equal $\pm$ $1.86°$ when FASTRAK and Electrogoniometer were used at the same time, and equal $\pm 1.74°$ when both pieces of equipment were used at the same time with the inclusion of the computer equipment. This showed effectively that the researcher could be confident that both systems agreed sufficiently, and the computer equipment did not have any effect on the output of FASTRAK.

It could be seen that both FASTRAK and Electrogoniometer agreed sufficiently and could give similar results. Also, the inclusion of the computer equipment did not interfere with the output of FASTRAK system and could be used safely with FASTRAK. This resulted in being able to use both FASTRAK and Electrogoniometer for the measurements of the range of motion of the elbow and wrist joints for larger scale experiments.

2.7 Discussion

The aim of the validity pilot study was to investigate the validity of the measurement tools, FASTRAK and Electrogoniometer, in terms of measurement accuracy in the measurements taken on the artificial rig at known angles. It was necessary for the researcher to investigate both pieces of equipment as both FASTRAK and Electrogoniometer were applicable to be used, and both systems needed to be checked to ensure their suitability for the purpose of the study. For the researcher to be able to choose between both the FASTRAK and Electrogoniometer systems and to discover which equipment could be used for larger scale experiments, measurement accuracy was examined by looking at the random errors, systematic errors and hysteresis in each system. In addition, the researcher looked at the level of agreement between both pieces of equipment.

2.7.1 Random errors

In terms of random errors, the researcher found that both pieces of equipment were similar at rest and when the rig was moved from one position to another. Random error at rest represented background system noise, and during movement it represented the operator errors by misalignment of the rig at each target angle. At rest, both systems showed that the random errors were acceptably small at less than 0.2°, and this level of inaccuracy within the system would be considered minimal and acceptable and ignored for future analysis. This showed that both systems gave valid readings at rest.

During movement, the random errors with FASTRAK and Electrogoniometer for the movement in the direction of flexion/extension were approximately the same, SD = 0.5° at each target angle 0°, 10° and 20°, while using a protractor with an increment of 1°. This showed effectively that FASTRAK and Electrogoniometer could give a range of data with 2SD of 1° which equalled the accuracy of the protractor. Also, this showed that both systems gave valid readings during movement.

However, the random errors with FASTRAK for the movement in the direction of supination/pronation were changed from one position to another, as seen in Table 2.3. The random errors increased from target angle 0° to 45°, and then decreased at target angle 85°. The largest random error was found at 45°, SD = 1.82°. This could be due to a movement in the pin locking mechanism, in that the smallest hole was built for target angle 0°; then a larger hole was built for target angle 45° and then back to a small hole at 85°. This could also be an error made accidentally while building the rig. This could lead to greater variations or more random errors with supination/pronation movements than flexion/extension movements. This may show that the readings could be less accurate for supination/pronation with the FASTRAK system.

2.7.2 Systematic errors and hysteresis

In terms of systematic errors, both systems showed different results. With FASTRAK for flexion/extension, there was an increasing amount of overshooting when the range increased from 0° to 20°. The largest error was approximately 1.34° overshooting at 20°. However, with the Electrogoniometer, there was an increasing amount of undershooting as the range increased from 0° to 20°. The largest error here was approximately 3.86° undershooting at 0°. This is a systematic error and any systematic errors found will be from the system itself, and the researcher cannot control for these. Because of this, the magnitude of the systematic errors found within the two systems was small enough to be considered acceptable in the context of a range of 20°.

With FASTRAK for supination/pronation, the systematic errors were undershooting at 45° and then overshooting at 85°. The largest systematic error was found to be approximately 1.71° overshooting at 85°. The systematic errors found could be considered acceptable in the context of a range of 85°.

In terms of hysteresis, hysteresis was presented as a percentage error in the context of a range of 20° for flexion/extension at target angles 0° and 10°, and in the context of a range of 85° for supination/pronation at target angles 0° and 45°.

Hysteresis showed the magnitude of the directional errors between the upward and downward movements.

Both systems showed that there were small hysteretic effects in which differences in the equipment readings occurred when moving the rig in the upward and downward directions. However, the hysteretic effects were different between the two systems. In FASTRAK for flexion/extension, the maximum hysteretic effect was observed at 10° and was 1% and that equated to a difference in the mean of 0.20˚ in a range of 20˚, which was less than the random error found, SD = 0.40˚. In FASTRAK for supination/pronation, the maximum hysteretic effect was observed at 45° and was 0.14%. This equated to a difference in the mean of 0.12˚ in a range of 85˚, which was less than the random error found, SD = 1.82˚.

In Electrogoniometer for flexion/extension, the maximum hysteretic effect was observed at 10° and was 2.92% and that equated to a difference in the mean of 0.58˚ in a range of 20˚, coming out with larger position errors than the random error found, SD = 0.40˚. Although it came out larger than the random error found, it was not massively larger than the random error. Because of that, this would be considered acceptable in the context of a range of 20˚.

Although Electrogoniometer came out with larger position errors than FASTRAK, it was not something extreme and would be considered acceptable, as discussed above, as it is from the equipment itself.

However, the small hysteretic effect could be considered acceptable and still not be an issue in the context of a range of 20° for flexion/extension in both systems. The small amount of hysteresis could be due to operator error when aligning the rig, or due to systematic error. Regardless of whether it is operator error or systematic error, the resulting error was small enough to be considered acceptable. This finding was consistent with the finding from Rowe et al. (2001), in which a small hysteretic effect was found with Electrogoniometer when it was attached to the arm and manipulated through a range of angles from −120° to +120° in ten-degree increments, of approximately 1 or 2 degrees, in a context of a range less than 100°. In that setting the effect was considered small enough that the results were clinically acceptable.

2.7.3 Measurement agreement

It was observed that both systems effectively agreed when used simultaneously and also when used in conjunction with external computer equipment. Furthermore, the inclusion of the computer equipment did not have any effect on the output of the FASTRAK system. The researcher is confident that the two quantitative methods used gave equivalent results because the bias was small enough to not cause a problem in the clinical setting, was approximately the same in both experiments and was close to zero (Bland and Altman, 1986, 1992; Myles and Cui, 2007; Giavarina, 2015). The discrepancies within the data ($\pm 2SD$) were almost the same in both experiments with and without computer equipment, as seen in Table 2.8. The bias was approximately $0.6° \pm 1.86°$ when both systems were used at the same time, and $0.39° \pm 1.74°$ when both FASTRAK and Electrogoniometer were used at the same time with the inclusion of the computer equipment.

2.8 Limitations of the study

There was a possibility that it would be better if the rig was drilled to the table instead of using a tape to fix the rig on the table. This would ensure more that the rig was unmovable when the mobile arm of the rig was moved from one position to another by the operator. Also, it would be better if several wedges were built which have an arch equal to the angles chosen for flexion/extension. This would help to avoid misaligning the rig into each angle.

2.9 Conclusion

In conclusion, minor differences could be seen in the accuracy, the errors and the extent of hysteretic effects identified between both FASTRAK and Electrogoniometer. However, these were deemed acceptable and can be ignored for future analysis. Furthermore, both systems agreed sufficiently and gave similar results, according to the Bland and Altman test. However, operationally, the Electrogoniometer had more advantages over the FASTRAK system. During the validity pilot study, the researcher found that FASTRAK stopped collecting data after 2 minutes. This may be due to the limited FASTRAK memory capacity. The researcher decided not to use FASTRAK for the next study, discussed in Chapter 3. Because of this, Electrogoniometer will be used in the next preliminary studies. Using Electrogoniometer will be more convenient with larger scale experiments, according to the time scale needed to perform the task and the ability to capture the whole data without being at risk of the system possibly being shut down while participants are performing the task, meaning the task would need to be repeated. This could be time consuming for the participants and could increase the fatigue effect.

3 Chapter 3: Preliminary Studies

3.1 Introduction

In this chapter, the discussion is about the preliminary studies that were done before implementing the main reliability study, which will be discussed in Chapter 4. The details of each preliminary study will be discussed in this chapter, as illustrated in Figure 3.1. The aim of these preliminary studies was to help the researcher to draw a methodological decision for larger scale experiments. It helped the researcher to examine the feasibility of the approach to be used in larger scale experiments, the assessment procedures and to identify any modifications which needed to be implemented before the larger scale experiments.

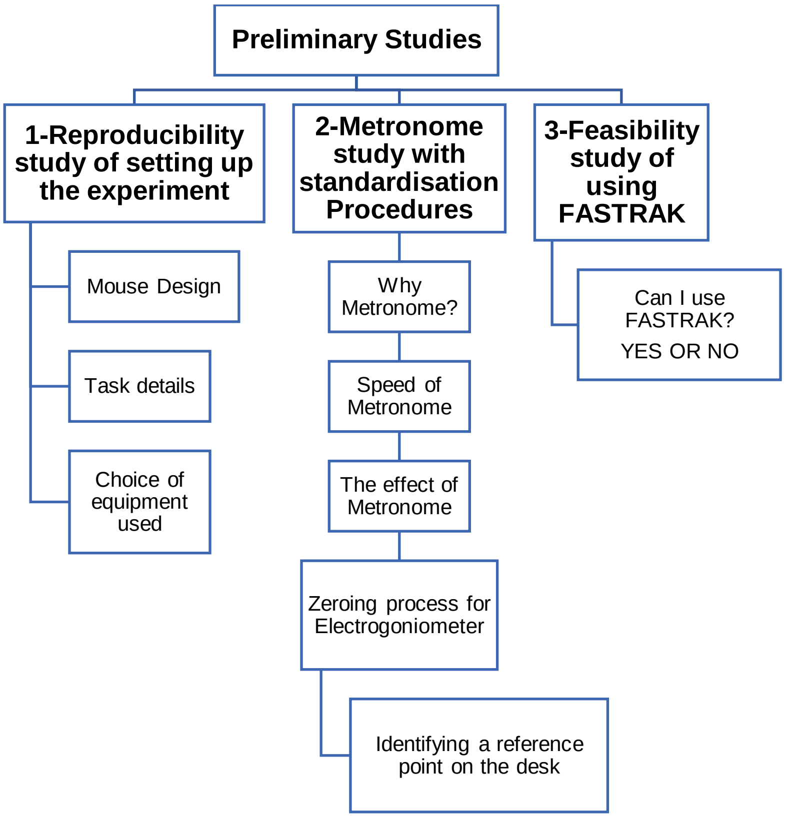


Figure 3.1 *Preliminary Studies*

3.2 Reproducibility study of setting up the experiment

For this study, one healthy participant (a right-handed, male, 43 years old, who used a Standard mouse daily) was needed to check the experimental set-up before implementing with a larger scale experiment. This participant was recruited by word of mouth. This participant read the participant information sheet (Appendix 6) and signed the consent form (Appendix 7). The participant performed two hyperlink tasks: the elbow hyperlink task, a clicking task that enabled elbow movements by moving the cursor up and down (vertical movement) (Figure 3.2), and the wrist hyperlink task, a clicking task that enabled wrist movements by moving the cursor right and left (horizontal movements) (Figure 3.3). Hyperlink tasks were chosen because the researcher wanted to see repetitive movements in the elbow and the wrist joint to capture the range of motion data needed for this experiment and she felt that this type of task would suit the purpose.

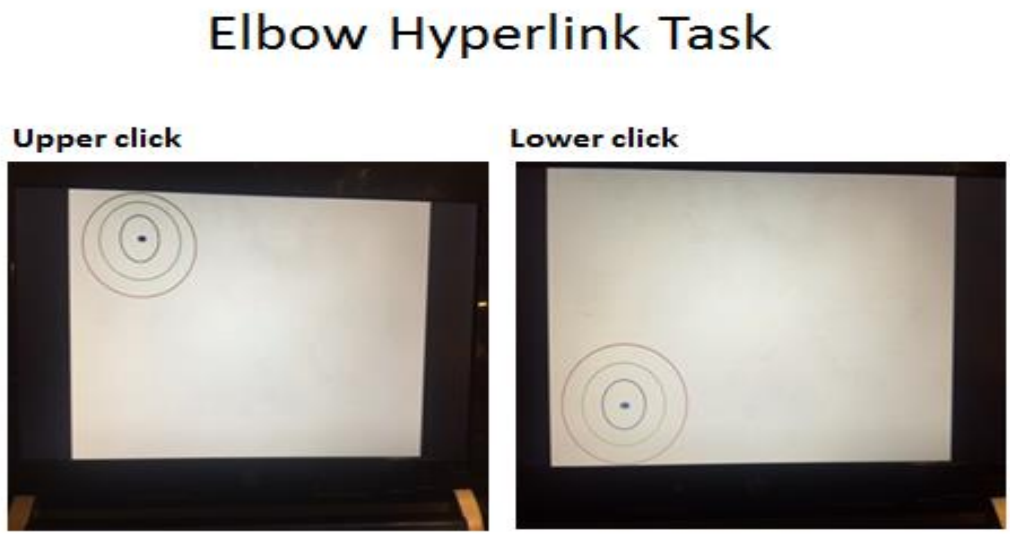


Figure 3.2 *Elbow Hyperlink Task.*

Figure 3.3 *Wrist Hyperlink Task.*

This participant performed the task using a Standard mouse (Hewlett Packard, 590509-002) and a Penguin mouse (Posturite Ltd, 9820099). The choice of the mouse design came because these two were the only ones available at the time for the preliminary studies and the researcher wanted to compare the range of motion data using a standard and vertical mouse. The Penguin mouse is a vertical mouse that allows right and left hands to share the workload to avoid any musculoskeletal disorders (Posturite, 1991, online). The Penguin mouse comes in three sizes: small, medium and large (Posturite, 1991, online).

The task and the computer mice were randomly allocated by drawing lots to ensure that the participant used the mice in random order. Before implementing the experimental procedures, this participant was allowed to practise by doing several trials to become familiar with the particular computer mouse used and the task.

The participant performed five trials and each trial consisted of using two mice for each hyperlink task. In addition, after each trial, all the sensors of Electrogoniometer were removed and then applied again for the next trial to test the intra-rater reliability of the experimental set-up.

A twin axis Electrogoniometer was used to measure elbow movements (flexion, extension) and wrist movements (flexion, extension, radial and ulnar deviation). The choice of the equipment came from the decision taken by the researcher following the validity pilot study results in Chapter 2.

Electrogoniometer measurements were taken at rest for 3 seconds and during movement. An Electrogoniometer sensor was placed over the elbow joint by attaching the distal end block to the forearm, using double sided adhesive tape, so that the centre axis of the end block coincided with the centre axis of the forearm (Biometrics Ltd, 2002). The proximal end block was attached to the upper arm with the centre axis of the end block coincident with the centre axis of the upper arm (Biometrics Ltd, 2002).

In addition, an Electrogoniometer sensor was placed on the dorsum of the wrist (Figure 3.4), using double-sided adhesive tape; the distal end block was placed over the third metacarpal and the proximal end block was attached to the forearm (Biometrics Ltd, 2002). The Electrogoniometer was zeroed using the zero button on the data link program while the participant's hand was resting in a neutral position on the desk.

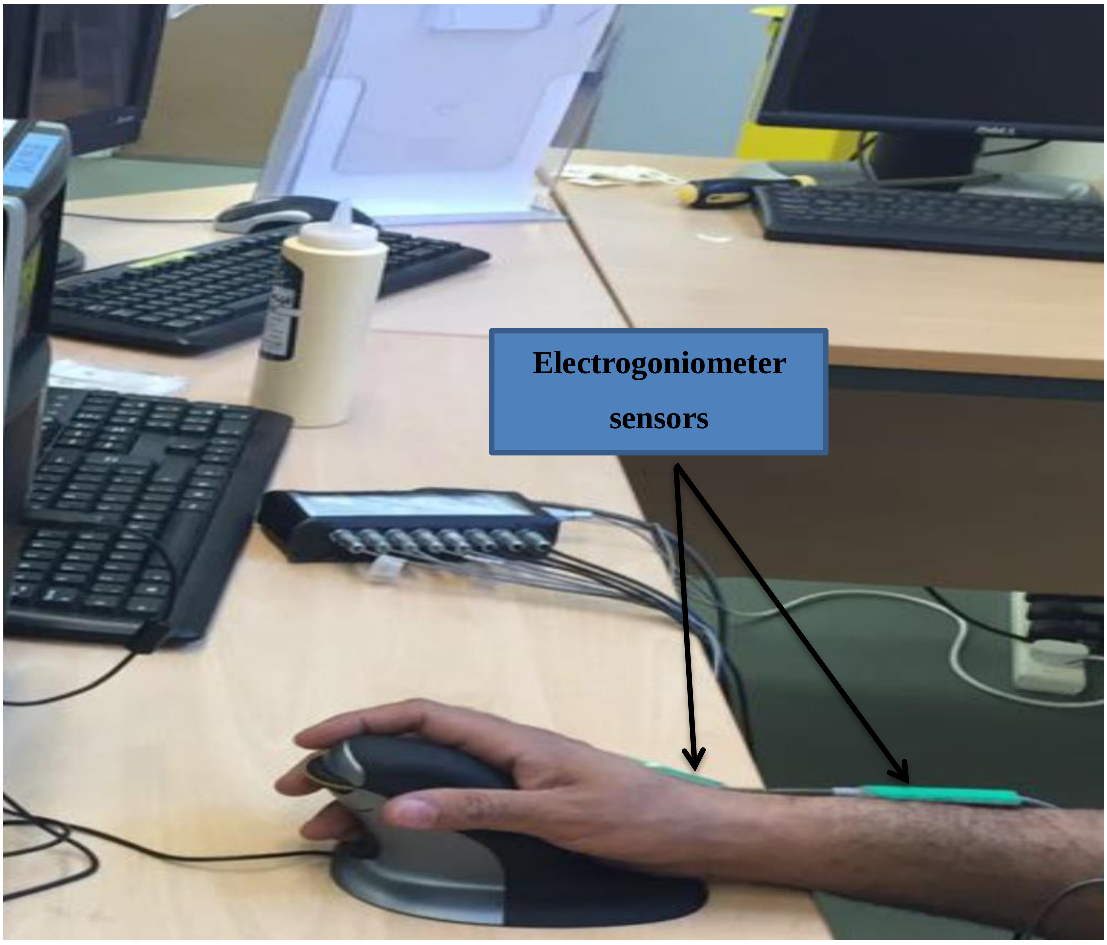


Figure 3.4 *Placement of Electrogoniometer sensors on the Wrist joint.*

This experiment took five hours to be completed. However, although the participant was permitted a break whenever he requested, it was still possible to develop a fatigue effect as a factor. The researcher found that the participant was double clicking, missing a click or overshooting whilst performing the task. This meant the graphical presentation of the range of motion data of the elbow and wrist was difficult to analyse. Because of this, the researcher decided to adjust the experimental set-up, discussed in section 3.3.

3.3 Metronome study with standardization procedures

This preliminary study was done for a clear graphical presentation of the range of motion data of the elbow and wrist joint, and furthermore, to help the participant be more precise whilst performing a clicking task to avoid missing a click or double clicking. The same equipment and the same test protocol were used in this study as in 3.2. However, the sensors remained in situ throughout this experiment.

Metronome software was used in this experiment to help the participant in the precision of the speed of movement. The metronome software was downloaded through a smartphone application called Metro Timer. The metronome speed was set at 30 times/min with 2 seconds between each beep, which allowed enough time for the participant to click and to shift to the next slide for the following click. The same participant as in the previous study in 3.2 participated in this study because the researcher wanted to see if the metronome made a difference to the participant's performance during a clicking task.

The participant performed one trial for both hyperlink tasks and used two computer mice: a Standard and a Penguin mouse. The researcher asked for one trial just to check the graphical presentation of the data. Before taking measurements, the Electrogoniometer was zeroed while the participant's hand was resting in a neutral position on the desk. The researcher ensured a standard joint position through the zeroing process by drawing a line on a piece of paper, using a ruler, and aligning the mid-point of the elbow joint to the second finger to avoid Wrist flexion/extension and Wrist radial/ulnar deviation.

The researcher illustrated a reference point on the desk where the participant should keep the computer mouse position at the beginning of each trial. The mouse position had been chosen by the participant to provide comfort whilst performing the task. Also, the way the participant held the computer mouse was kept unchanged throughout the experiment. The aim of these changes was to improve the repeatability of the range of motion data.

In conclusion, the researcher considered the following to be appropriate for the next main reliability study: first, using a Metronome; second, the zeroing process for the Electrogoniometer while the participant's hand was in a neutral position on the desk and by drawing a line on a piece of paper; third, the use of a reference point on the desk for the beginning of each trial. Those three factors helped the participant to be more organised in performing the task. The speed of the metronome was found to be functional and gave the participant enough time to move the cursor for the next click in both hyperlink tasks as well as allowing him to be more structured in performing the task. These three factors helped to have a better graphical presentation for the range of motion data.

3.4 Feasibility of using FASTRAK

The researcher found that both FASTRAK and Electrogoniometer were comparable from the validity pilot study in Chapter 2 in terms of accuracy, random and systematic errors, hysteresis and equivalency. Although both systems were comparable, the Electrogoniometer was found to be the easiest and most convenient to use. The guidelines for using the Electrogoniometer and the placement of the sensors were available in detail through the Biometrics website. Furthermore, in the published literature (Rowe et al., 2001; Carey and Gallwey, 2002; Johnson et al., 2002; Nordander et al., 2013), the placement of Electrogoniometer sensor was as described in the Biometrics guidelines. Because of that, the researcher was confident in using the Electrogoniometer system. Only one study was found that discussed the placement of FASTRAK sensors; however, this study mentioned that further research should be done (Prokopenko, et al., 2001).

From the validity pilot study, the researcher found that the FASTRAK capacity could be on for only two minutes. This could be considered a risk factor if the time needed to perform the experiment took more than two minutes. Thus, FASTRAK was excluded in the next reliability study, discussed in Chapter 4, and the Electrogoniometer system used for the measurement of elbow and wrist range of motion.

4 Chapter 4: The analysis of the reliability of elbow and wrist range of motion and forearm muscle activity when using three computer mice designs (Pilot study)

4.1 Introduction

This chapter outlines the work carried out to investigate the reliability of the range of motion measurements of the elbow and wrist taken by the Electrogoniometer on 15 participants. This work was carried out to investigate the reliability of muscle activity of Biceps, Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors. The work carried out in the reliability study took place prior to implementing the main experiment. It was necessary to investigate practical experimental issues relating to repeatability of the measurements in the range of motion of the elbow and wrist and muscle activity of the forearm. Reliability in this instance is defined as the degree to which an assessment tools gives stable and consistent results (Packer et al., 1993).

This chapter covers the methods, results and discussion for the study into the reliability of the range of motion and muscle activity data that were taken within 3 trials with each computer mouse used, Standard, Penguin and Evoluent, and within two consecutive days.

4.1.1 Aim

The aim for this reliability study was to test the reliability of the range of motion data of the elbow and wrist joint and the reliability of the Forearm muscle activity whilst performing a computer hyperlink task using three different computer mouse designs.

4.1.2 Research Questions

1. How can the reliability of wrist flexion/extension and wrist radial/ulnar deviation during the wrist hyperlink task using Standard, Penguin and Evoluent mice (within and between-days reliability) be determined?

2. How can the reliability of elbow flexion/extension during the elbow hyperlink task using Standard, Penguin and Evoluent mice (within and between-days reliability) be determined?

3. How can the reliability of the average and maximum voltage of the Biceps, Triceps, Brachioradialis, Wrist Flexors, and Wrist Extensors during wrist

and elbow hyperlink tasks using Standard, Penguin and Evoluent mice (within-days reliability) be determined?

4.2 Ethics approval

This reliability study was approved by the Faculty of Research Ethics and Governance Committee (FREGC) on 24th October 2013 (for the completed ethics proposal and the letter of approval, see Appendix 4).

4.3 Sampling and Participants

This study used a convenience sampling approach for the data collection to be facilitated over a short duration of time (Hicks, 1995). This resulted in a sample of 15 healthy participants, aged between 19 and 51 (7 females, 8 males). The participants were recruited via email (Appendix 5) with an attached information sheet (Appendix 6). Flyers were handed out to students around the campus with the same wording as the email (Appendix 5) and the study was advertised in the blog of the Centre for Sport and Exercise Science and Medicine (SESAME). The demographic data of each participant are demonstrated in Table 4.1.

Table 4.1 *Summary of the Demographic data of the 15 participants in the Reliability Study*

No.	Sex	Age Range	Dominant Hand	Frequency of computer mouse use
15	-7 Females -8 Males	18-51 years old	-12 Right handed. -3 Left handed.	-10 used Standard mouse. -5 used Laptops.

The inclusion criteria allowed for healthy male and female participants aged 18 to 70 years old and participants, who were either right handed or left handed. The exclusion criteria would not permit participants with current musculoskeletal disorders or pain in the neck, shoulder, elbow and wrist joints. In addition, participants with a surgical history and participants allergic to medical tape were excluded.

4.4 Equipment used in this experiment

This experiment used a twin axis Electrogoniometer to measure the range of motion data of the elbow (flexion, extension) and wrist (flexion, extension, radial deviation and ulnar deviation). A metronome was included in this study, as described in Chapter 3. Three computer mouse designs were used: Standard (Hewlett Packard, 590509-002), Penguin (Posturite Ltd, 9820099), and Evoluent (Posturite Ltd, 411508308040) mice (Figure 4.1).

Penguin Mouse

Source: Author's own

Evoluent Mouse

Source: Author's own

Standard Mouse

Source: Author's own

Figure 4.1 *The three different types of computer mouse design*

Surface Electromyography (EMG) was also used. The type of EMG sensor and the pre-amplifier used in this experiment was the NOS.SX230, manufactured by Biometrics Ltd. EMG measurements were taken using the Data LINK DLK 900 together with up to five EMG sensors (Biometrics Ltd, 2002). The Biometrics EMG sensors contained pre-amplifiers, comprising all the necessary gain and filter circuits so that the researcher needed only to connect the sensor to the Data Link and configure the channels to be used for EMG measurements (Biometrics Ltd, 2002).

4.5 Experimental methods

The data collection was carried out by a single researcher and took place in the Human Movement Laboratory at the University of Brighton, School of Health Sciences. The participants attended two sessions on two consecutive days and each session lasted for one hour.

The same test protocol used in the previous preliminary study with a metronome using Electrogoniometer for the range of motion measurements, as discussed in Chapter 3, was adopted in this study. Furthermore, the surface EMG sensors were placed over the selected muscles. Measurements were taken for muscle activity of the forearm (Biceps, Triceps, Brachioradialis, wrist flexors, wrist extensors).

The EMG sensors were placed according to the guidelines in Criswell (2011), with minor adjustments made for individual differences in body size and morphology to achieve the best signal. A ruler was used to follow the Criswell guidelines and minor adjustments were made, if required, following careful palpation of the target muscles. The palpation included active contraction of the muscle against moderate resistance applied by the researcher.

For the forearm extensors, one sensor was placed over the wrist extensor bundle (on the dorsal aspect and 5 cm below the elbow over the belly of the muscle in the direction of the muscle fibres). For the forearm flexors, one sensor was placed over the wrist flexor bundle (on the ventral aspect and 5 cm distal to the elbow over the belly of the muscle in the direction of the muscle fibres) (Criswell, 2011). For Biceps, one sensor was placed on the dorsal aspect of the upper arm and in the centre of the muscle belly parallel to the muscle fibers (Criswell, 2011). For Triceps, one sensor was placed parallel to the muscle fibre approximately 2 cm medial from the midline of the arm (Criswell, 2011). For Brachioradialis, one sensor was placed distal to the elbow approximately 4 cm from the lateral epicondyle on the medial fleshy mass (Criswell, 2011). In addition, a reference electrode (ground electrode) was placed on the non-dominant hand over the bony area on the wrist joint. The ground electrode is necessary to provide a reference for the differential inputs and to cancel the electrical interference on the skin. The placement of surface EMG sensors is shown in Figure 4.2. The EMG data were sampled at 1000 Hz.

Muscles chosen in this study were those most frequently identified in the literature as the most important muscles for wrist flexion/extension (W.F/E), wrist radial/ulnar deviation (W.RD/UD), and elbow flexion/extension (E.F/E).

The researcher carried out necessary preparations when applying EMG sensors to the skin. Typically, the skin was cleaned with alcohol and dry shaved with a disposable razor if required. These preparations helped to reduce the impedance associated with the skin-sensor connection and enhanced the quality of the signal being recorded (Clancy et al., 2002).

At the beginning of each experiment, all the information about the experiment, including the purpose of the study was explained to the participants verbally and provided in writing by using an information sheet (Appendix 6). Participants then needed to sign a consent form (Appendix 7) to indicate their agreement to take part in the study. The participants performed three trials with each computer mouse (Figure 4.2) and for both hyperlink tasks, as described in Chapter 3; participants completed 9 trials with the elbow hyperlink task and 9 trials with the wrist hyperlink task in each laboratory visit. Figure 4.2 shows an example of how the participants performed the hyperlink task using the Penguin mouse design.

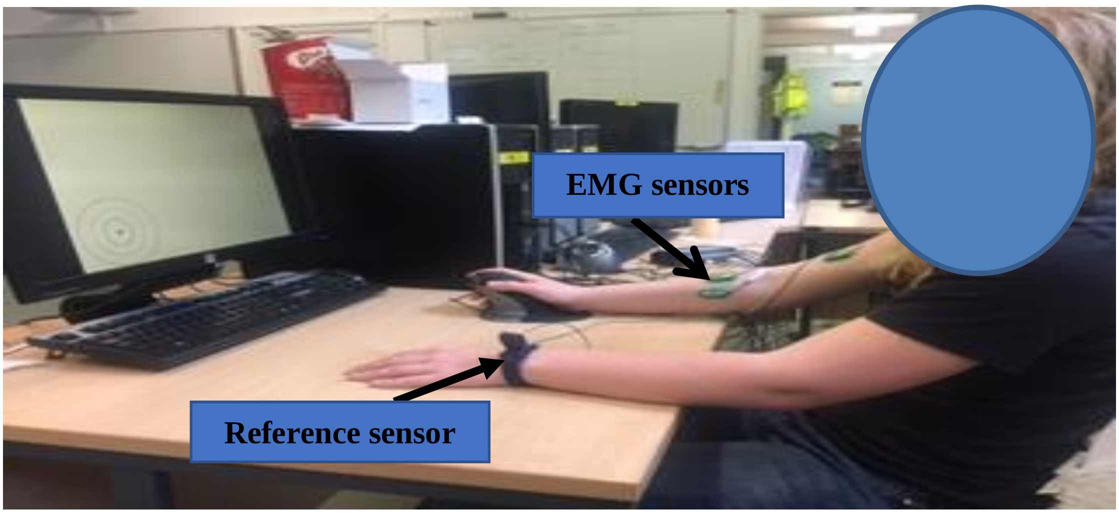


Figure 4.2 *A participant performs the hyperlink task using a Penguin mouse*

Before implementing the experimental procedures, familiarisation was done by performing the task with each mouse design prior to the experiment and without collecting data to ensure that the participants understood both hyperlink tasks and were familiar with each computer mouse used. The number of trials used for familiarisation were dependent on the participants' needs to be confident in performing the task and to be familiar in using each computer mouse design such as knowing where the right click was, as well as the left click.

4.6 Data Processing

4.6.1 Range of motion data

The data processing was carried out using Microsoft Excel 2010. After processing the first 8 participants, the researcher realised the data set contained noise and a Butterworth filter was adopted with a cut off frequency of 8 Hz to reduce the noise. The data from all 15 participants were processed using an automated template and a fourth-order zero-lag low-pass Butterworth filter was applied with a cut off filter of 8 Hz.

In each data set, all the maximum and minimum points in the range of motion graph were noted using the automated template. The difference between each maximum and minimum point was calculated for each movement. Then the mean difference and SD of the difference were calculated using the automated template.

4.6.2 EMG data

The raw EMG data were processed using MATLAB R2017a. The raw EMG data were filtered to remove noise elements that had different frequencies from the signal (Nawab et al. 2010). First, it was filtered using a fifth-order high-pass Butterworth filter, with 20 Hz cut off frequency. This filter was applied forwards and backwards to prevent alteration of the timing of data events. Then the data were filtered again using a fifth-order low-pass Butterworth filter with 300 Hz cut off frequency. This filter was applied forwards and backwards. Next the data were full wave rectified. An RMS function was used to linear envelop the EMG data, with a 100-point window with no overlap and no zero padding.

Then the data were exported to Excel and processed using Microsoft Excel 2010. The data processing was performed for all 15 participants. An automated template was created in Microsoft Excel 2010 to perform the data processing for the average and maximum voltage of the forearm muscles during the wrist and elbow hyperlink tasks and with each mouse design, namely, Standard, Penguin and Evoluent. The average and maximum voltage were calculated using all the active data after the resting tone; starting from minute one. The average voltage was measured because it represented the amount of work the muscles were doing across a time period. The average gave an idea of the underlying muscle activity (De Luca, 1997). The maximum voltage was simply the highest recorded EMG value in any given time period and often taken to be a good indicator of the size of force (De Luca, 1997).

4.7 Reliability analysis

Intraclass correlation coefficient (ICC) and Standard Error of measurement (SEM) were used to assess reliability. Statistical analysis was performed using IBM SPSS statistics version 22.

A two-way model ICC was used and formula (2,1) was used specifically. Formula (2,1) was described as each subject was evaluated on two separate days, and the reliability calculated from a single measurement (Vincent and Weir, 2012). Also, on each day, the experiment was assumed to be performed under identical conditions.

To calculate the SEM, 1-way repeated measure ANOVA was calculated first to establish the mean square error (MSE). MSE is the amount of variance that can occur by chance (Vincent and Weir, 2012). 1-way repeated measure ANOVA was used to compare three or more group means, where the participants were the same in each group (Field, 2016). In this pilot study, the same group of subjects were measured on two consecutive days and were subjected to 3 trials/mouse design on each day; the response to each of these conditions was compared. SEM was calculated using this formula: $\sqrt{MSE}$ in preference to the more commonly used SEM formula: $SD\sqrt{1 - ICC}$, the latter formula being sensitive to the type of ICC model used, of which there are six, each sensitive to the between-subjects variability. Therefore, SEM determined using this formula could vary markedly, depending on the ICC variant used (Vincent and Weir, 2012). In contrast, the mean square error is constant for a given set of data and therefore, the SEM value does not depend on the ICC model used.

In this pilot study, a lower magnitude of SEM in the range of motion data or muscle activity data meant lower variations were found. This represented higher reliability. In this pilot study, higher reliability meant that the measurements taken were found to be repeatable. Conversely, a higher magnitude of SEM in the range of motion data or muscle activity data meant higher variations were found. This represented lower reliability, meaning that the measurements taken were found to be less repeatable. SEM acted as an indication of reliability in this pilot study.

In this pilot study, the degree of reliability was interpreted according to the magnitude of SEM only. This was because of a lack of confidence in using the ICC data obtained; with some data sets in both ROM and muscle activity data the ICC results were negative in value. They were then adjusted to zero since the ICC as type of correlation should take values between 0 and 1.

The score obtained from SEM would be the best estimate of the true score, in that any range of motion measurements/muscle activity measurements obtained would be around the SEM (Vincent and Weir, 2012). SEM thus defined is as an absolute index of reliability indicating the precision of a test and largely independent of the between-subjects variability (Vincent and Weir, 2012).

4.8 Computer mice comparison analysis

Although the primary function of this study was to assess the reliability of the measurements, the data were also analysed to give a preliminary idea of the patterns of joint movement and muscles activity when comparing the use of the different mice.

Computer mice comparisons were performed to know whether there was a difference in wrist flexion/extension and wrist radial/ulnar deviation in the wrist hyperlink task while using three mice, and also to know whether there was a difference in elbow flexion/extension while using three different mice during the elbow hyperlink task as well as knowing whether there was a difference in the average/maximum voltage of the Biceps, Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors with each mouse design and during the elbow and wrist hyperlink tasks.

The statistical analysis was performed using IBM SPSS statistics version 22. The significance level was set at $p < 0.05$. The analysis was performed and interpreted according to Field’s (2016) suggestions.

1-way repeated measure ANOVA was used because the same group of subjects was subjected to 3 trials with each mouse design in their first laboratory visit. To interpret the results from 1-way repeated measure ANOVA output, the researcher looked first at the level of significance in Mauchly’s test of Sphericity. Sphericity meant that the variation within experimental conditions was approximately the same. Sphericity can be assessed by Mauchly’s test to test the hypothesis that the variances of the differences between experimental conditions were equal. This meant that Mauchly’s test statistic was not significant ($p > 0.05$) and the assumption of sphericity had not been violated. The researcher then looked at the test of Within-Subjects Effects table that represented the ANOVA results to look at the row labelled sphericity assumed. If the assumption was not violated ($p < 0.05$), then the means of the measurements taken were significantly different.

If Mauchly's test statistic was significant ($p < 0.05$), this meant that the assumption of sphericity had been violated. The researcher then looked at the test of Within-Subjects Effects table to correct the *p*-value for F-ratio. Greenhouse-Geisser correction was looked at or Huynh-Feldt correction to correct the sphericity by correcting the *p*-value for F-ratio. Greenhouse-Geisser correction would be chosen if the average between the two *p*-values (Greenhouse-Geisser and Huynh-Feldt) was < 0.75. However, if the average between two *p*-values was > 0.75, Huynh-Feldt correction would be chosen. After having selected the appropriate *p*-value, if the value was < 0.05, then the means of the measurements taken were significantly different.

A basic post hoc test procedure was performed to compare the main effects between mouse designs using a Bonferroni test. The Bonferroni test was chosen to control type I error rate, rejecting the null hypothesis when true.

4.9 Results

The results were divided into between-days reliability and within-days reliability (Day 1) for range of motion data; each will be discussed. The results of muscle activity data were divided into within-days reliability only (Day 1).

4.9.1 Range of motion data

4.9.1.1 <u>Between-days reliability</u>

What is the reliability of wrist flexion/extension and wrist radial/ulnar deviation during wrist hyperlink task using Standard, Penguin and Evoluent mice?

According to Table 4.2, the SEM results showed that the measurements taken with the Penguin mouse had greater variations in wrist flexion/extension of $\pm 7.18°$ SEM, whereas with the Evoluent mouse demonstrated the least variations of $\pm 1.63° SEM$ when compared with the Standard and Penguin mice.

For wrist radial/ulnar deviation, Table 4.2 showed that the measurements with Penguin mouse had greater variations of $\pm 4.62°$ SEM. In contrast, the Evoluent mouse demonstrated less variation during wrist radial/ulnar deviations with $\pm 2.11°\ SEM$.

Table 4.2 *ICC and SEM for wrist flexion/extension and radial/ulnar deviation during wrist hyperlink task using Standard, Penguin and Evoluent mice.*

Mouse Design	**Wrist flexion/extension**		**Wrist radial/ulnar deviation**	
	ICC	**SEM**	**ICC**	**SEM**
Standard	0.668	2.22°	0.553	3.31°
Penguin	0.245	7.18°	0.421	4.62°
Evoluent	0.553	1.63°	0.00	2.11°

What is the reliability of elbow flexion/extension during elbow hyperlink task?

Table 4.3 showed that the measurements taken with the Standard and Penguin mice had greater variations in elbow flexion/extension with $\pm 1.41° \, SEM$, whereas the Evoluent mouse had the least variations with $\pm 0.881° \, SEM$.

Table 4.3 *ICC and SEM for elbow flexion/extension during elbow hyperlink task using Standard, Penguin and Evoluent mice*

Mouse Design	**E.FE**	
	ICC	**SEM**
Standard	0.746	1.41°
Penguin	0.759	1.42°
Evoluent	0.640	0.881°

4.9.1.2 Within-Days reliability

What is the reliability of wrist flexion/extension and wrist radial/ulnar deviation during wrist hyperlink task using Standard, Penguin and Evoluent mice?

According to Table 4.4, the SEM results showed that measurements taken with the Standard mouse had the highest variations during wrist flexion/extension with $\pm 3.79° \, SEM$. In contrast, the Evoluent mouse had the least variations in wrist flexion/extension of about $\pm 1.27° \, SEM$.

Table 4.4 *ICC and SEM for wrist flexion/extension and wrist radial/ulnar deviation during wrist hyperlink task and while using Standard, Penguin and Evoluent mice.*

Mouse Design	**W.FE**		**W.RD/UD**	
	ICC	**SEM**	**ICC**	**SEM**
Standard	0.615	3.79°	0.832	2.65°
Penguin	0.897	2.96°	0.840	3.22°
Evoluent	0.849	1.27°	0.844	0.724°

For wrist radial/ulnar deviation, it was found from Table 4.4 that the measurements taken with the Evoluent mouse had the least variations with $\pm 0.724° \; SEM$. In contrast, the Penguin mouse demonstrated more variation during wrist radial/ulnar deviations with $\pm 3.22° \; SEM$.

What is the reliability of elbow flexion/extension during elbow hyperlink task?

Table 4.5 showed that the measurements taken with the Standard and Penguin mice had the least variations in elbow flexion/extension with about $\pm 1.21°$ SEM, whereas the Evoluent mouse had the highest variations with $\pm 1.35° \; SEM$ when compared with the Penguin and Standard mice.

Table 4.5 *ICC and SEM results for elbow flexion/extension during elbow hyperlink task using Standard, Penguin and Evoluent mice.*

Mouse Design	**E.F/E**	
	ICC	**SEM**
Standard	0.858	1.21°
Penguin	0.836	1.21°
Evoluent	0.698	1.35°

In comparing the results of SEM in between-days reliability presented in Tables 4.2 and 4.3 with an SEM in within-days reliability presented in Tables 4.4 and 4.5, it was found that the SEM results with within-days reliability had fewer variations than between-days reliability. This demonstrated that the data with within-days reliability were more repeatable and these data would be used for the next stage analysis for the computer mice comparisons.

4.9.1.3 Computer mice comparison results

4.9.1.3.1 Wrist flexion/extension during wrist hyperlink task:

Mauchly's test indicated that the assumption of sphericity had been violated within three mouse designs in wrist flexion/extension, $\chi^2(2) = 7.44$, *p* = 0.024. Therefore, the Greenhouse-Geisser corrected tests were reported (*p* = 0.001). This meant that there was a significant difference in the measurements taken of wrist flexion/extension with all the participants while using three different mouse designs (*F* = 13.4, *p* = 0.001). It was found that there was a significant difference in the measurements taken for wrist flexion/extension between the Standard and Penguin mice (*p* = 0.016), and between the Evoluent and Penguin mice (*p* = 0.003).

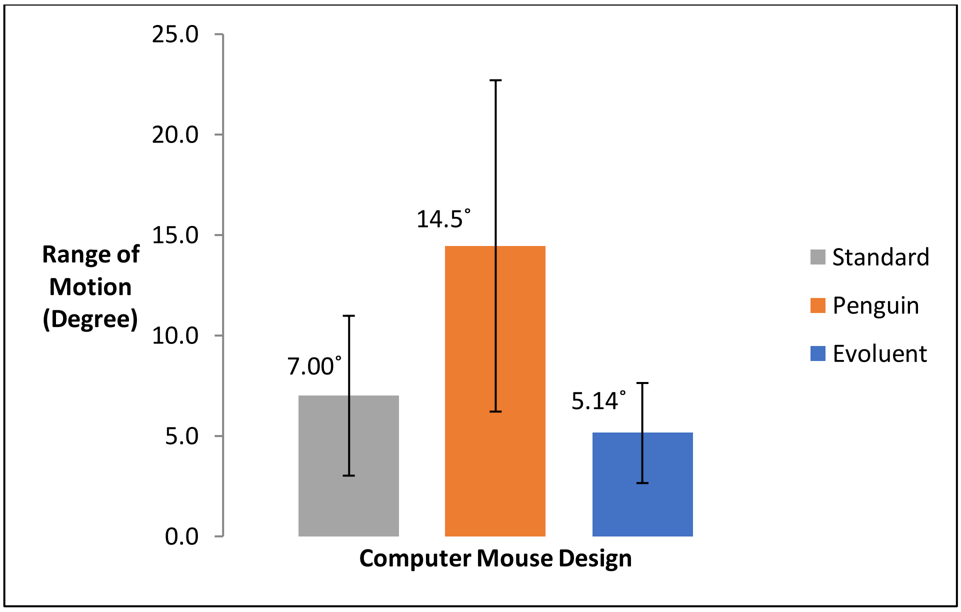


Figure 4.3 *Population mean of wrist Flexion-extension with each mouse design during wrist hyperlink task and with the 15 participants in Day 1.*

4.9.1.3.2 Wrist radial/ulnar deviation during wrist hyperlink task

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in wrist radial/ulnar deviation, $\chi^2(2) = 0.742$, *p* = 0.690. Therefore, the sphericity assumed test was reported (*p* < 0.001). This meant that there was a significant difference in wrist radial/ulnar deviation with all the participants while using three different computer mouse designs (*F* = 42.3, *p* < 0.001). It was found that there was a significant difference in the measurements taken for wrist radial/ulnar deviation between the Standard and Evoluent mice (*p* <

0.001), Standard and Penguin mice (*p* = 0.003) and between the Penguin and Evoluent mice *(p* = 0.002).

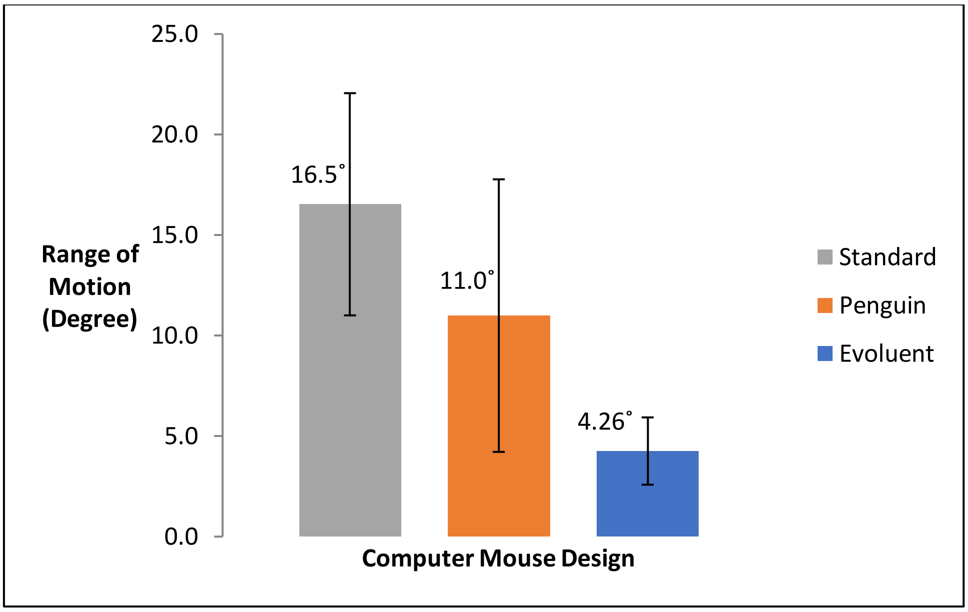


Figure 4.4 *Population mean of wrist radial-ulnar deviation with each mouse design during wrist hyperlink task and with the 15 participants in Day 1.*

4.9.1.3.3 Elbow flexion/extension during elbow hyperlink task

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in elbow flexion/extension, $\chi^2(2) = 1.97$, *p* = 0.374. Therefore, the Sphericity Assumed test was reported (*p* < 0.001). This meant that there was a significant difference in elbow flexion/extension with all the participants while using three different computer mouse designs (*F* = 35.1, *p* < 0.001).

A significant difference in elbow flexion/extension was found between the Standard and Evoluent mice (*p* < 0.001), and between the Penguin and Evoluent mice (*p* < 0.001).

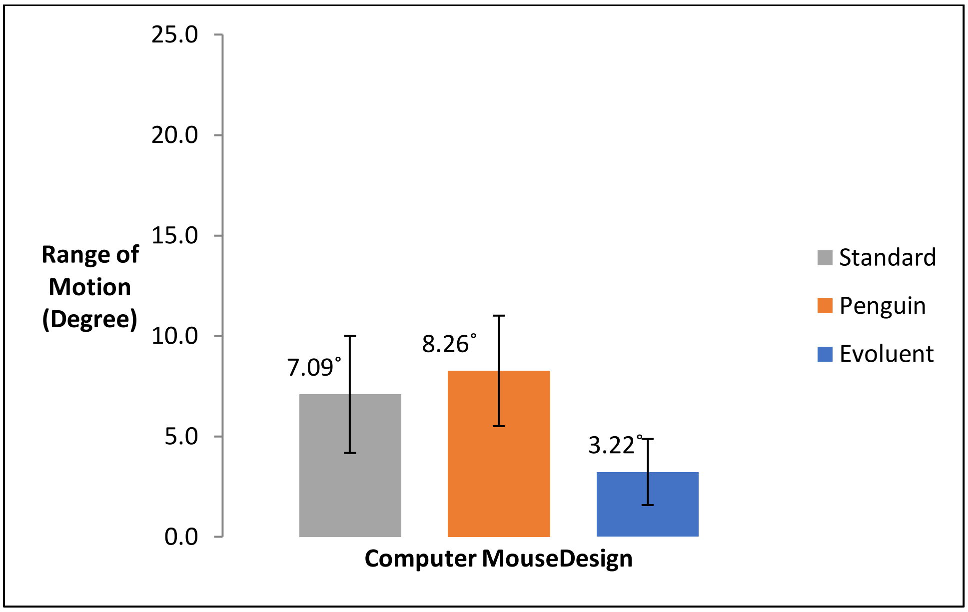


Figure 4.5 *Population mean of elbow flexion-extension with each mouse design during elbow hyperlink task and with the 15 participants in Day 1.*

4.9.2 Muscle activity data

4.9.2.1 Within-Days reliability

What is the reliability of the average and maximum voltage of Biceps, Triceps. Brachioradialis, Wrist Flexors and Wrist Extensors during elbow and wrist hyperlink task using Standard, Penguin and Evoluent mice?

According to Tables 4.6, 4.7, 4.8 and 4.9, the SEM results showed that the measurements taken with the Standard, Penguin and Evoluent mice had no variations in the average and maximum voltage of Biceps, Triceps, Brachioradialis, wrist Flexor and wrist Extensor muscles of $\pm 0.00\ \mu V$ SEM.

Table 4.6 *ICC and SEM results for the average voltage of muscle activity during elbow hyperlink task using Standard, Penguin and Evoluent mice.*

	Standard mouse		**Penguin mouse**		**Evoluent mouse**	
Muscle	**ICC**	**SEM**	**ICC**	**SEM**	**ICC**	**SEM**
Biceps	0.754	0.00 μV	0.792	0.00 μV	0.859	0.00 μV
Triceps	0.446	0.00 μV	0.556	0.00 μV	0.869	0.00 μV
Brachioradialis	0.885	0.00 μV	0.00	0.00 μV	0.960	0.00 μV
W.Flexor	0.875	0.00 μV	0.804	0.00 μV	0.750	0.00 μV
W.Extensor	0.879	0.00 μV	0.851	0.00 μV	0.789	0.00 μV

Table 4.7 *ICC and SEM results for the maximum voltage of muscle activity during elbow hyperlink task using Standard, Penguin and Evoluent mice.*

	Standard mouse		**Penguin mouse**		**Evoluent mouse**	
Muscle	**ICC**	**SEM**	**ICC**	**SEM**	**ICC**	**SEM**
Biceps	0.792	0.00 μV	0.515	0.00 μV	0.702	0.00 μV
Triceps	0.727	0.00 μV	0.816	0.00 μV	0.902	0.00 μV
Brachioradialis	0.727	0.00 μV	0.291	0.00 μV	0.635	0.00 μV
W.Flexor	0.613	0.01 μV	0.777	0.00 μV	0.541	0.00 μV
W.Extensor	0.727	0.00 μV	0.297	0.00 μV	0.866	0.00 μV

Table 4.8 *ICC and SEM results for the average voltage of muscle activity during wrist hyperlink task using Standard, Penguin and Evoluent mice.*

	Standard mouse		**Penguin mouse**		**Evoluent mouse**	
Muscle	**ICC**	**SEM**	**ICC**	**SEM**	**ICC**	**SEM**
Biceps	0.720	0.00 μV	0.424	0.00 μV	0.735	0.00 μV
Triceps	0.917	0.00 μV	0.877	0.00 μV	0.856	0.00 μV
Brachioradialis	0.858	0.00 μV	0.755	0.00 μV	0.898	0.00 μV
W.Flexor	0.931	0.00 μV	0.752	0.00 μV	0.923	0.00 μV
W.Extensor	0.877	0.00 μV	0.736	0.00 μV	0.621	0.00 μV

Table 4.9 *ICC and SEM results for the maximum voltage of muscle activity during wrist hyperlink task using Standard, Penguin and Evoluent mice.*

	Standard mouse		**Penguin mouse**		**Evoluent mouse**	
Muscle	**ICC**	**SEM**	**ICC**	**SEM**	**ICC**	**SEM**
Biceps	0.886	0.00 μV	0.287	0.00 μV	0.201	0.00 μV
Triceps	0.886	0.00 μV	0.901	0.00 μV	0.793	0.00 μV
Brachioradialis	0.471	0.00 μV	0.503	0.00 μV	0.385	0.00 μV
W.Flexor	0.845	0.00 μV	0.813	0.00 μV	0.848	0.00 μV
W.Extensor	0.656	0.00 μV	0.492	0.00 μV	0.879	0.00 μV

4.9.2.2 Computer mice comparison

4.9.2.2.1 Elbow hyperlink task

During the elbow hyperlink task, it was found that there was no significant difference in the average voltage of Biceps, Triceps, Brachioradialis and Wrist Extensors. Also, there was no significant difference in the maximum voltage of Biceps, Triceps and Brachioradialis. The significant results only will be discussed in this chapter and presented in the next section.

4.9.2.2.1.1 Average voltage of Wrist Flexors

Mauchly's test indicated that the assumption of sphericity had been violated within the three mice designs in the average voltage of Wrist Flexors, $\chi^2(2) = 12.9$, $p <$ 0.001. Therefore, the Greenhouse-Geisser corrected tests were reported (p = 0.012). This meant that there was a significant difference in the average voltage of Wrist Flexors with all the participants while using three different computer mouse designs (F = 7.15, p = 0.012). A significant difference in the average voltage of Wrist Flexors was found between the Penguin and Evoluent mice (p = 0.012).

The average voltage of the Wrist Flexors was increased with the Penguin mouse (mean = 0.0129 μV). However, it was decreased with the Evoluent mouse (mean = 0.00713 μV).

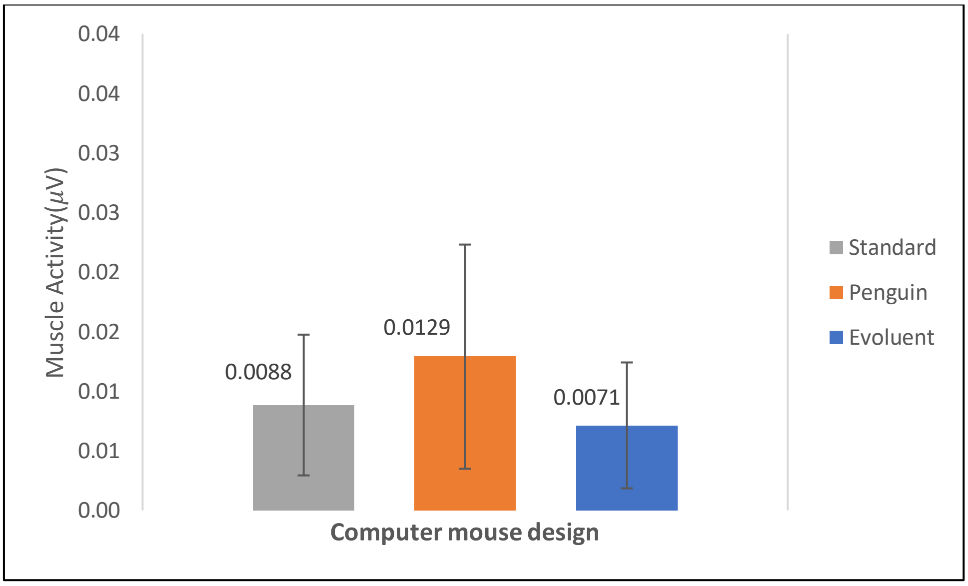


Figure 4.6 *Population mean of mean voltage Wrist Flexors with each mouse design during elbow hyperlink task and with the 15 participants in Day 1.*

4.9.2.2.1.2 Maximum voltage of Wrist Flexors

Mauchly's test indicated that the assumption of sphericity had been violated within the three mouse designs in the maximum voltage of Wrist Flexors, $\chi^2(2) = 6.99$, p = 0.030. Therefore, the Greenhouse-Geisser corrected tests were reported (p = 0.05). This meant that there was a significant difference in the maximum voltage of Wrist Flexors with all the participants while using three different computer mouse designs (*F* = 3.83, *p* = 0.05). A significant difference in the maximum voltage of Wrist Flexors was found between the Standard and Evoluent mice (*p* = 0.024).

The maximum voltage of the Wrist Flexors was increased with the Penguin mouse (mean = 0.0387 μV). In contrast, it was decreased with the Evoluent mouse (mean = 0.0233 μV).

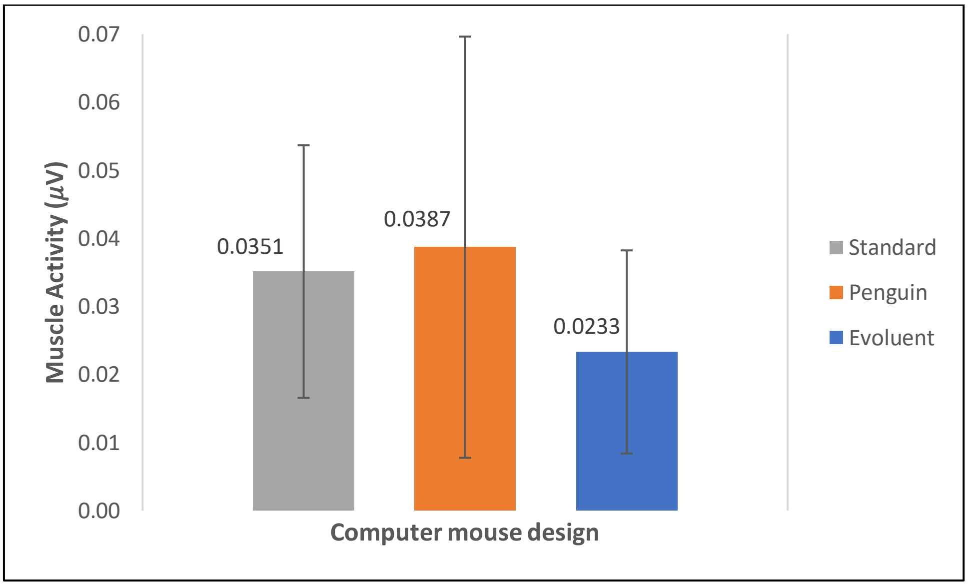


Figure 4.7 *Population mean of maximum voltage of Wrist Flexors and with each mouse design during elbow hyperlink task and with the 15 participants in Day 1.*

4.9.2.2.1.3 Maximum voltage of Wrist Extensor

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the maximum voltage of Wrist Extensors, $\chi^2(2) = 0.861$, *p* = 0.300. Therefore, the Sphericity Assumed test was reported (*p* < 0.001). This meant that there was a significant difference in the maximum voltage of Wrist Extensors with all the participants while using three different computer mouse designs (*F* = 17.1, *p* < 0.001). A significant difference in the maximum voltage of Wrist Extensors was found between the Standard and Evoluent mice (*p* < 0.001) and between the Penguin and Evoluent mice (*p* = 0.001).

The maximum voltage of the Wrist Extensors was increased with the Standard mouse (mean = 0.0241 μV). However, it was decreased with the Evoluent mouse (mean = 0.00502 μV).

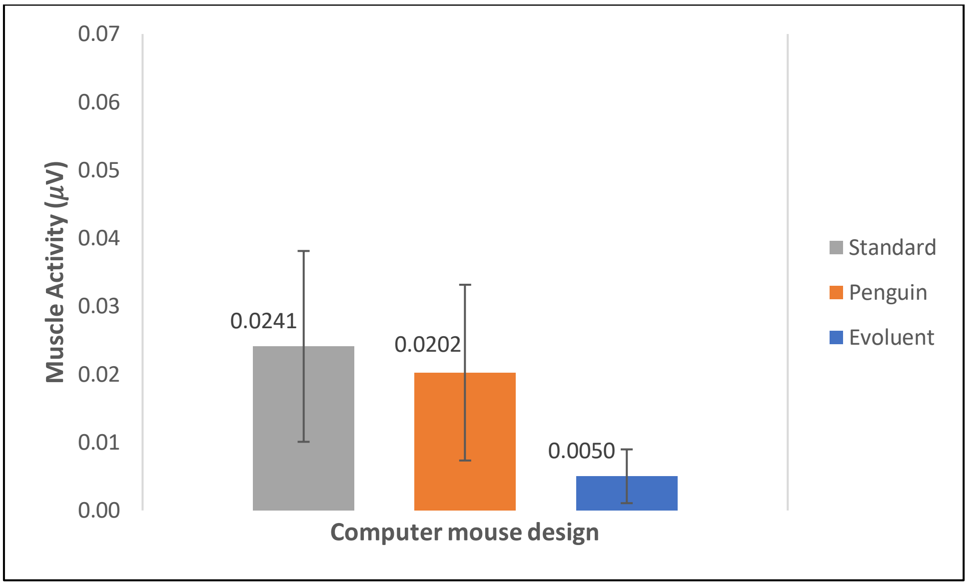


Figure 4.8 *Population mean of maximum voltage of Wrist Extensors with each mouse design during elbow hyperlink task and with the 15 participants in Day 1.*

4.9.2.2.2 Wrist hyperlink task

During the wrist hyperlink task, it was found that there was no significant difference in the average voltage of Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors. Also, there was no significant difference in the maximum voltage of Triceps, Brachioradialis and Wrist Extensors. The significant results only will be discussed in this chapter and presented in the next section.

4.9.2.2.2.1 Average voltage of Biceps

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the average voltage of Biceps, $\chi^2(2) = 2.33$, *p* = 0.313. Therefore, the Sphericity Assumed test was reported (*p* = 0.003). This meant that there was a significant difference in the average voltage of Biceps with all the participants while using three different computer mouse designs (*F* = 7.26, *p* = 0.003). A significant difference in the average voltage of Biceps was found between the Standard and Penguin mice (*p* = 0.013).

The average voltage of Biceps was increased with the Penguin mouse (mean = 0.00502 μV), whereas it was decreased with the Standard mouse (mean = 0.00304 μV).

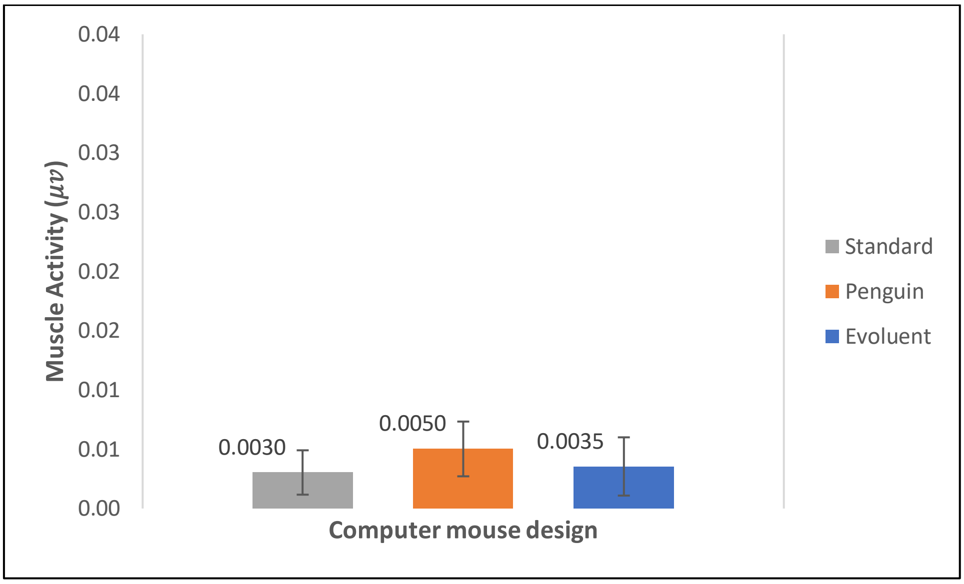


Figure 4.9 *Population mean of mean voltage of Biceps with each mouse design during wrist hyperlink task and with the 15 participants in Day 1.*

4.9.2.2.2.2 Maximum voltage of Biceps:

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the maximum voltage of Biceps, $\chi^2(2) = 0.045$, *p* = 0.978. Therefore, the Sphericity Assumed test was reported (*p* = 0.003). This meant that there was a significant difference in the maximum voltage of Biceps with all the participants while using three different computer mouse designs (*F* = 7.21, *p* = 0.003). A significant difference in the maximum voltage of Biceps was found between the Standard and Penguin mice (*p* = 0.023) and between the Penguin and Evoluent mice (*p* = 0.012).

The maximum voltage of Biceps was increased with the Penguin mouse (mean = 0.0145 μV). However, it was decreased with the Evoluent mouse (mean = 0.00915 μV).

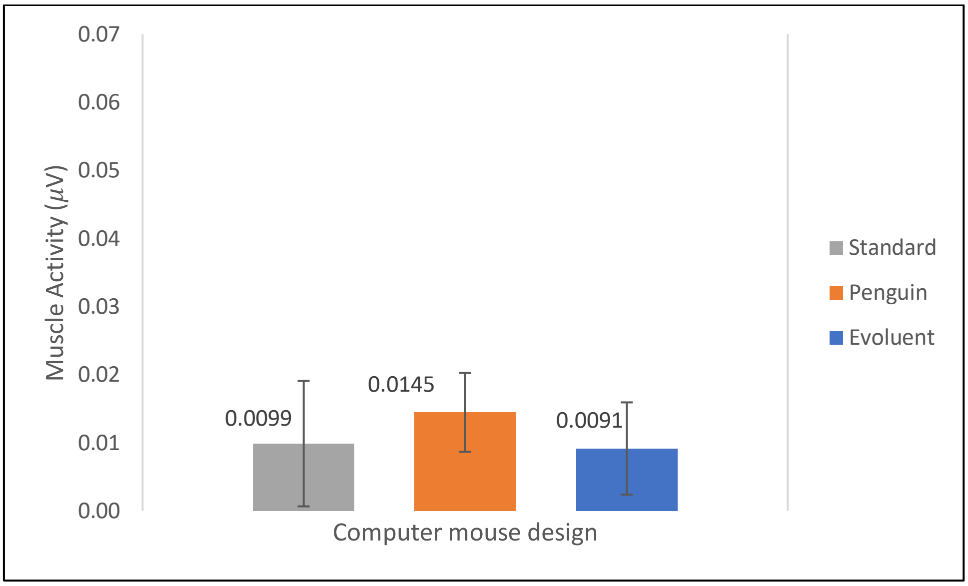


Figure 4.10 *Population mean of maximum voltage of Biceps with each mouse design during wrist hyperlink task and with the 15 participants in Day 1.*

4.9.2.2.2.3 Maximum voltage of Wrist Flexors

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the maximum voltage of Wrist Flexors, $\chi^2(2) = 5.23$, *p* = 0.073. Therefore, the Sphericity Assumed test was reported (*p* = 0.017). This meant that there was a significant difference in the average voltage of Wrist Flexors with all the participants while using three different computer mouse designs (*F* = 4.75, *p* = 0.017). A significant difference in the maximum voltage of Wrist Flexors was found between the Standard and Evoluent mice (*p* = 0.040) and between the Penguin and Evoluent mice (*p* = 0.020).

The maximum voltage of the Wrist Flexors was increased with the Penguin mouse (mean = 0.0365 μV). In contrast, it was decreased with the Evoluent mouse (mean = 0.0256 μV).

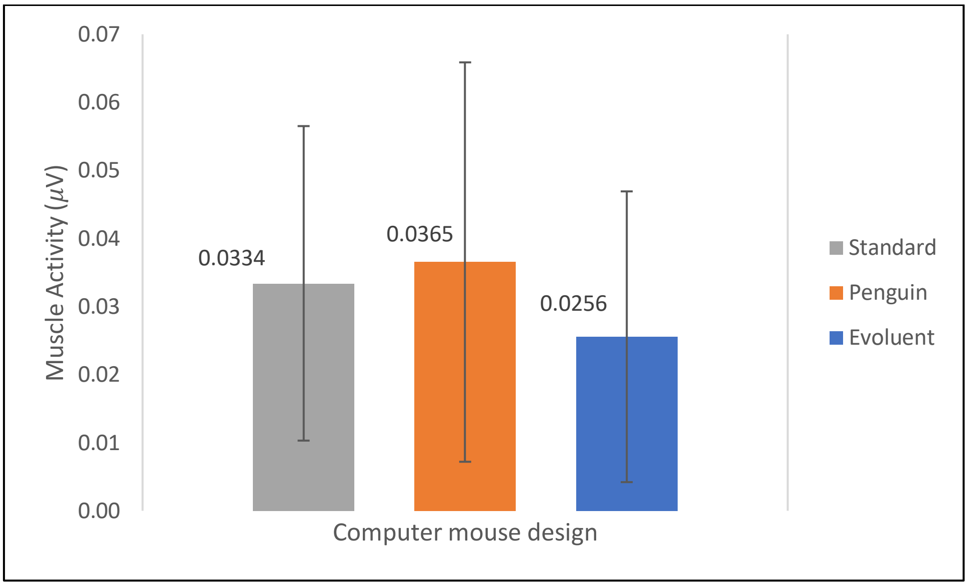


Figure 4.11 *Population mean of maximum voltage of Wrist Flexors with each mouse design during wrist hyperlink task and with the 15 participants in Day 1.*

4.10 Summary of the results

4.10.1 Reliability analysis

4.10.1.1 In between-days reliability

The Evoluent mouse produced more repeatable measurements in wrist flexion/extension, wrist radial/ulnar deviation and elbow flexion/extension when compared with the other mice used.

4.10.1.2 In within-days reliability

The Evoluent mouse produced more repeatable measurements in wrist flexion/extension and wrist radial/ulnar deviation. However, the Penguin and Standard mice produced more repeatable measurements in elbow flexion/extension.

The measurements taken with the Standard, Penguin and Evoluent mice produced repeatable measurements in the average and maximum voltage of Biceps, Triceps, Brachioradialis, wrist Flexors and wrist Extensors muscles in the wrist and elbow hyperlink tasks.

4.10.2 Computer mice analysis

There was a significant difference between the three mice designs on the range of motion of wrist flexion/extension, wrist radial/ulnar deviation in the wrist hyperlink task, and on elbow flexion/extension in the elbow hyperlink task ($p < 0.05$).

In the elbow hyperlink task, there was a significant difference between the three mice designs on the average voltage of the Wrist Flexors. Also, there was a significant difference on the maximum voltage of the Wrist Flexors and Extensors between the three mice designs.

In the wrist hyperlink task, there was a significant difference on the average voltage of Biceps between the three mice designs. Furthermore, there was a significant difference in the maximum voltage of the Biceps and the Wrist Flexors between the three mice designs.

4.11 Discussion

4.11.1 Reliability of the range of motion data

In this section, the discussion concerns the range of motion and SEM results presented in Tables 4.2, 4.3 ,4.4 and 4.5. Lower SEM implied that less variability was found between repeated measurements which, in turn, implied greater reliability for the corresponding range of motion data. Any measurements obtained were likely to be within $\pm SEM$ of the average representative value.

First, the data presented in Tables 4.2 and 4.3 on the between-days comparison data are discussed. The tests were performed over two laboratory visits and the average of three trials in Day 1 laboratory visit were combined and compared with the average of three trials in Day 2 laboratory visits for the 15 participants. The aim here was to look at the repeatability of the measurements, as assessed using the magnitude of SEM, for wrist flexion/extension, wrist radial/ulnar deviation, and elbow flexion/extension when using the three different computer mice.

Second, the results discussed are presented in Tables 4.4 and 4.5, obtained from the three trials with each mouse design and with each movement in Day 1 laboratory visit for the 15 participants. The aim of this was to look at whether there was a difference in the reliability of within-days reliability data and between-days reliability data, by looking at whether the amount of variability, magnitude of SEM, was the same or different. If the variability was the same, the researcher would be confident in using the between-days data; however, if not the same, the researcher would choose the data with fewer variations because less variation in data would be the more reliable data.

According to the magnitude of SEM, less variation would imply a more consistent range of motion, meaning that the participants were repeating the same movement every time, whether the task was performed with a large or small range of motion. There is evidence which suggests that moving the hand in precise stereotypical movements every day could lead to WRMSD. Usually, stereotypical movements are indicated by lower SEM. According to the SEM results, it could be seen that mainly, the Evoluent mouse had the least variation in the range of movement of W.F/E and W.RD/UD. The least variations were also found with the Penguin and Standard mice, but only in the measurements taken for elbow flexion/extension.

It has been found that individuals performing repetitive stereotypical movements were at high risk of developing WRMSD (Cappell, 2006). This was due to mechanical stress at specific joints or tendons (Cappell, 2006), which could lead to CTS, Tennis elbow and DeQuervain’s syndrome. Repetitive stereotypical movements could lead to the tendons and muscles being overstretched (Waugh, 2005). This could also lead to muscle and tendon damage, fatigue within tendons, ligaments, neural tissue, and other soft tissues and then an increased risk of WRMSD, for example, RSI, CTS, Tennis elbow and DeQuervain’s syndrome (O’Neil et al., 2001; Reilly,1995; Zetterberg and Ofverholm, 1999).

Moreover, Cook et al. (2000) and Ortiz-Hernández et al. (2003) pointed out that mouse users adopting a particular working posture of wrist pronation, extension and ulnar deviation whilst performing a computer task had a greater risk of developing musculoskeletal disorders such as CTS and repetitive strain injury (RSI). This was thought to be due to increased force applied on the forearm as well as repetition of the same movements (Cook et al., 2000; Ortiz- Hernández et al, 2003). At present, the data were analysed to range of motion data only and not posture. In light of this evidence, posture analysis of the joint was also undertaken in the next phase of this research study.

Furthermore, the greater variability in range of motion found with the Penguin mouse for W.RD/UD, Standard mouse for W.F/E and Evoluent mouse for E.F/E could minimise the stereotypical movements whilst performing a computer task. At this point, the picture was not yet clear or straight forward to be able to draw a conclusion about which mouse design could prevent from pathology. This would be tested in the next phase of this research study.

According to the SEM results for within-days data in Tables 4.4 and 4.5, less variation was found in the within-days data when compared with the between-days data in Tables 4.2 and 4.3. However, the magnitude of SEM in within-days reliability data was slightly higher than the between-days reliability in the measurement taken for wrist flexion/extension during the wrist hyperlink task ($\pm 1.6°$) with the Standard mouse, and with the Evoluent mouse for the measurements taken for elbow flexion/extension during the elbow hyperlink task ($\pm 0.5°$). The higher SEM magnitude found was not great enough to create an issue with future analysis; the small difference found was considered acceptable in the average range found with wrist flexion/extension using the Standard mouse (7.00°) and in the average range found with the Evoluent mouse for elbow flexion/extension (3.22°). Therefore, the researcher was not concerned about the level of variation found. The conclusion was that the data from within-days reliability were more repeatable due to less variation being found in general, according to the magnitude of SEM. Given the above, the researcher felt confident in using these data for the preliminary analysis of the computer mouse comparisons.

4.11.2 Reliability of the average/maximum voltage data

The discussion concerns the average and maximum EMG voltage. The SEM results are presented in Tables 4.6, 4.7, 4.8 and 4.9. The results were obtained from the three trials with each mouse design and with each muscle in Day 1 laboratory visit. The aim of this was to look at whether there was a difference in the reliability of the measurements taken, average and maximum voltage, as assessed using the magnitude of SEM for Biceps, Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors, using the three different mice design during the elbow and wrist hyperlink tasks.

The researcher felt confident in using the data from Day 1 only for within-days reliability, and without doing between-days reliability when comparing the results from Day 1 to Day 2 laboratory visits. Because the researcher found that within-days reliability for Day 1 was repeatable for ROM data, she felt confident to use this data only and without the need to look at Day 2 data for within-days reliability or between-days reliability.

The measurements taken for the average and maximum voltage of the Biceps, Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors during the elbow and wrist hyperlink tasks using the Standard, Penguin and Evoluent mice were found to be repeatable ($\pm 0.00\mu V\ SEM$).

According to the magnitude of SEM, less variation implied a more consistent EMG measurement. In this case, SEM equalled zero. This meant that the measurements taken for the average and maximum voltage for the five muscles during the elbow and wrist hyperlink tasks were perfectly reliable with the 3 mice designs because no variations were found. This showed that the EMG variables tested in this study (maximum and average voltage) were reliable and could be used for a clinical decision. If EMG variables which are not reliable were used, the measurements taken could be erroneous, possibly leading to inaccurate clinical decisions (Smoliga et al., 2010). By choosing a reliable EMG variable for a given muscle, accurate decisions when utilising EMG for diagnostics decisions could be made by clinicians (Smoliga et al., 2010).

However, clinically, this could lead to an increased risk of WRMSD because of no variations being found ($\pm 0.00\ \mu VSEM$) with each muscle and with each mouse design. This meant that the participants were using the same amount of muscle activity, and the muscles exerted the same amount of force every time they performed the task. Therefore, this would mean the possibility that using the same amount of muscle activity and exerting the same amount of force everyday could lead to muscle fatigue and then increase the risk of WRMSD in the long run.

Muscle fatigue could be indicated by lower SEM. Moreover, muscle fatigue could increase the risk of WRMSD. This would be due to weakness in the muscle which is a lack of muscle strength and the feeling that extra effort is required to perform the task. Then this would increase the force applied on the muscle, leading to pain, discomfort, numbness and hand tremors (Tittranonda et al., 2000; Szeto and Lin, 2011). There would be a decline in the ability of the muscles to generate force if there was muscle fatigue (Nur et al., 2015). Nur et al. (2015) and Phinyomark et al. (2012) found that muscle fatigue usually occurred due to prolonged repetitive tasks. Also, Nur et al. (2015) mentioned that muscle fatigue occurred due to static low loads tasks. In this reliability study, the participants performed a standardised repetitive regulated movement and because it was a computer mouse task, it was a low load task because the mice used were not heavy. This could be the reason why there were no variations found with each muscle and within the 15 participants because the task was standardised so that each participant was performing the same. In this pilot study, fatigue was not likely to be a major factor because the experimental task was a low-load task and the mice used were light in weight.

4.11.3 Computer mice comparison for the ROM data

After doing the reliability analysis, the researcher wanted to compare the three mice designs on the range of motion of the elbow and wrist joint. The researcher needed to know whether any significant differences could be found in the measurements taken of the elbow and wrist while using three different mice. Furthermore, the preliminary analysis of mice comparison was performed to provide an insight or guidance into the type of mouse design that would be used for future experimental design. It would also give an idea which data set should be taken for mice comparison Thus, within-days data were used for this analysis.

The preliminary analysis results from a 1-way repeated measure ANOVA found that there was a significant difference between the three mice designs on the range of motion of elbow flexion/extension, wrist flexion/extension and radial/ulnar deviation ($p < 0.05$), meaning that mouse design affected the range of motion of the wrist and elbow. The findings from the preliminary analysis in this study were consistent with the findings from the Flodgren et al. (2007), Gustafsson and Hagberg (2003), Hedge et al. (2010), Houwink et al. (2009) and Keir et al. (1999) studies. These studies found a significant difference with the mouse design on wrist and elbow range of motion ($p < 0.05$).

It was found that the least range of motion in wrist flexion/extension (mean = 5.14°), wrist radial/ ulnar deviation (mean = 4.26°), and in elbow flexion/extension (mean = 3.22°) was with the Evoluent mouse in comparison with the Standard and Penguin mice. However, it was found that the highest range in wrist flexion/extension (mean = 14.5°) and in elbow flexion/extension (mean = 8.26°) was with the Penguin mouse. Also, it was found that the highest range of motion in wrist radial/ulnar deviation was with the Standard mouse (mean = 16.5°).

After reviewing the literature, it was found that the mouse design that increased the range of motion could increase the musculoskeletal symptoms such as pain and muscle fatigue and then lead to an increased risk of WRMSD because posture would be deviated away from the midline position (Cook et al., 2000).

Flodgren et al. (2007) found that a Standard mouse increased the range of motion of wrist flexion/extension, wrist radial/ulnar deviation and elbow supination/pronation when performing a computer painting task. Because of this, the Standard mouse could lead to an increased risk of WRMSD for people using it. This could cause musculoskeletal symptoms such as pain and muscle fatigue (Flodgren et al., 2007).

In contrast, the mouse with less range of motion would allow the forearm to be more in a standard or neutral position (Hedge et al., 2010). This then could minimise the risk of WRMSD. Less ulnar deviation was found with the Evoluent mouse during a cursor positioning task when compared with three vertical mice and a Standard mouse (Hedge et al., 2010). This was because the ulnar surface of the hand was close to the work surface when using this mouse, giving little opportunity for ulnar deviation, which could keep the hand in a more neutral position (Hedge et al., 2010). Therefore, it could minimise the risk of WRMSD (Hedge et al., 2010). This could demonstrate that a mouse design that increased the ROM of the wrist or elbow joint could position the joint away from the neutral position, as stated in the Cooke et al. (2000) study. This then could increase the risk of WRMSD. On the other hand, a mouse design that would decrease the ROM of the wrist or elbow joint could position or keep the forearm close to the neutral position, as stated in Hedge et al. (2010). This then could promote musculoskeletal heath and decrease/prevent the risk of injury.

Gustafsson and Hagberg (2003) and Houwink et al. (2009) found that less wrist extension and ulnar deviation was found with a vertical mouse when compared with the Standard mouse. Also, it was found that the level of exertion increased when using the Standard mouse ($p < 0.05$) (Gustafsson and Hagberg, 2003). Both studies found that a vertical mouse could have a better effect on the posture of the forearm when compared to the posture of the forearm using a Standard mouse. This was because the vertical mouse could promote a more neutral position of the forearm (Gustafsson and Hagberg, 2003; Houwink et al., 2009). Therefore, this could promote musculoskeletal health (Gustafsson and Hagberg, 2003; Houwink et al., 2009).

Generally, in research the mouse with fewer variations would be the mouse that could minimise the risk of WRMSD. However, as discussed in the reliability analysis in section 4.11.1, clinically this meant that fewer variations enhanced stereotypical movements and moving the hand in precise stereotypical movements could lead to WRMSD. Also, in the literature, the mouse that allowed less range of motion was the mouse that would minimise the risk of WRMSD. After reviewing the literature and the results from this chapter, the researcher thought that possibly the ideal scenario to minimise the risk of WRMSD in a clinical setting would be by using a mouse that allowed higher variability and a small range of motion around the neutral position whilst performing the task. However, this has not yet been tested to confirm that ideal scenario.

From these preliminary results, it appeared that the computer mouse with less range of motion could also be the mouse with less variation among the mice tested in this study, as seen with the Evoluent mouse in W.F/E and W.RD/UD. There was a possibility that this mouse could lead to increased risk of WRMSD. It was possible that the mouse with fewer variations in the range of motion could increase stereotypical movements in the long run because variations would relate to computer users repeating the same movements constantly, thereby maintaining the same range every time they performed the same task. Also, because the ranges would be kept the same, there was a possibility that the range in this case could be less than the mouse that caused higher variations and then lead to stereotypical movements, and then an increased risk of WRMSD.

The results from this study also suggested that the mouse which promoted a higher range of motion might also be the mouse with higher variation and could therefore minimise the risk of WRMSD. The mouse with higher variation could possibly increase the range of motion in comparison to the mouse with less variation. This was because of users not maintaining or repeating the same range every time they performed the same task. Therefore, there was a possibility that it could minimise the stereotypical movement and then reduce the risk of WRMSD. There was insufficient evidence from the experiments in this research to date to decide whether the size of movement or variation was the most important factor in causing WRMSD. There was not enough evidence at this stage to confirm this, and more data would be needed to test this concept.

4.11.4 Computer mice comparison for the EMG data

In this section, the influence of the three mice designs on the average and maximum voltage of the Biceps, Triceps, Brachioradialis, Wrist Flexors and Wrist Extensors during elbow and wrist hyperlink tasks are explored. The researcher wanted to know whether any significant differences could be found in the measurements taken with each muscle while using three different mice. Within-days data (Day 1) were used for this analysis.

The preliminary analysis results from a 1-way repeated measure ANOVA found that during the elbow hyperlink task, there was a significant difference in the average voltage of Wrist Flexors, and a significant difference in the maximum voltage of the Wrist Flexors and Extensors ($p < 0.05$). Regarding measurements taken during the wrist hyperlink task, there was a significant difference in the average voltage of Biceps, and in the maximum voltage of the Biceps and Wrist Flexors ($p < 0.05$). This meant that mouse design influenced the EMG data.

In this pilot study, it could be seen that the results were divided between significant difference and non-significant difference during the elbow and wrist hyperlink tasks and for the average and maximum voltage. The reason for the conflicting results could be due to this study having explored different mice designs, and this might have caused these changes in the muscle activity. The reasons for the conflicting results could also be as stated in Phinyomark et al. (2012). First, this was due to different muscles studied and each muscle having different muscle fibre composition and distribution. Second, the difference in participants' gender could have produced the difference in fibre diameter and types. Hence, this could be one of the main reasons for different results being found. Third, different results between two genders could be due to the differences in skinfold layers. The results of the Won et al. (2003) study were consistent with the reasons mentioned by Phinyomark et al. (2012) and showed that female computer users had higher EMG values in all muscles and in all tasks and this was statistically significant ($p < 0.05$). The Won et al. (2003) results suggested there were biomechanical and physiological differences in exposure to physical risk factors between males and females even when performing a standard computer task. It should be mentioned that this research would not look at gender differences as a variable.

According to the literature, a mouse that increased the average voltage and/or the maximum voltage was likely to cause pathology. This would be consistent with Tittiranonda et al. (2000), Szeto and Lin (2011), and Nur et al. (2015). The Tittiranonda et al. (2000) study found increased muscle activity of FDS, ECU, Extensor indicis proprius (EIP) and UT when using a Standard mouse compared to other input devices in their study. Also, they found that the Standard mouse tended to create higher loads on the upper trapezius and ECU, leading to increased shoulder elevation and wrist ulnar deviation. Moreover, Szeto and Lin (2011) found that there was an association between higher muscle activity and the level of discomfort; when muscle activity increased, the level of discomfort would increase and then lead to muscle fatigue. Persistent fatigue could, in turn, promote muscle damage.

However, a mouse that allowed less average voltage and/or less maximum voltage could minimise the risk of pathology. This would be consistent with the findings from Chen and Leung (2007) in that the muscle activity of ECU decreased as the slanted angle of the mouse increased and the results were significant ($p < 0.05$) compared to a Standard mouse. This could minimise the risk of WRMSD (Szeto and Lin, 2007).

After reviewing the literature and the EMG results from this chapter, the researcher thought it possible that the mouse design that allowed less average voltage and/or less maximum voltage would be the mouse that could minimise the risk of WRMSD. This could be seen mainly with the Evoluent mouse with the five muscles tested in the average and maximum voltage in the elbow and wrist hyperlink tasks, and with a Standard mouse in the average voltage of Biceps in the wrist hyperlink task. However, these mice were the mice with lower variability. The mouse that increased the average voltage and/or increased the maximum voltage would be the mouse that could increase the risk of WRMSD. This was seen mainly with the Penguin and Standard mice. However, they were also the mice with lower variations.

For EMG analysis, multiple variables have often been interpreted together to determine the physiological nature of the muscles (Smoliga et al., 2010). This was the reason why the researcher looked at the results of the average and maximum voltage together to generate a better understanding of the muscle activity.

The EMG findings were different from the ROM data. With ROM data, it was found that the mouse with lower variations could increase the risk of WRMSD by enhancing stereotypical movements, and the mouse with higher variations could minimise the risk of WRMSD. With EMG data, no variations were found for the five muscles with the three mice designs. After reviewing the ROM and EMG data, this confirmed that there was insufficient evidence from this study's experiment to date to decide whether the amount of variations with ROM and EMG data or the size of movement with ROM data and the magnitude of muscle activity was the most causative factor leading to WRMSD. More data would be needed to examine that and to examine which mouse design could lead to injury and which could prevent from pathology.

4.12 Limitations of the study

This study had a well-designed method because of the significant amount of time the researcher had spent in experimenting different study designs, as discussed in Chapter 3. However, because this study required access to people, it would have been better to calculate the sample size, which would help to increase the probability of rejecting the null hypothesis if the null hypothesis was false. In addition, the recruitment of participants might be a limitation because the researcher spent 4 months to reach 15 participants.

Also, it would have been better to test other variables related to movement data such as posture beside the range of motion. This would give a clear idea about the type of variables to choose for the final study. Testing different variables could help to find the variable that could relate to WRMSD.

4.13 Conclusion

The researcher should bear in mind for future experimental work that the within-days data presented more repeatable results. An extra period of time might also be given to each participant to become familiar with using the mouse or to practise using each mouse in a different setting to promote a normal working posture. For future experimental work, the researcher may need to look at other variables such as posture to capture the differences in the posture of the forearm while using different mice.

In conclusion, the work carried out in this pilot study formed an important foundation for the final study. It helped to draw the final decision about the design of the study, the type of variables which best informed the final study, and to draw a valid conclusion.

5 Chapter 5 (Final Study): Analysis of computer mouse design on the posture, biomechanics and muscle activity of the elbow and wrist joints

5.1 Introduction

Before implementing this larger scale experiment, preliminary studies were done to help to draw a methodological decision for this larger scale experiment. Also, it helped to examine the feasibility of the approach that was used in this final study, the assessment procedures and to identify any modifications which needed to be implemented before a larger scale experiment.

It was found from the preliminary studies that the Electrogoniometer is a valid and reliable tool for use with movement data. Also, the Electrogoniometer was found to be the easiest and the most convenient to use over the FASTRAK. Furthermore, it was found that within-days reliability data produced more repeatable measurements, according to SEM, when compared to between-days reliability. This alerted the researcher that the measurements taken for the final study should be done in one laboratory visit and that it would be a good idea for the participants to use the mouse for some period of time during the laboratory visit and before starting the main experimental task. This would help the participants to adopt a comfortable posture and become more familiar in using the mouse.

In addition, for the final study, the researcher needed to look at other variables such as looking at posture to capture the differences in the posture of the forearm while using different mice. The ROM variables were unable to show a clearer picture in how to be linked with WRMSD. All of this helped the researcher to draw the final methodological decision for use in this final study. The details will be discussed in this chapter.

This chapter outlines the work carried out to investigate the influence of three different computer mice designs on the posture, biomechanics of the elbow and wrist, and on the muscle activity of the forearm (biceps, triceps, brachioradialis, wrist flexors and wrist extensors).

The chapter covers the methods, results and discussion for the study of the analysis of three mice designs. The measurements were taken within one laboratory visit and with one trial with each computer mouse design used: Standard, Penguin and Evoluent.

5.1.1 Equipment used in this study

In this study, the same equipment as in the reliability study was used except for the metronome, which was not used. The details of the equipment can be found in Chapter 4 section 4.4.

In addition, the study equipment included a computer screen, adjustable chair, computer desk, a Penguin mouse (Posturite Ltd, 9820099), a Standard mouse (Hewlett Packard, 590509-002), and an Evoluent mouse (Posturite Ltd, 411508308040).

5.1.2 Aim

The overarching aim for this study was to understand how the design of a computer mouse influenced the posture and biomechanics of the elbow and wrist, and the muscle activity of the forearm.

5.1.3 Research Questions

1. How does the design of a computer mouse affect the posture and movement of the wrist and elbow during typical use?

2. How does the design of the computer mouse influence the muscle activity of the forearm during typical use?

3. How does the design of the computer mouse affect the overall body posture during typical use?

4. How does the design of a computer mouse affect the usability during typical use?

5.2 Ethics Approval

The research plan was approved on 4th April 2013 by the University of Brighton and then followed by the approval of the Faculty of Research Ethics and Governance Committee (FREGC) on 24th October 2013 (for the completed ethics proposal and letter of approval, see Appendix 4).

5.3 Sampling and Participants

The same sampling technique as in the previous pilot studies was used in this experiment. This resulted in a sample of 50 healthy participants, aged between 19 and 70 (32 females, 18 males). The participants were recruited via email (Appendix 5) with an attached information sheet (Appendix 8). Flyers were handed out to students around the campus with the same wording as the email (Appendix 5). The demographic data of the participants are demonstrated in Table 5.1.

Table 5.1 *Summary of the Demographic data of the 50 participants in the Final Study*

No.	**Sex**	**Age Range**	**Dominant Hand**	**Frequency of computer mouse use**
50	-32 Females -18 Males	19-70 years old	-44 Right-handed -6 Left-handed	-31 used Standard mouse. -18 used Laptops. -1 Mac Mouse.

The inclusion criteria allowed for healthy male and female participants and participants who were either right-handed or left-handed. The exclusion criteria would not permit participants with current musculoskeletal disorders or pain in the neck, shoulder, elbow and wrist joints. In addition, participants with a surgical history and participants allergic to medical tape were excluded.

5.4 Experimental Methods

5.4.1 Overview of the design of the study

The data collection was carried out by a single researcher and took place in the Human Movement Laboratory at the University of Brighton, School of Health Sciences. The participants attended for one laboratory visit, and each visit lasted for up to 90 minutes.

At the beginning of each experiment, all information about the experiment, including the purpose of the study, was explained to the participants verbally and provided in writing by use of an information sheet (Appendix 8). Participants then signed a consent form (Appendix 7). Prior to data collection, the participants were allowed to become familiar with each computer mouse design. The participants played an Air Hockey game using the Standard mouse, and the score was noted. Figure 5.1 illustrates the Air Hockey game.

A participant playing Air Hockey game during the familiarisation session.

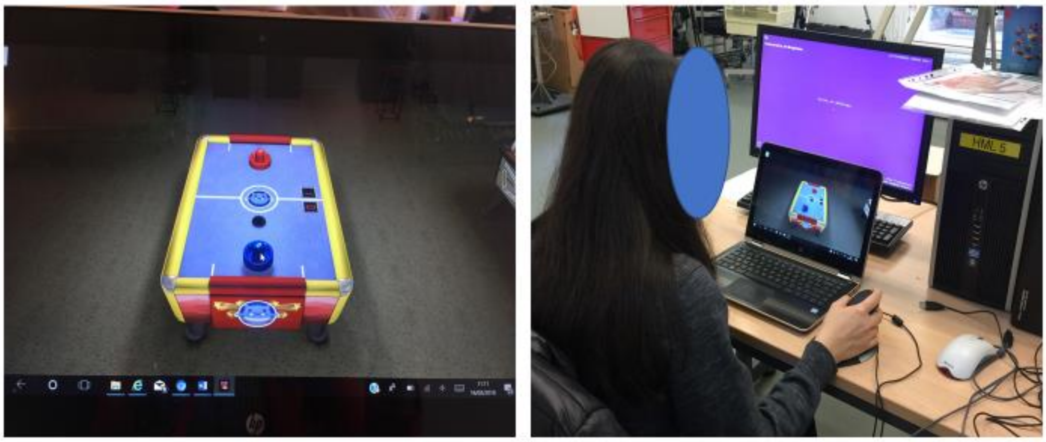


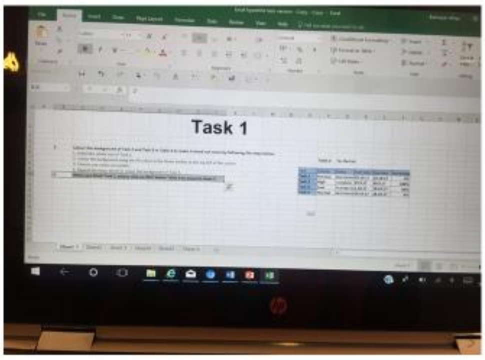
Figure 5.1 *Air Hockey Game*

Then the participants performed the game again with the Penguin and Evoluent mice until they reached a similar score to that achieved with the Standard mouse. The score was a useful indicator that they were able to use each mouse effectively.

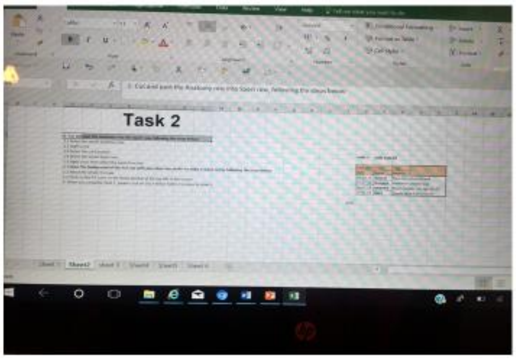
After that, the participants had a chance to become familiar with the main experimental task. The main experimental task was an Excel task that consisted of five different sheets (5 tasks); it was created by the researcher and was chosen to simulate the job of office workers and for anyone using a computer for personal use. In each sheet, there was a table and specific instructions to be performed in the table. Figure 5.2 shows the Excel task with the experimental set-up; the Excel worksheet is also included on the USB stick appended to this thesis. After the familiarisation session, the participants had a break for up to 30 minutes.

Excel Task

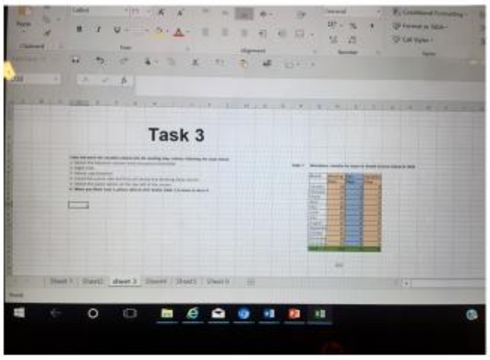
Task 1



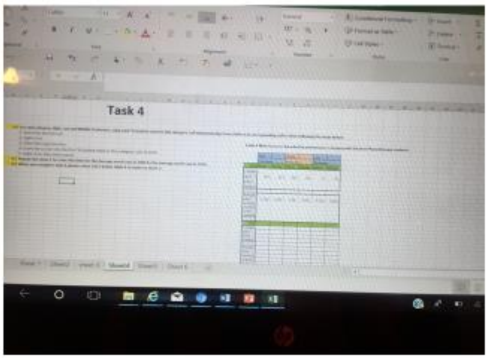
Task 2



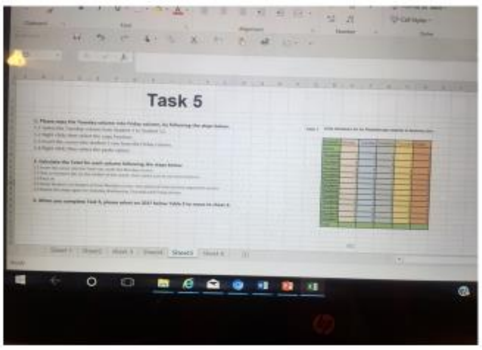
Task 3



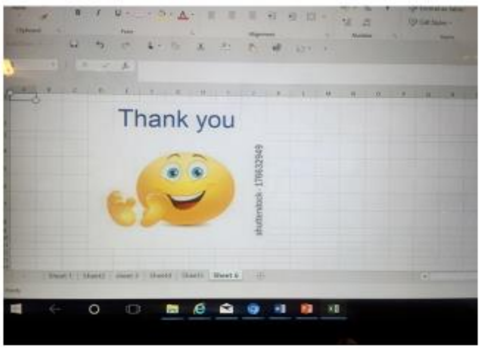
Task 4



Task 5



End of the task



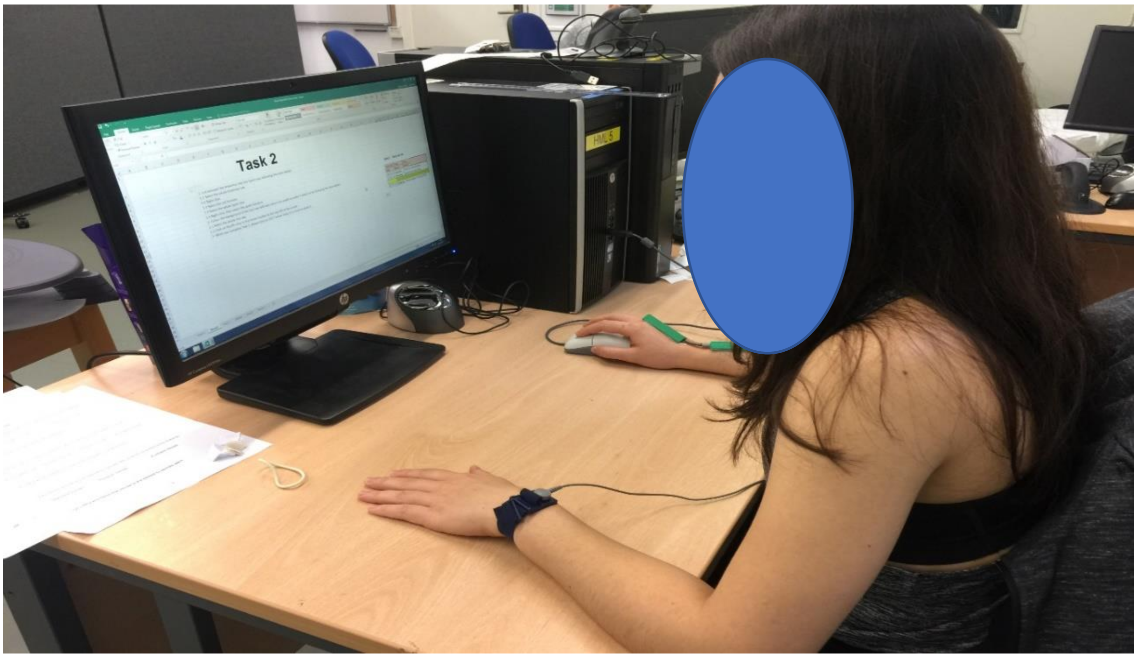


Figure 5.2 *The Excel Task and the Experimental set-up.*

During data collection, the participants performed an Excel task 3 times, one trial with each mouse design. The computer mice were randomly allocated to each participant by drawing lots to ensure that the participants used the mice in random order. Measurements were taken for muscle activity of the biceps, triceps, brachioradialis, wrist flexors, and wrist extensors; measurements of the static posture and maximum joint position achieved were taken (elbow flexion/extension, wrist flexion/extension and wrist radial/ulnar deviation). Muscle activity and maximum joint position achieved measurements were taken in Task 1 (the beginning of the experiment), Task 3 (the middle of the experiment), and Task 5 (the end of the experiment). Static posture measurements were taken only prior to Task 1 for 3 seconds when the participants were holding the mouse.

The experimental workstation was set up according to the Health and Safety Executive (HSE, 2017, online) guidelines such as the height of the screen according to the eye level, and the distance of the screen according the arm length (HSE, 2017, online). Furthermore, the participants were able to adjust the height of the chair according to their height.

The placement of the Electrogoniometer sensors was the same as in the pilot study in Chapter 3, and the surface EMG sensors were the same as in the reliability pilot study (Chapter 4, section 4.5). The Electrogoniometer and surface EMG were zeroed while each participant’s hand was resting in a neutral position on the desk. The researcher ensured a standard joint position by aligning the mid-point of the elbow joint to the second finger to avoid wrist flexion/extension and wrist radial/ulnar deviation.

5.4.2 Rapid Upper Limb Assessment

RULA was used in the middle of the experiment (Task 3) to analyse the overall posture whilst performing the task with each particular mouse design (Appendix 1). RULA was considered to be a quick observation method of posture analysis and it was used as part of the ergonomic assessment to check whether the participants' posture was at risk whilst performing the task with each computer mouse.

In this study, RULA was used to give an insight into which mouse design enabled the posture to be maintained in a more standard position such as maintaining the wrist and elbow in a neutral position, in the midline of the body; also, maintaining the neck between 0° and 10° flexion with no twisting or side bending, as well as keeping the trunk in a neutral position with no twisting or side bending (Dockrell et al., 2012).

RULA had two sections. For Section A, the researcher scored the participants' posture of the upper arms, lower arms, wrist, and wrist twist whilst performing the computer. For Section B, the researcher scored the neck, trunk and legs whilst performing the computer task. The posture risk score ranged from 1 to 4; a score of 1 indicated the best or the most neutral posture and higher scores showed a more unbalanced position. The Grand score was used to provide the observed posture into an action level that indicated the required intervention.

5.4.3 Usability Questionnaire

A usability questionnaire (Appendix 9) was distributed at the end of the experiment to check the participants' perceptions of each mouse used and their influence on posture. Furthermore, the questionnaire was used to investigate mouse preferences, the computer mice ease of use to learn which mouse was perceived to be the most comfortable and easiest to use, and also to help to understand the usability of each mouse in terms of familiarity with the mouse features. The questionnaire was made by the researcher and included closed and open type questions. The closed questions were ranking questions for the participants to rank from 1 to 3, with 1 meaning the best and 3 meaning the worst. The ranking was to help the participants choose the response that best represented their opinions on and degree of satisfaction with the computer mouse design. The open-ended questions allowed the participants to include more information such as their feelings and attitudes as well as their understanding of each mouse design used, allowing the researcher to have a better perception of each participant's true feelings on each mouse design (see Appendix 9).

5.5 Sample size calculation

The sample size calculation was performed using G*Power software version 3.1 prior to the study. In this software, the researcher calculated the sample size using an F-test, which was the 1-way repeated measure ANOVA. The 1-way repeated measure was chosen because the same group of subjects were subjected to 3 experimental conditions, one with each mouse design and also because this study had one independent variable, the mouse design. The outcome of this calculation showed that 95% power required a sample size of 50.

5.6 Data Processing

5.6.1 Parametric Data

5.6.1.1 Movement data

For the maximum joint position achieved, the data processing was carried out using Microsoft Excel 2010. An automated template was created in Microsoft Excel 2010 to perform the data processing for the maximum joint position achieved of the elbow flexion/extension, wrist flexion/extension and wrist radial/ulnar deviation during the Excel task and with each mouse design, Standard, Penguin and Evoluent. A fourth-order zero-lag low-pass Butterworth filter, with 8 Hz cut off frequency, was used in each data set.

The maximum joint position achieved was calculated during Task 5 to capture the maximum learning and fatigue effects. In each data set, all the maximum points in each movement graph were noted. Then the average of all the maximum points and SD were calculated for each movement and for each participant,

The static posture was calculated prior to beginning Task 1 while the participants were instructed to hold the mouse still for 3 seconds. These data were collected for wrist flexion/extension (W.F/E), wrist radial/ulnar deviation (W.RD/UD) and elbow flexion/extension (E.FE). The mean of the 3 seconds and SD were calculated for each movement.

In static posture and maximum joint position achieved, a negative value represented wrist extension, wrist radial deviation and elbow flexion. The positive value represented wrist flexion, wrist ulnar deviation and elbow extension.

5.6.1.2 EMG data

The raw EMG data from Task 5 were processed using MATLAB R2017a. The raw EMG data were filtered to remove noise elements that have different frequencies from the signal (Nawab et al. 2010). The same data processing in the reliability study with EMG data was used in this study. The details of how the data were processed was discussed in Chapter 4 section 4.6.2. In this study, the average and maximum voltages were calculated using all the active data.

5.6.2 Non-Parametric Data

5.6.2.1 RULA

The overall score of Sections A and B were calculated by following the RULA guidelines. From these two values, a final score, called a Grand score, was calculated. The instructions for scoring the RULA are in Appendix 1. All the results from RULA were combined in a table and ranked so that the lowest score had a rank of 1.

5.6.2.2 Questionnaire results

All the quantitative rankings from each participant were combined in a table using Microsoft Excel 2010 and then exported to IBM SPSS statistics version 22 for further analysis. The researcher analysed each participant's qualitative response for each question and developed themes. A summary of the 50 participants' responses is in Appendix 10.

5.7 Movement and EMG data analysis

Computer mice comparisons were performed to know whether there is a difference in the static posture and maximum joint position achieved of wrist flexion/extension, wrist radial/ulnar deviation and elbow flexion/extension while using three mice designs and also to know whether there is a difference in the average and maximum voltage of the Forearm muscles while using three different mice. The statistical analysis was performed using IBM SPSS statistics version 22. The significance level was set at $p < 0.05$. The analysis was performed and interpreted according to Field's (2016) suggestions. 1-way repeated measure

ANOVA was used because the same group of subjects was subjected to 3 experimental conditions, one with each mouse design.

5.8 RULA and Quantitative Questions analysis

RULA and the quantitative questions were non-parametric data. Because of this, a Friedman's ANOVA test was used using IBM SPSS statistics version 22. Friedman's ANOVA was chosen because it tested the differences between 2 or more conditions and the same entities provided scores in all conditions (Field, 2016). In this study, there were 3 experimental conditions for the same group of subjects. With RULA, only the ranking score was used for Friedman's ANOVA test.

A follow-up test was done after the Friedman's ANOVA test. The follow-up test was a Pairwise Comparison: all pairwise. The all pairwise was selected to compare the entities in pairs to know where the significant difference was. For example, it compared the ranking of the Evoluent mouse with the Penguin mouse, the Evoluent with the Standard mouse, and between the Penguin and Standard mice.

Furthermore, with RULA data, the mean of the Grand score was calculated with each mouse design. This helped to know whether there was an overall posture deviation with each mouse design. Also, the mean of each part of the body was calculated to know which part of the body had a posture deviation. Although the RULA data were ordinal data, the mean calculations were preferred over the median. This was seen done in the Meksawi et al. (2012) study because the mean was able to show where the posture deviation was, unlike the median. This study was discussed in Chapter 1, section 1.4.2.3.

5.9 Results

The significant results only are discussed in this chapter and presented in each section below.

5.9.1 Static posture

5.9.1.1 Wrist flexion/extension

Mauchly's test indicated that the assumption of sphericity had not been violated within three mouse designs in wrist flexion/extension, $\chi^2(2) = 0.247$, *p* = 0.884. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the measurements taken of wrist flexion/extension with all the participants while using three different mouse designs, *F* = 33.6, *p* < 0.001. It was found that there was a significant difference in the measurements taken for wrist flexion/extension between the Evoluent and Standard mice (*p* < 0.001).

The average wrist resting position for the 50 participants was into extension with the three mice designs. Furthermore, the wrist extension was significantly greater with the Evoluent mouse (mean = 37.6˚). However, the least wrist extension was with the Penguin mouse (mean = 24.2˚).

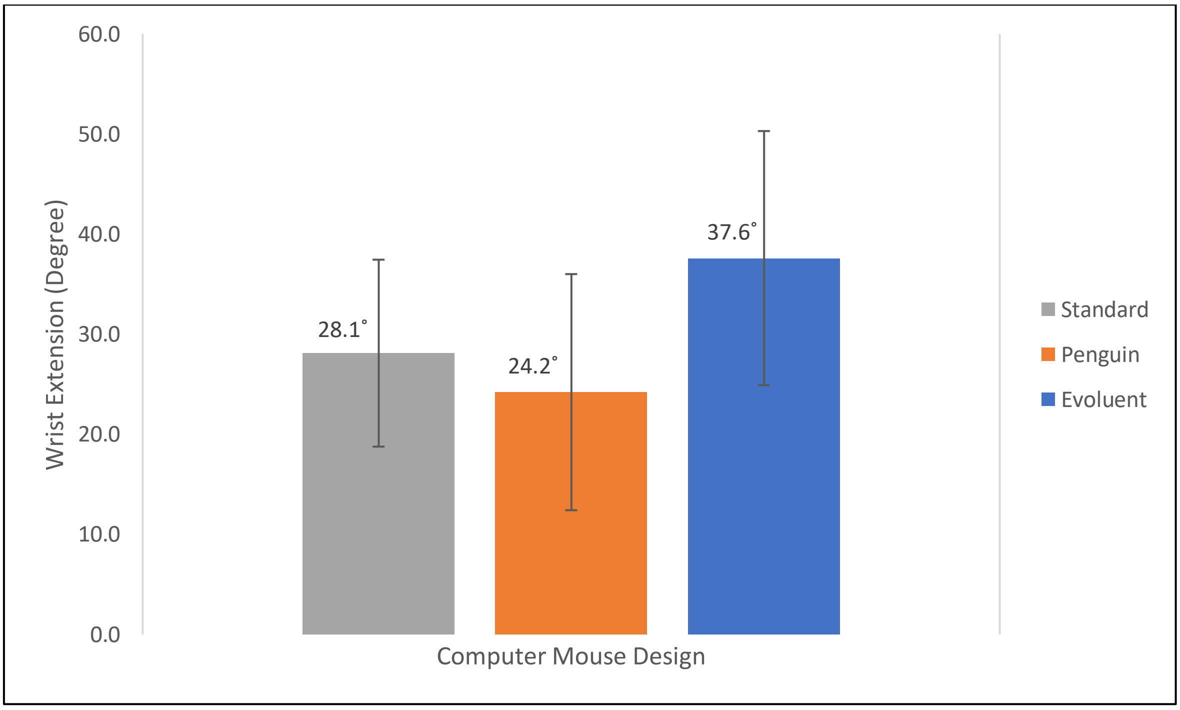


Figure 5.3 *Population mean of wrist extension at rest with each mouse design and with the 50 participants.*

5.9.1.2 Wrist radial/ulnar deviation

Mauchly's test indicated that the assumption of sphericity had not been violated within three mouse designs in wrist radial/ulnar deviation, $\chi^2(2) = 4.39$, *p* = 0.111. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the measurements taken of wrist radial/ulnar deviation with all the participants while using three different mouse designs, *F* = 29.3, *p* < 0.001. It was found that there was a significant difference in the measurements taken for wrist radial/ulnar deviation between the Evoluent and Standard mice (*p* < 0.001), and between the Penguin and Standard mice (*p* < 0.001).

The wrist posture with the Standard mouse was significantly different from the other two mice. The Standard mouse positioned the wrist into ulnar deviation. However, the Evoluent and Penguin mice positioned the wrist into radial deviation. Less radial deviation at rest was found with the Evoluent mouse when compared to the Penguin mouse.

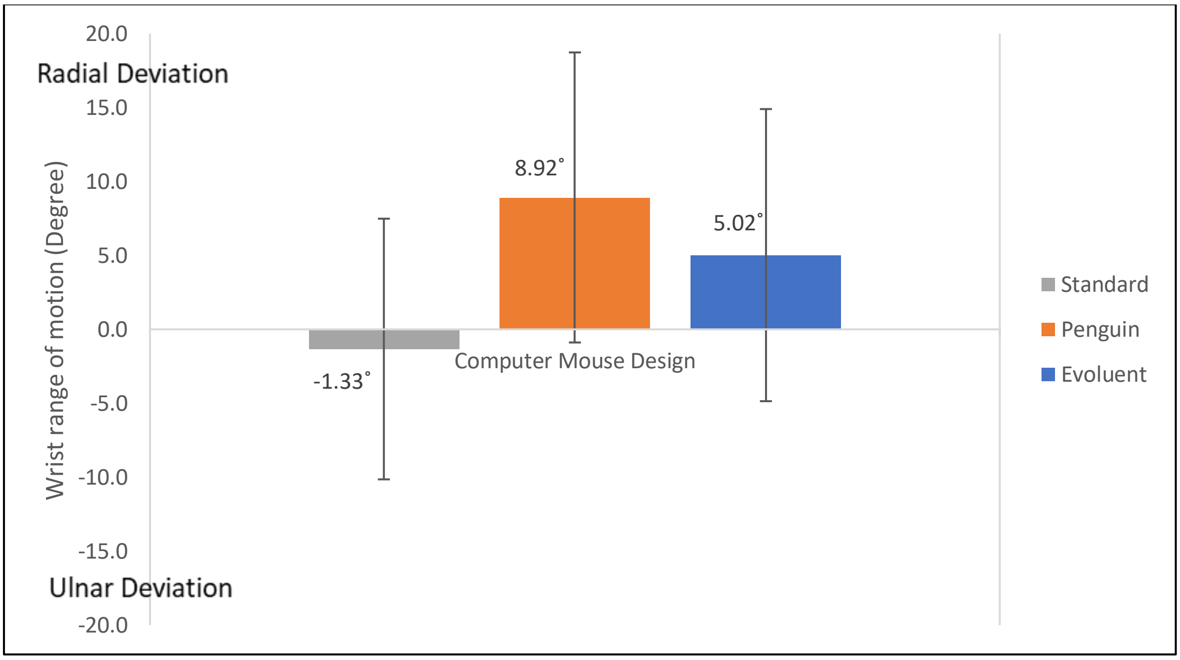


Figure 5.4 *Population mean of wrist radial deviation at rest with each mouse design and with the 50 participants.*

5.9.2 Maximum joint position achieved

5.9.2.1 Wrist flexion/extension

Mauchly's test indicated that the assumption of sphericity had not been violated within three mouse designs in wrist flexion/extension, $\chi^2(2) = 3.36$, *p* = 0.186. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the measurements taken of wrist flexion/extension with all the participants while using three different mouse designs, *F* = 14.7, *p* < 0.001. It was found that there was a significant difference in the measurements taken for wrist flexion/extension between the Evoluent and Standard mice (*p* < 0.001).

Figure 5.5 showed that the wrist extension was significantly greater with the Evoluent mouse than the other two mice. The maximum wrist joint position achieved in wrist extension for the 50 participants was the least with the Penguin (mean = 35.4˚) and Standard mice (mean = 35.5˚).

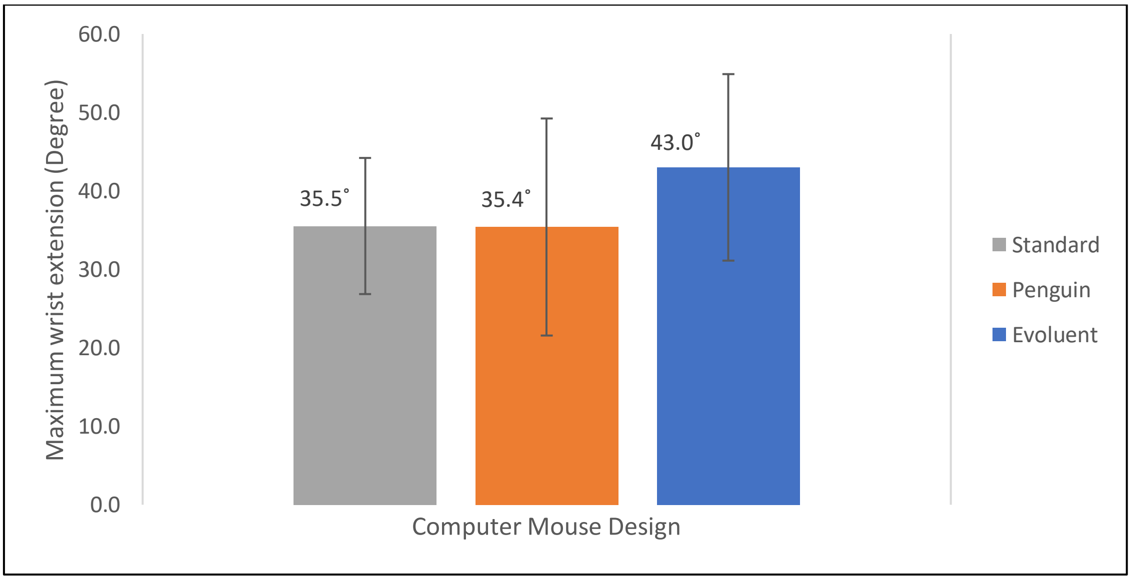


Figure 5.5 *Population mean of maximum wrist extension with each mouse design and with the 50 participants.*

5.9.2.2 Wrist radial/ulnar deviation

Mauchly's test indicated that the assumption of sphericity had not been violated within three mouse designs in wrist radial/ulnar deviation, $\chi^2(2) = 1.40$, *p* = 0.495. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the measurements taken of wrist radial/ulnar deviation with all the participants while using three different mouse designs, $F = 5.89$, $p < 0.001$. It was found that there was a significant difference in the measurements taken for wrist radial/ulnar deviation between the Evoluent and Standard mice ($p = 0.012$), and between the Penguin and Standard mice ($p = 0.033$).

The wrist posture with the Standard mouse was significantly different from the other mice. The Standard mouse positioned the wrist into ulnar deviation, and the other mice positioned the wrist into radial deviation. The maximum radial deviation achieved with the 50 participants was more with the Evoluent mouse (mean = 5.17˚) than the Penguin mouse (mean = 3.95˚).

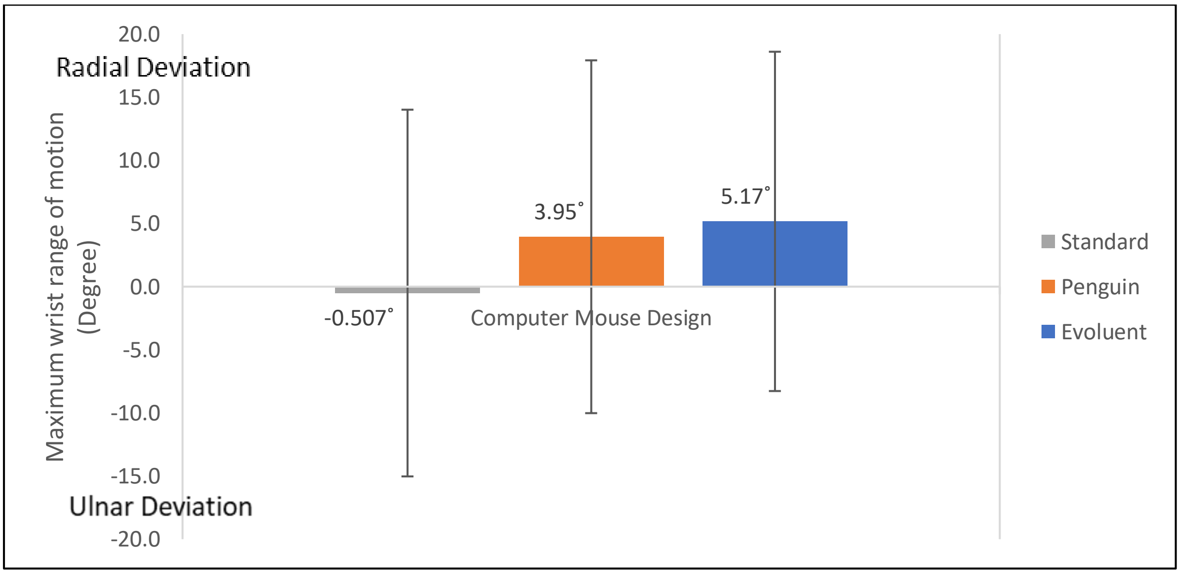


Figure 5.6 *Population mean of maximum wrist radial deviation with each mouse design and with the 50 participants.*

5.9.2.3 Elbow flexion/extension

Mauchly's test indicated that the assumption of sphericity had not been violated within three mouse designs in elbow flexion/extension, $\chi^2(2) = 1.02$, $p = 0.602$. Therefore, the sphericity assumed corrected test was reported ($p = 0.005$). This meant that there was a significant difference in the measurements taken of elbow flexion and extension with all the participants while using three different mouse designs, $F = 5.56$, $p = 0.005$. It was found that there was no significant difference in the measurements taken for elbow flexion/extension between the Evoluent and

Standard mice (p = 1.000) and between the Penguin and Standard mice (p = 0.091).

The maximum joint position achieved for elbow flexion with the 50 participants was greater with the Penguin mouse (mean = 13.7˚). However, it was less with the Evoluent mouse (mean = 6.70˚).

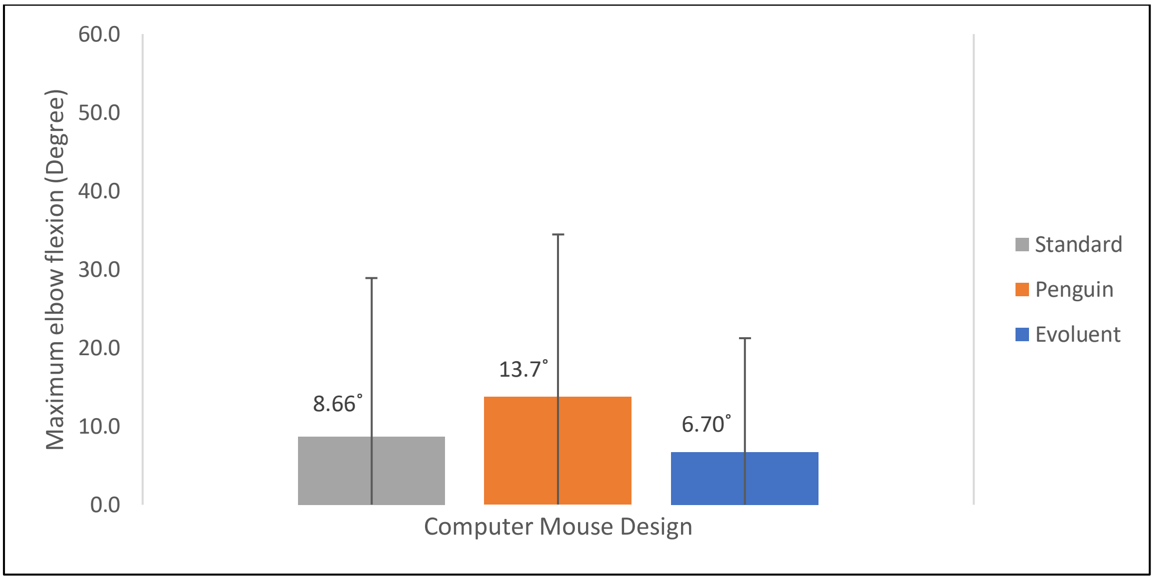


Figure 5.7 *Population mean of maximum elbow flexion with each mouse design and with the 50 participants.*

5.9.3 Muscle activity data

5.9.3.1 Average Voltage

5.9.3.1.1 Average voltage of Triceps

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the average voltage of triceps, $\chi^2(2) = 2.33$, p = 0.312. Therefore, the sphericity assumed corrected test was reported (p < 0.001). This meant that there was a significant difference in the average voltage of triceps with all the participants while using three mice designs (F = 11.7 p < 0.001). It was found that there was a significant difference in the measurements taken of the average voltage of triceps between the Penguin and Standard mice (p = 0.001). Figure 5.8 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was found from Figure 5.8 that the average voltage of triceps within 50 participants was more with the Evoluent mouse (mean = 0.00725 μV) and the least with the Penguin mouse (mean = 0.00425 μV).

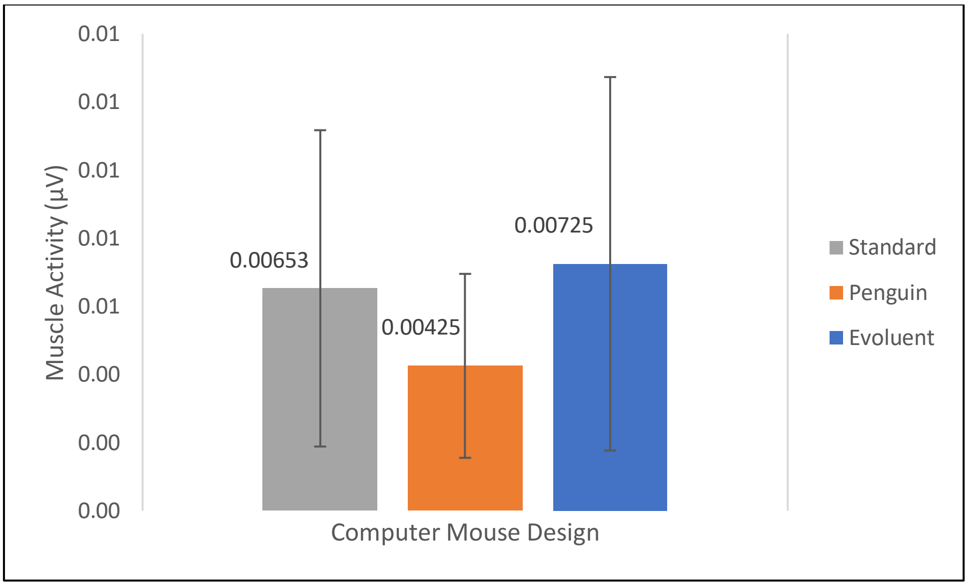


Figure 5.8 *Population mean of mean voltage of Triceps with each mouse design and with 50 participants.*

5.9.3.1.2 Average voltage of Brachioradialis

Mauchly's test indicated that the assumption of sphericity had been violated within the three mouse designs in the average voltage of brachioradialis, $\chi^2(2) = 11.4$, *p* = 0.003. Therefore, the Greenhouse-Geisser corrected tests were reported (*p* = 0.001). This meant that there was a significant difference in the average voltage of brachioradialis with all the participants while using three mice designs (*F* = 8.73, *p* = 0.001). It was found that there was a significant difference in the measurements taken of the average voltage of brachioradialis between the Evoluent and Standard mice (*p* < 0.001), and between the Penguin and Standard mice (*p* = 0.025). Figure 5.9 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was found from Figure 5.9 that the average voltage of brachioradialis within 50 participants was more with the Standard mouse (mean = 0.00778 μV) and the least with the Evoluent mouse (mean = 0.00672 μV).

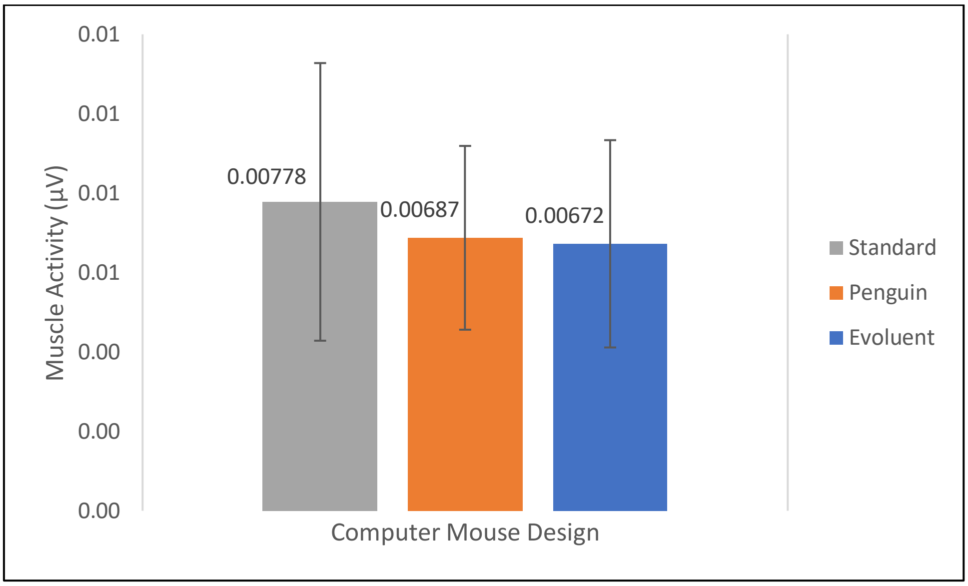


Figure 5.9 *Population mean of mean voltage of Brachioradialis with each mouse design and with 50 participants.*

5.9.3.1.3 Average voltage of Wrist Flexors

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the average voltage of wrist flexors, $\chi^2(2) = 3.58$, *p* = 0.167. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the average voltage of Wrist Flexors with all the participants while using three mice designs (*F* = 9.86, *p* < 0.001). It was found that there was a significant difference in the measurements taken of the average voltage of wrist flexors between the Evoluent and Standard mice (*p* < 0.001), and between the Penguin and Standard mice (*p* = 0.024). Figure 5.10 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was found from Figure 5.10 that the average voltage of the wrist flexors was more with the Standard mouse (mean = 0.0137 μV) and the least with the Evoluent mouse (mean = 0.0107 μV).

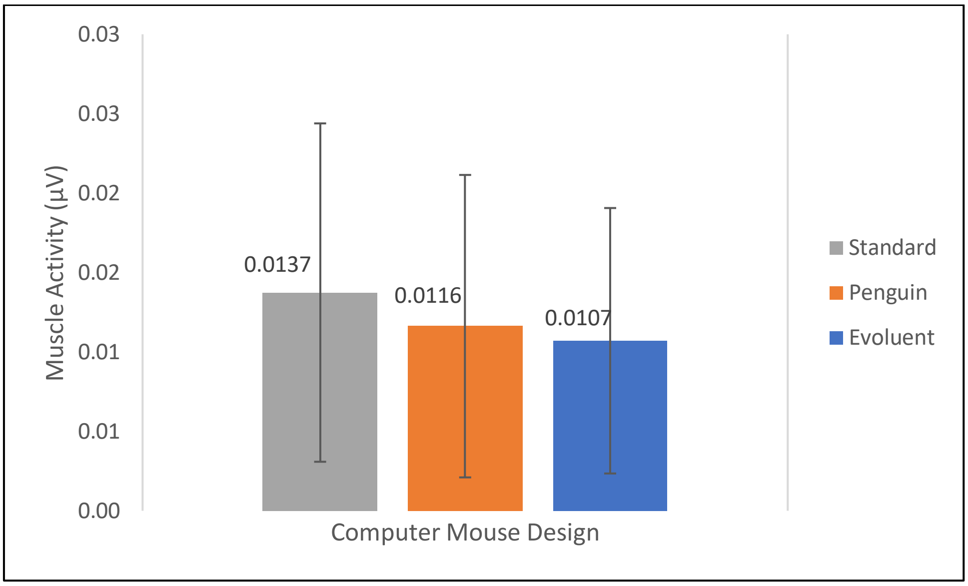


Figure 5.10 *Population mean of mean voltage of wrist Flexors with each mouse design and with 50 participants.*

5.9.3.1.4 Average voltage of Wrist Extensors

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the average voltage of wrist extensors, $\chi^2(2) = 0.307$, *p* = 0.858. Therefore, the sphericity assumed corrected test was reported (*p* < 0.001). This meant that there was a significant difference in the average voltage of Wrist Extensors with all the participants while using three mice designs (*F* = 9.86, *p* < 0.001). It was found that there was a significant difference in the measurements taken of the average voltage of wrist extensors between the Evoluent and Standard mice (*p* = 0.004), and between the Penguin and Standard mice (*p* = 0.001). Figure 5.11 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was found from Figure 5.11 that the average voltage of wrist extensors was more with the Standard mouse (mean = 0.0334 μV) and the least with the Penguin mouse (mean = 0.0260 μV).

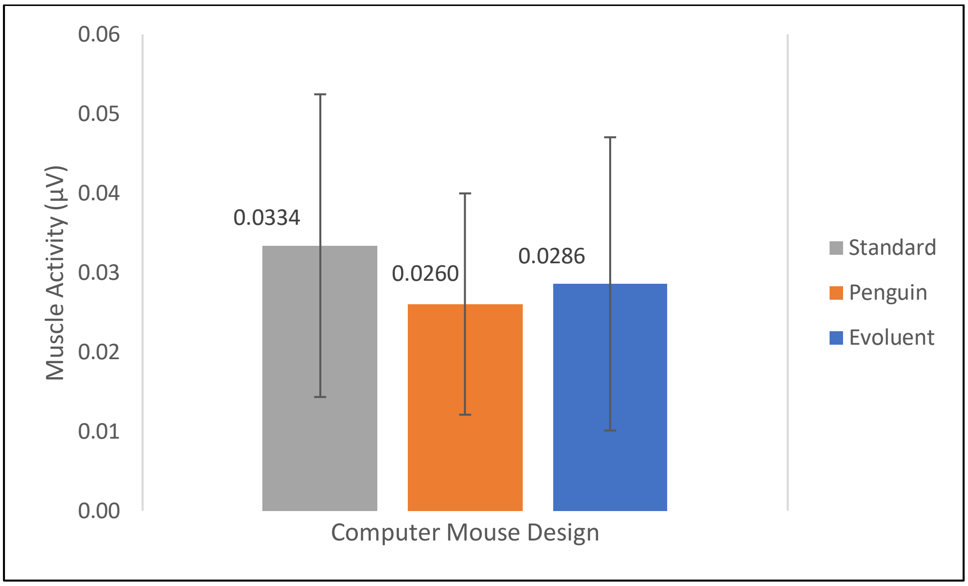


Figure 5.11 *Population mean of mean voltage of Wrist Extensors with each mouse design and with 50 participants.*

5.9.3.2 *Maximum Voltage*

5.9.3.2.1 Maximum Voltage of Biceps

Mauchly's test indicated that the assumption of sphericity had been violated within the three mouse designs in the maximum voltage of biceps, $\chi^2(2) = 8.10$, *p* = 0.017. Therefore, the Greenhouse-Geisser corrected tests were reported (*p* = 0.006). This meant that there was a significant difference in the maximum voltage of biceps with all the participants while using three mice designs (*F* = 5,98, *p* = 0.006). It was found that there was no significant difference in the measurements taken of the maximum voltage of biceps between the Penguin and Standard mice (*p* = 0.066), and between the Evoluent and standard mice (*p* = 1.000). Figure 5.12 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was initiated from Figure 5.12 that the maximum voltage of biceps with the 50 participants was more with the Penguin mouse (mean = 0.0383 μV). The least maximum voltage of Biceps was with the Evoluent mouse (mean = 0.0218 μV).

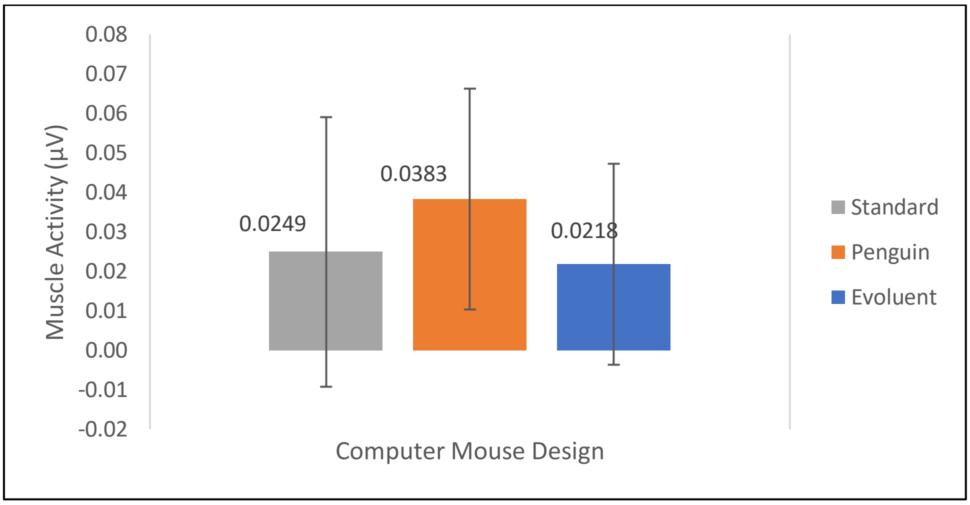


Figure 5.12 *Population mean of maximum voltage of Biceps with each mouse design and with 50 participants.*

5.9.3.2.2 Maximum voltage of Wrist Extensors

Mauchly's test indicated that the assumption of sphericity had not been violated within the three mouse designs in the maximum voltage of wrist extensors, $\chi^2(2) = 5.33$, *p* = 0.070. Therefore, the sphericity assumed corrected test was reported (*p* = 0.007). This meant that there was a significant difference in the maximum voltage of Wrist Extensors with all participants while using three mice designs (*F* = 5,26, *p* = 0.007). It was found that there was a significant difference in the measurements taken of the maximum voltage of wrist Extensors between the Evoluent and Standard mice (*p* = 0.009). Figure 5.13 demonstrated the descriptive statistics with each mouse design and with the 50 participants.

It was found from Figure 5.13 that the maximum voltage of wrist extensors with the 50 participants was more with the Standard mouse (mean = 0.0843 μV). However, the least maximum voltage of wrist extensors was with the Evoluent mouse (mean = 0.0697 μV).

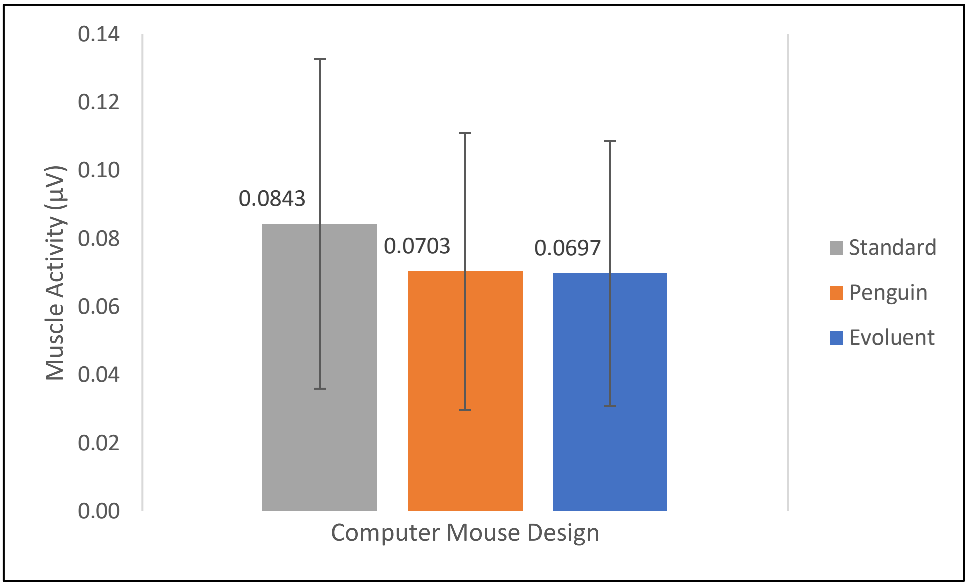


Figure 5.13 *Population mean of maximum voltage of Wrist Extensors with each mouse design and with 50 participants.*

5.9.3.3 <u>Summary of the results from the average and maximum voltage</u>

Tables 5.13 and 5.14 presented the summary of the findings. The arrows illustrated how each mouse design affected each muscle: an increase in the average voltage or the maximum voltage illustrated by an upward pointing arrow (↑), and a decrease in the average voltage or the maximum voltage illustrated by a downward pointing arrow (↓).

Table 5.2 *Summary of the results of the average voltage for each muscle with each mouse design.*

Average voltage	Biceps	Triceps	Brachio	W.Flexors	W.Extensors
Penguin	not sig	↓			↓
Evoluent	not sig	↑	↓	↓	
Standard	not sig		↑	↑	↑

Table 5.3 *Summary of the results of the maximum voltage for each muscle with each mouse design.*

Maximum voltage	Biceps	Triceps	Brachio	W.Flexors	W.Extensors
Penguin	↑	not sig	not sig	not sig	
Evoluent	↓	not sig	not sig	not sig	↓
Standard		not sig	not sig	not sig	↑

5.9.4 Rapid Upper Limb Assessment

5.9.4.1 Friedman's ANOVA results

From the related-samples Friedman's two-way analysis of variances by ranks test, it was found that the overall sitting posture for the 50 participants significantly changed with the three mice designs used, $x^2(2) = 56.5$, $p < 0.001$. Pairwise Comparison with adjusted *p*-value showed that there was a significant difference between the Evoluent and Standard mice ($p < 0.001$, $T = -1.19$), and between the Penguin and Standard mice ($p < 0.001$, $T = -0.910$). Figure 5.14 showed the output of Friedman's ANOVA test.

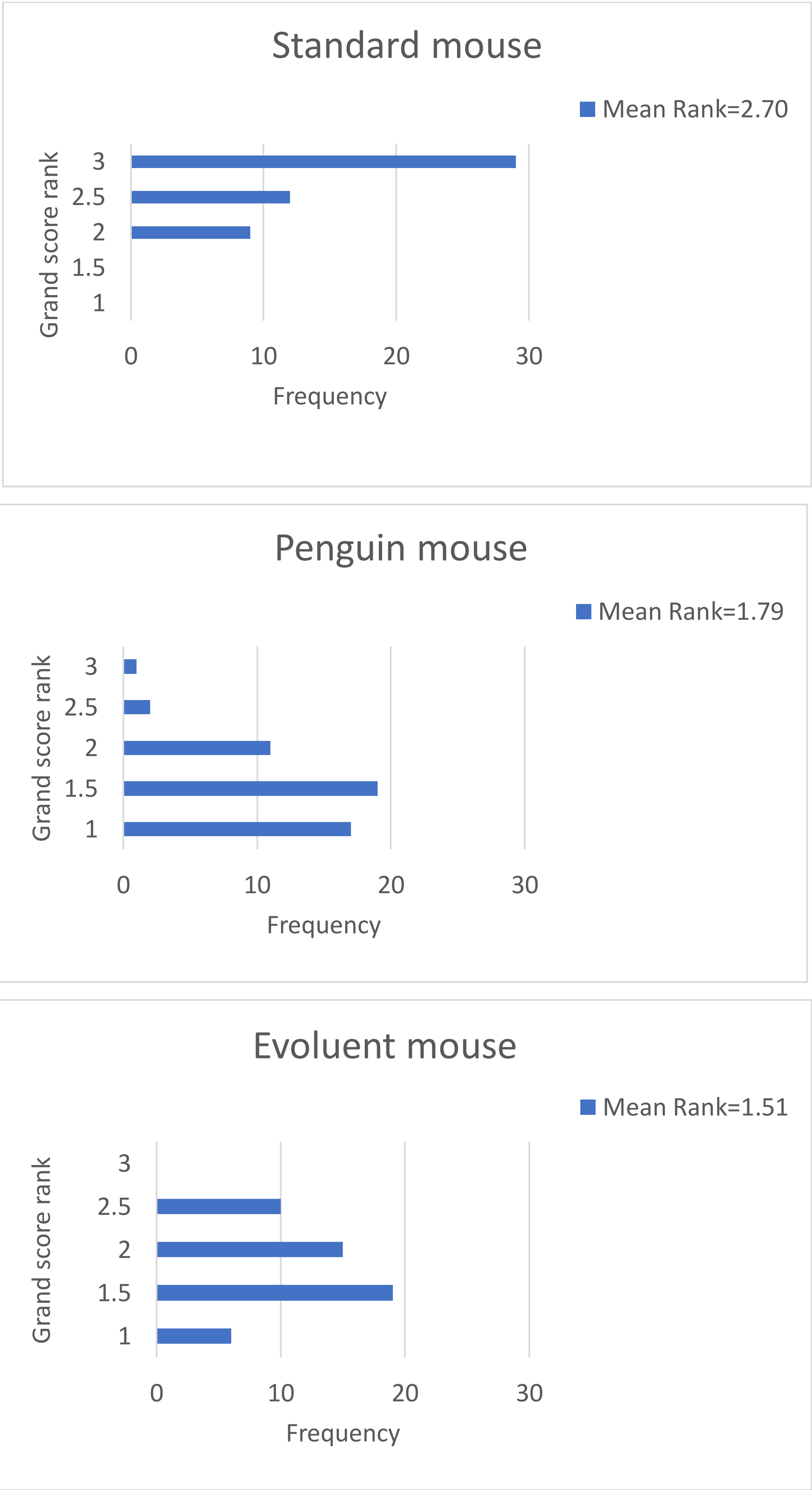


Figure 5.14 *Related–Samples Friedman's Two-Way Analysis of Variance by Ranks*

5.9.4.2 Grand Score results

Table 5.4 showed that the Penguin mouse had the lowest mean Grand score (Score = 2). Score 2, according to RULA, meant low risk and the work posture was acceptable. The Evoluent mouse had a Grand score of 3, and the Standard mouse had a Grand score of 4. A Grand score of 3 to 4 meant further investigation was needed, and work habit changes may be required.

Table 5.4 *Mean Grand Score with each mouse design and with the 50 participants.*

RULA Grand Score	Penguin	Evoluent	Standard
Average	2	3	4

5.9.4.3 Taking the mean in each part of the body

Table 5.5 showed that the Penguin mouse had a mean of 1 in each part of the body. This meant that there was no deviation in the overall posture within 50 participants.

The Evoluent mouse showed a cause for concern; posture deviated from the neutral position in neck (mean = 2) and trunk (mean = 2). Also, the Standard mouse showed a cause for concern; posture deviated in all body parts.

Table 5.5 *Mean of the score in each part of the body from RULA within 50 participants.*

Mouse Design	Upper arm	Lower arm	Wrist	Wrist twist	Neck	Trunk	Legs
Penguin	1	1	1	1	1	1	1
Evoluent	1	1	1	1	2	2	1
Standard	2	2	3	2	2	2	2

5.9.5 Questionnaire

5.9.5.1 Quantitative Questions

Question 1: Put these mice in order according to which mouse is the most comfortable to use and the least comfortable to use.

From the 50 participants' responses, the Evoluent mouse was found to be the most comfortable mouse to use (56% respondents). On the other hand, the Standard mouse was found to be the least comfortable to use (48% respondents).

From the related-samples Friedman's two-way analysis of variances by ranks test, it was found that there was a significant difference between the Standard, Penguin and Evoluent mice in terms of comfort to use, $x^2(2) = 9.88$, p = 0.007. Pairwise Comparison with adjusted p-value showed that there was a significant difference between the Evoluent and Standard mice (p = 0.006, T = -0.620). Figure 5.15 showed the output of Friedman's ANOVA test.

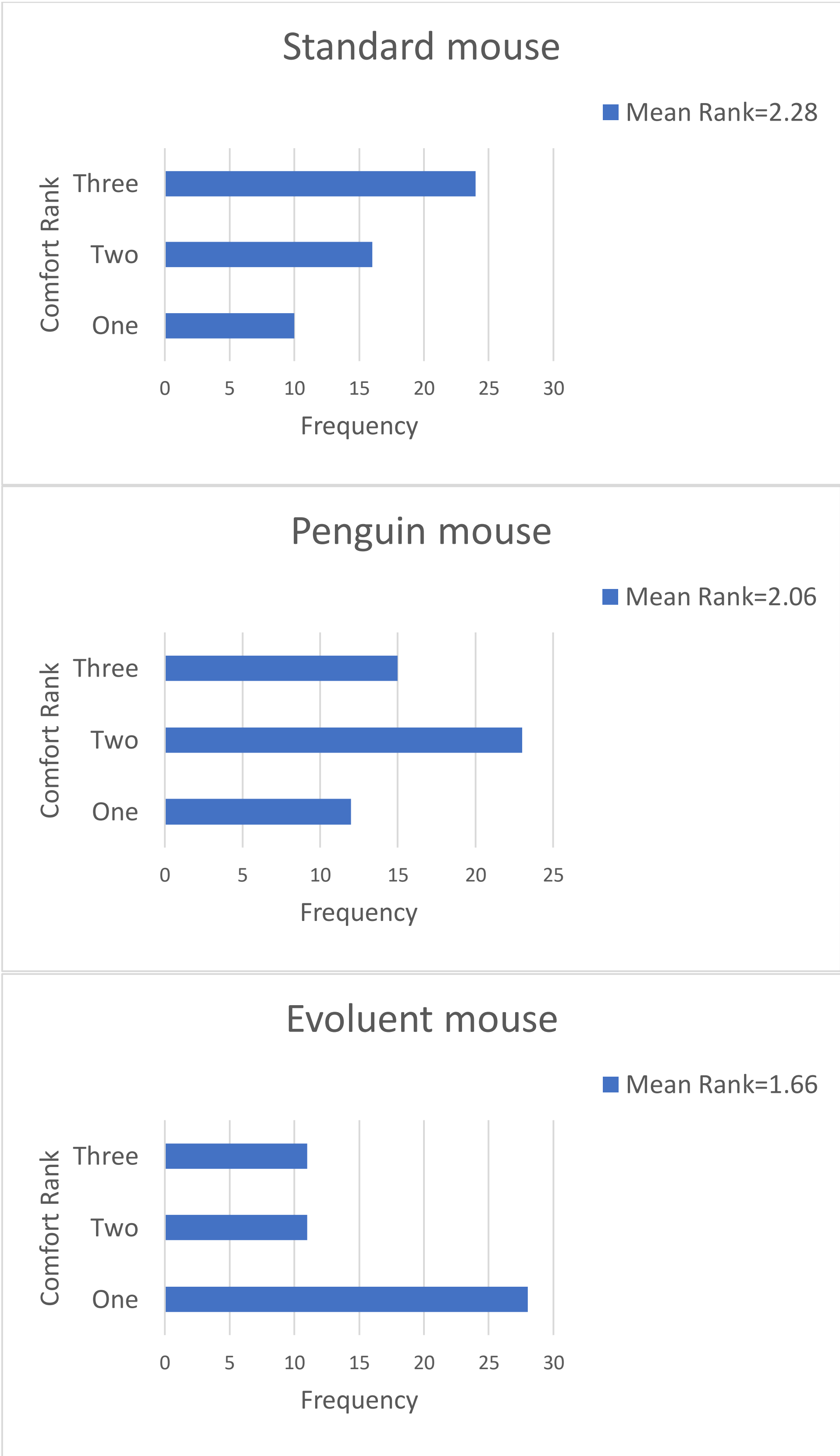


Figure 5.15 *Related–Samples Friedman's Two-Way Analysis of Variance by Ranks*

Question 5: Put these mice in order according to which mouse is the easiest to operate in terms of pressing the buttons.

From the 50 participants, it was found that the Standard mouse was the easiest to operate in terms of pressing the buttons (clicking) (50% respondents). It was found that the Penguin was the least easy in terms of pressing the buttons (44% respondents).

From the related-samples Friedman's two-way analysis of variances by ranks test, it was found from the 50 participants that pressing the mouse buttons significantly changed with the Standard, Penguin and Evoluent mice, $x^2(2) = 6.76$, *p* = 0.034. However, Pairwise Comparison with adjusted *p*-value showed no significant difference between the three mice designs used in terms of pressing the buttons. There was no significant difference between the Standard and Evoluent mice (*p* = 0.083, *T* = 0.440), no significant difference between the Standard and Penguin mice (*p* = 0.064, *T* = 0.460), and no significant difference between the Evoluent and Penguin mice (*p* = 1.000, *T* = 0.020). This could be because the significant values were adjusted by the Bonferroni correction for multiple tests, as stated in Field (2016). Figure 5.16 showed the output of Friedman's ANOVA test.

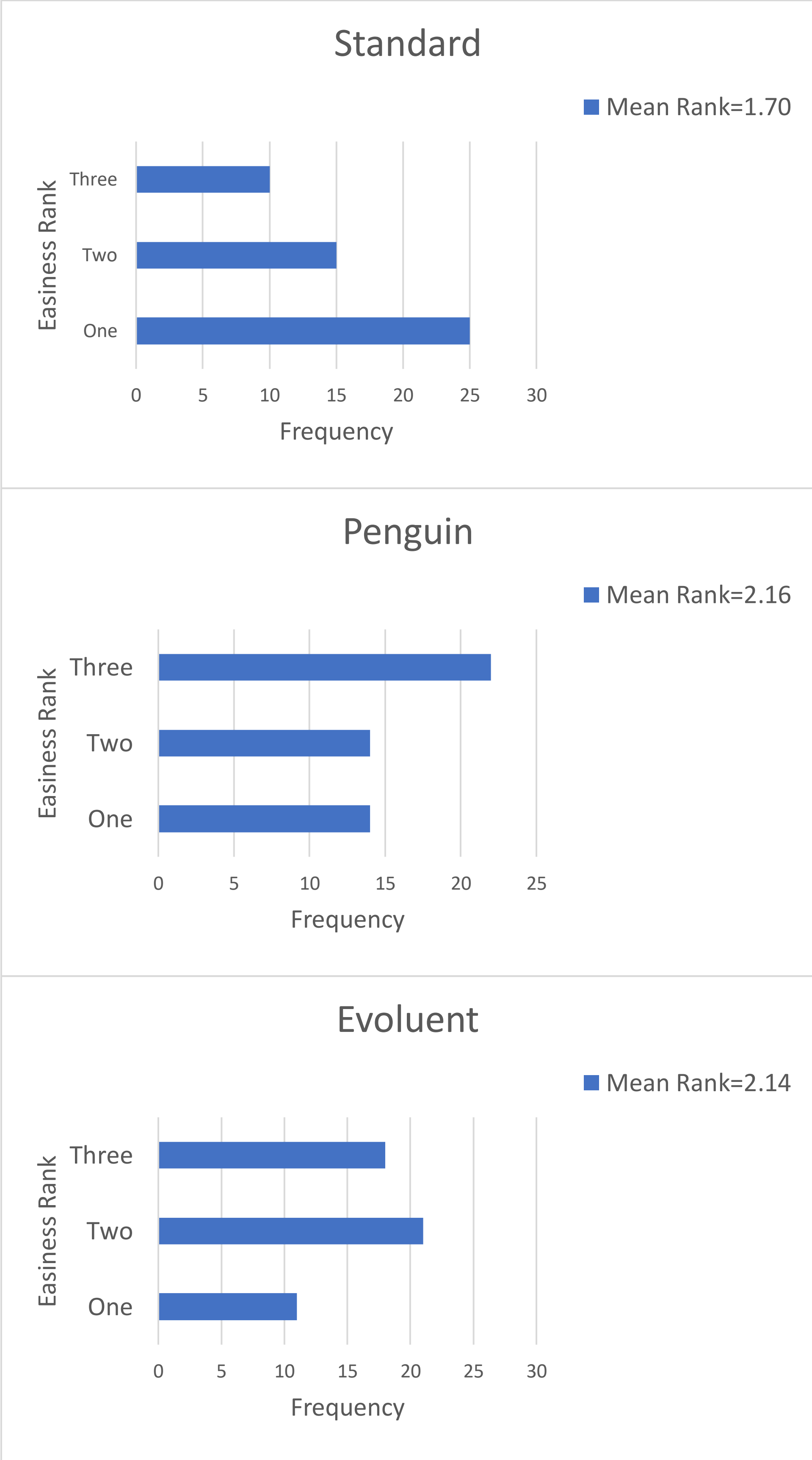


Figure 5.16 *Related-Samples Friedman's Two-Way Analysis of Variance by Ranks.*

5.9.5.2 Qualitative Questions

Question 2: Why did you find them comfortable/uncomfortable?

Most of the participants chose the Evoluent mouse as the most comfortable mouse to use (56% respondents). This was because they felt that it did not allow much arm movement; how their fingers were placed on the mouse; how their hand fit comfortably around the mouse; and they did not have to adjust or move the mouse around much to move the cursor. In addition, it was more supportive, and this mouse positioned their arm in a more natural way.

One participant mentioned that the Evoluent mouse was comfortable because "it was less friction against the surface". Another participant mentioned this mouse was the most comfortable because he "did not feel pressure around [his] hand, and because it was sensitive, easy to glide and light weight".

In contrast, the Standard mouse was the least comfortable mouse to use in comparison with the Evoluent and Penguin mice (48% respondents). This was because some of the participants felt pain by the end of the task and because they felt the need to do more arm movements; they felt they needed to make more effort to perform the task. Furthermore, because it was the least sensitive, it required more arm movements, especially in the shoulder and elbow joint.

One participant mentioned that the Standard mouse was the least comfortable because "I felt too much friction and it was not easy to glide on the surface (stiff), and I felt I needed more muscle work".

Another participant mentioned that "this mouse does not fit to the shape of my hand like other mice designs used, and it was difficult to use after using the other mice".

Question 4: Why did you find this mouse is the easiest to move around?

Out of 50 participants, 50% respondents indicated that the Evoluent mouse was the easiest mouse to move around. This was due to how their hand rested on the Evoluent mouse and how it positioned their hand in a more natural way. Because of the mouse sensitivity, they felt less arm movement and the movement was smoother and more fluid.

Five participants mentioned that it was the easiest because it was easy to press the buttons and they could push/pull easier and faster with real synchronization of their movement on the screen as well as because it was easy to navigate the screen.

One participant stated that the Evoluent was the easiest to move around because "it was light, restful, comfortable, and because of the shape of the mouse".

In contrast, the Penguin mouse was the least easy to move around (24% respondents). This was because they did not enjoy moving the mouse and sometimes they felt friction on the surface whilst moving it.

One participant mentioned that "I sweated a lot on my hand and this is because of the rubber material". Another participant mentioned something similar, stating that "it was sticky sometimes so that I needed to move the mouse up sometimes to move it around".

Question 6: Why did you find this mouse the easiest to operate in terms of pressing the buttons?

The majority indicated that the Standard mouse was the easiest to operate in terms of pressing the buttons (50% responses). This was because they were familiar with this type of mouse design, the Standard mouse being the most common mouse design used. They felt it was straightforward as they did not have to think where to click as with the other mice designs used.

One participant stated that "the buttons were exactly in the right place for my fingers; fingers stayed on a button and it is easier to click". Another participant stated that "I do not need to remind myself how to operate this mouse; my reaction is quicker".

The Penguin mouse was the least easy in terms of pressing the buttons (44% respondents). This was because the left click with this mouse was unreachable. They required more thought for the left click.

Question 8: Why did you find it easy to become familiar with it?

The majority felt the Standard mouse was the easiest mouse to become familiar with (48% respondents). This was because the Standard mouse was the most common mouse used in their daily life and also because it was a simple design and easy to use.

The Penguin and Evoluent mice were the least easy to become familiar with (26% respondents for Penguin, 26% respondents for Evoluent). With the Penguin mouse, some participants felt that the grip was difficult. Also, because of the weight of the arm on the Penguin mat, they felt a distraction, and this required them to adapt the use of hand much more.

With the Evoluent mouse, they felt that three buttons were confusing, and also that they needed time to get used to it. This was because of the right click: they needed to click on the lowest button, but they tended to click on the middle button by mistake. Moreover, because of the mouse sensitivity, it would take extra time to get used to it.

Question 9: Can you give three words to describe each mouse used?

In this section, the descriptive words for each mouse design used will be a selection from the constructive and undesirable words chosen by the researcher from each participant’s response. They were the most repeated words by the 50 participants. The complete set of descriptive words are in Appendix 10.

The descriptive words for the Evoluent mouse were: comfortable, relaxed, light, efficient, smooth, dynamic and sensitive; uncomfortable, irritating, painful, fast, unprecise, clunky, unusual and complicated.

For the Penguin mouse, the descriptive words were; comfortable, supportive, controllable, sleek, fast, adaptable, easy and precise; chunky, annoying, heavy, fiddly, jerky, clumsy and clunky.

For the Standard mouse, the descriptive words were: most common, familiar, easy, simple, comfortable, visual and basic; awkward, rough, heavy, hard, tiring, bulky, boring, old fashioned.

Question 10: From the three mice, which one do you prefer? And what do you prefer about it and why?

The majority preferred the Evoluent mouse (58% respondents). This was because they felt it was fast in movement (sensitive) and because it was a sensitive mouse, they did not need to move their arm much; it was quick to respond. It also positioned their hand in a more natural position. It was less tiring and there was no restraint in the hand; it was precise and comfortable. Furthermore, it was easy to use and easier to adapt to once the position of the right click was mastered. They preferred this mouse because it glided along the surfaces smoothly.

One participant stated: “After a week of using it, I would use it myself at home”. Another participant stated: “Once you are familiar with it, it is easy to use, smooth and efficient”.

The Penguin mouse came in second place (26% respondents). Some participants preferred this mouse because it was more supportive to the hand, comfortable, and not as sensitive as the Evoluent mouse and also because it had a good shape and the buttons were accessible. It allowed a relaxed posture to the arm and was smooth in movement and became easier to operate with time.

One participant stated: “After this experiment, I prefer the Penguin mouse because it is the most relaxing for me and it does not need many movements considering the position of the buttons”.

In total, the Standard mouse was the least preferred; just 16% respondents preferred this mouse because of its familiarity and its ease of use.

One participant said: “I prefer this mouse just because it is the old one”.

Question 11: Is there any other feedback you would like to give me that we have not covered?

The 50 participants stated that every aspect was covered, and they only gave a little information about each mouse used.

With the Evoluent mouse, 100% respondents stated that it was more difficult to do the right click because they needed to use their ring fingers. Some participants stated that it had a slippery surface because of the shiny material and it would be less slippery if it used a non-shiny material.

With the Penguin mouse, some participants stated that it was difficult to do the left click and they felt this type of mouse design was more suitable for computer games rather than personal computer use. Some participants felt that the rubber handle made this mouse very comfortable to grab and to hold the hand around the mouse. However, some participants felt the rubbery material made this mouse more slippery to hold and their fingers were very sweaty and stuck to the buttons a lot.

With the Standard mouse, some participants felt some aching in the thumb and wrist when using it.

5.9.6 Key findings from the final study results

5.9.6.1 In static posture measurements

1. The wrist extension was significantly greater with the Evoluent mouse than the other mice.

2. With wrist radial/ulnar deviation, the wrist posture was significantly different with the Standard mouse than the other two mice. The Standard mouse positioned the wrist into ulnar deviation, and the other mice positioned the wrist into radial deviation.

5.9.6.2 Maximum joint positioned achieved

1. The wrist extension was significantly greater with the Evoluent mouse than the other mice.

2. With wrist radial/ulnar deviation, the wrist posture was significantly different with the Standard mouse. The Standard mouse positioned the wrist into ulnar deviation, and the other mice positioned the wrist into radial deviation.

3. The elbow flexion was significantly greater with the Penguin mouse. However, it was significantly lower with Evoluent mouse.

5.9.6.3 EMG

1. The average and maximum voltage of wrist extensors and flexors increased with the Standard mouse.

2. The maximum voltage of biceps increased with the Penguin mouse. However, the average voltage of triceps and wrist extensors decreased with the Penguin mouse.

3. The average voltage of triceps increased with the Evoluent mouse. However, the average voltage of brachioradialis and wrist flexors, and the maximum voltage of wrist extensors decreased with the Evoluent mouse.

4. The Evoluent and Penguin mice were similar and there was no clear difference between them.

5.9.6.4 RULA

1. The mean rank of the Standard mouse was the highest in ranking. Possibly this mouse allowed further deviation from the neutral position.

2. The Penguin mouse had the lowest average Grand score (Score = 2). This could mean that the other mice may cause a deviation in posture.

3. By taking the mean in each part of the body from RULA:

    a. There was no cause for concern with the Penguin mouse (mean = 1 in each part of the body).

    b. There was a cause for concern with the Evoluent mouse. Posture deviated in neck and trunk.

    c. There was a cause for concern with the Standard mouse. Posture deviated in all parts of the body.

5.9.6.5 Usability Questionnaire

1. The Evoluent mouse was significantly more comfortable than the other two mice, and the Standard mouse was significantly the easiest in terms of pressing the buttons.

2. The majority preferred the Evoluent mouse as the most preferred mouse design (58% respondents).

5.10 Discussion

5.10.1 Static posture

In this section, the discussion concerns the static posture results, with the aim to compare the three mice designs on the static posture of the elbow and wrist joint at rest. The results were interpreted in relation to its starting position, the neutral position, as an absolute zero and were compared to the normal ROM value. Thus, a mouse that positioned the joint into the mid-ROM or less than the mid-ROM might be the mouse promoting musculoskeletal health. In this study, the neutral position was when the participants' arm rested flat on the desk.

It was found that the static posture with both the Evoluent and Penguin mice was the same at rest. They typically positioned the wrist into extension and radial deviation, and the elbow into flexion. However, the Standard mouse positioned the wrist into extension and ulnar deviation, and the elbow into flexion. The results from a 1-way repeated measure ANOVA found that there was a significant difference between the three mice designs on the static posture of wrist flexion/extension and radial/ulnar deviation ($p < 0.05$) suggesting that mouse design affected the static posture of the wrist. The findings from this study were consistent with the findings from Keir et al. (1999), who found a significant difference with mouse designs and wrist posture ($p < 0.05$). Overall, the vertical mouse led to a more neutral position of the wrist during the task, and a more radial posture in the static position ($p < 0.05$) (Keir et al., 1999).

It was found that the wrist extension associated with the Evoluent mouse was significantly greater than the other two mice used in this study (Evoluent 37.6˚ $\pm$ 12.7˚; Standard 28.1˚ $\pm$ 9.34˚; Penguin 24.2˚ $\pm$ 11.8˚). The wrist extension was more than the mid-ROM of about 2˚ with the Evoluent mouse. The normal ROM of wrist extension equalled 70˚ (Moroz, 2017). This meant that it could hold the wrist in a tensed posture, which could then lead to WRMSD in the long run. Also, if it remained in a specific posture for a longer duration, this might be associated with deviating the wrist into the end or extreme ROM and this could mean a greater risk of injury because of increased static load on the forearm (Flodgren et al., 2007).

With regard to wrist radial/ulnar deviation, the wrist posture with the Standard mouse was significantly different from the other two mice. The Standard mouse positioned the wrist into ulnar deviation (1.33˚$\pm$8.81˚), and the other mice positioned the wrist into radial deviation (Penguin 8.92˚±9.81˚; Evoluent 5.02˚±9.88˚). It was found that the amount of ulnar deviation with the Standard mouse was very small, less than the mid-ROM. The ROM of ulnar deviation is typically between 30˚-50˚ (Moroz, 2017). Several studies (Cook et al., 2000; Ortiz-Hernandez et al., 2003) found a greater risk of WRMSD with those participants adopting an uncomfortable position of the forearm. Mouse users adopted a particular working posture of wrist pronation, extension and ulnar deviation, whilst performing a computer task, which could lead to musculoskeletal disorders such as Carpal Tunnel Syndrome (CTS) and repetitive strain injury (RSI) (Cook et al., 2000; Ortiz-Hernandez et al., 2003). In this study, it was found that the Standard mouse typically positioned the wrist into extension and ulnar deviation at rest, which could lead to increased risk of WRMSD, according to the findings from the Cook et al. (2000) and Ortiz-Hernandez et al. (2003) studies.

However, the Evoluent mouse was associated with the smallest amount of radial deviation in the wrist when compared with the Penguin mouse. Even though the Penguin mouse positioned the wrist into more radial deviation than the Evoluent mouse, the amount of radial deviation found with the Penguin mouse was in the mid-ROM; normal ROM of wrist RD = 20˚ (Moroz, 2017). In this context, this did not cause any concern and could possibly mean that the Penguin mouse might be associated with a more relaxed, neutral wrist posture at rest. Also, this could prevent or minimise the risk of injuries with computer mouse users.

After reviewing the literature and the results from this study, two factors might be associated with increasing the risk of injury at rest. First, for the awkward sustained posture, it seems that an awkward sustained posture occurred if there was a deviation from the ideal working posture of the arm, away from neutral position. The more the joint departed from the neutral position, the greater the likelihood of musculoskeletal injuries (Carey and Gallwey, 2002) because keeping the arm in a tensed, fatiguing position whilst holding the computer mouse led to a co-contraction of the muscles, increasing the force applied on the tendon; then microtrauma would occur within the tendon, followed by tendinitis. Second, when the wrist posture is on ulnar deviation, for this factor, from the static posture results, a concern might be raised with the Standard mouse because it positioned the wrist into ulnar deviation. Although the amount of ulnar deviation was less than the mid-ROM, two studies were found whereby adopting the wrist into pronation, extension and ulnar deviation increased the likelihood of injury with computer mouse users (Cook et al., 2000; Ortiz-Hernandez et al., 2003). Moreover, a concern might be raised with the Evoluent mouse because it deviated the wrist into extension more than the mid-ROM. A study by Carey and Gallwey (2002) showed that moving the joint into mid-ROM was safer than moving the joint into an extreme ROM, since moving the joint into mid-ROM promoted a more relaxed posture around the neutral position. This then could promote musculoskeletal health.

5.10.2 Maximum joint position achieved

In this section, the discussion concerns the maximum joint position achieved results, with the aim to compare the three mice designs on the maximum joint position achieved of the elbow and wrist whilst performing the task. This would help to understand how far the wrist and elbow moved from the anatomical neutral position and give an insight into which mouse design moved the wrist and elbow away from the neutral position. The result interpretations were the same as explained in section 5.10.1 in that it would be in relation to its starting position, the neutral position. Thus, a mouse that moved the joint into the mid-ROM or less than the mid-ROM might be the mouse that promotes musculoskeletal health.

It was found that the pattern of the movement whilst participants performed the task was the same as at rest when holding the mouse. The wrist posture with the Evoluent and Penguin mouse was into extension and radial deviation, and the elbow posture was into flexion. With the Standard mouse, the wrist posture was into extension and ulnar deviation, and the elbow posture was into flexion.

The results from a 1-way repeated measure ANOVA found that there was a significant difference between the three mice designs on the maximum joint position achieved for wrist flexion/extension, wrist radial/ulnar deviation and elbow flexion/extension ($p < 0.05$). This meant that the mouse design influenced the maximum joint position achieved of the elbow and wrist. The findings from this study were consistent with the findings from Keir et al. (1999) in that there was a significant difference between mouse design on wrist posture and movement. It was found that the vertical mouse led to a more neutral position of the wrist during the task ($p < 0.05$).

First, with regards to wrist F/E, it was found that the wrist extension was significantly greater with the Evoluent mouse than the other mice tested in this study (Evoluent $43.0^{\circ} \pm 11.9^{\circ}$, Penguin $35.4^{\circ} \pm 13.8^{\circ}$, Standard $35.5^{\circ} \pm 8.67^{\circ}$). The amount of wrist extension was more than the mid-ROM of about 8˚ (normal ROM of wrist extension equalled 70˚) (Moroz, 2017). This meant that the Evoluent mouse moved the wrist away from the anatomical neutral position because moving the joint into more than the mid-ROM meant moving the joint away from the neutral position and this increased the likelihood of injury. This was consistent with a systematic review by You et al. (2014), who found nine studies that showed that the relative risk of work-related CTS increased with increasing hours of exposure to wrist deviation either in extension or flexion ($p < 0.01$).

Second, for wrist RD/UD, it was found that the wrist posture with the Standard mouse was significantly different from the other mice. It positioned the wrist into ulnar deviation ($0.507^\circ \pm 14.5^\circ$), while the other two mice positioned the wrist into radial deviation (Evoluent $5.17^\circ \pm 13.4^\circ$; Penguin $3.95^\circ \pm 14.0^\circ$). The Standard mouse moved the wrist into a small amount of UD. However, as stated in the discussion of the static posture in the studies by Cook et al. (2000) and Ortiz-Hernandez et al. (2003), a mouse design found to adopt a working posture of wrist pronation, wrist extension and UD could lead to an increased risk of RSI and CTS.

The maximum radial deviation was found with the Evoluent mouse when compared with the Penguin mouse. Although the Evoluent mouse had the maximum radial deviation, it was less than the mid-ROM of radial deviation (normal ROM of RD = 20°) (Moroz, 2017). In this context, this did not give any cause for concern. Hedge et al. (2010) found less ulnar deviation with the Evoluent mouse during a cursor positioning task when compared with three vertical mice and a Standard mouse. This was because the ulnar surface of the hand was close to the work surface when using this mouse, giving little opportunity for ulnar deviation, which could keep the hand in a more neutral position (Hedge et al., 2010). Therefore, it could minimise the risk of WRMSD (Hedge et al., 2010). In this study, both the Evoluent and Penguin mice moved the wrist into radial deviation.

It should be mentioned that the Penguin mouse was the only mouse design that kept the wrist joint closer to the anatomical neutral position in both movements of extension and radial deviation. This could possibly mean that the Penguin mouse could promote musculoskeletal health because the Penguin mouse might be associated with a more relaxed and neutral wrist posture whilst performing a computer task.

Gustafsson and Hagberg (2003) and Houwink et al. (2009) found less wrist extension and ulnar deviation with a vertical mouse when compared with the Standard mouse. Gustafsson and Hagberg (2003) also found that the level of exertion increased when using the Standard mouse ($p < 0.05$). Both studies found that the vertical mouse could have a better effect on the posture of the forearm when compared to the posture of the forearm using a Standard mouse because the vertical mouse could promote a more neutral position of the forearm (Gustafsson and Hagberg, 2003; Houwink et al., 2009). Therefore, this could promote musculoskeletal health (Gustafsson and Hagberg, 2003; Houwink et al., 2009).

Third, for elbow flexion/extension, it was found that elbow flexion was significantly increased with the Penguin mouse and significantly decreased with the Evoluent mouse (Penguin$13.7^{\circ} \pm 20.7^{\circ}$; $\text{Evoluent } 6.70^{\circ} \pm 14.5^{\circ}$; $\text{Standard } 8.66^{\circ} \pm 20.2^{\circ}$). Even though the Penguin mouse positioned the elbow into more flexion than the other mice, it was less than the mid-ROM (normal ROM of elbow flexion = 150˚) (Moroz, 2017). In this context, this did not give any cause for concern.

After reviewing the literature, it was found that a mouse design that deviated the joint away from the neutral position could increase the musculoskeletal symptoms such as pain and muscle fatigue and then lead to an increased risk of WRMSD (Cook et al., 2000; Carey and Gallwey, 2002). This was because the more the joint deviated from the neutral position, the more risk there was towards WRMSD because when the arm is moving into the extremes of joint ROM, this increased the risk of injury more than moving the arm at mid-ROM. This could be due to the joint being in an at-risk position or in an unbalanced position (far away from the neutral position). This would lead to increased stress on the joint and muscles. Then muscle-tendon fatigue and strain could occur (Aarås et al., 2002; Delisle et al., 2004; Flodgren et al., 2007; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). This would also be because of repetitive movements of the forearm and prolonged duration of computer and mouse use (Aarås et al., 2002; Delisle et al., 2004; Flodgren et al., 2007; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999).

After reviewing the literature and the results from this chapter, possibly the ideal scenario to minimise the risk of WRMSD in a clinical setting would be by using a mouse that kept the joint posture around or close to the neutral position whilst performing the task, meaning that a mouse that moved the joint into the mid-ROM or less than the mid-ROM might be the mouse promoting musculoskeletal health. Because of this, concerns were raised with the Evoluent and Standard mice when using this study data because the Evoluent mouse moved the wrist outside the mid-ROM of wrist extension, and the Standard mouse positioned the wrist into ulnar deviation, although the amount of UD was small. These findings and concerns were the same findings and concerns with the static posture. This could possibly mean that both the Evoluent and Standard might be associated with a tensed, non-neutral wrist posture at rest and during movement, and that might increase the risk of WRMSD.

5.10.3 Average and Maximum voltage of the EMG data

In this section, the aim was to compare the three mice designs on the average and maximum voltage of the biceps, triceps, brachioradialis, wrist flexors and wrist extensors. This would help to know whether any significant differences could be found in the average and maximum voltage with each muscle while using three different mice. Also, this would help to see the patterns of muscle activity when comparing the use of the different mice.

For EMG analysis, multiple variables have often been interpreted together to determine the physiological nature of the muscles (Smoliga et al., 2010). As stated in Chapter 4, the average voltage was measured because it represented the amount of work the muscles did across a time. The average would give an idea of the underlying muscle activity (De Luca, 1997). The maximum voltage would simply be the highest recorded EMG value in any given time period and often taken to be a good indicator of the size of force (De Luca, 1997). In addition, those EMG variables (maximum and average voltage) were found to be reliable from the preliminary study in Chapter 4 and could be used for a clinical decision. If EMG variables which are not reliable are used, the measurements taken could be erroneous and may lead to inaccurate clinical decisions (Smoliga et al., 2010). By choosing a reliable EMG variable for a given muscle, clinicians could make more accurate decisions when utilising EMG for diagnostics decisions (Smoliga et al., 2010), the reason why the results of the average and maximum voltage were looked at together to generate a better understanding of the muscle activity.

The analysis results from a 1-way repeated measure ANOVA for the average voltage found a significant difference in the average voltage of triceps, brachioradialis, wrist flexors and wrist extensors ($p < 0.05$). Regarding the maximum voltage, it was found that there was a significant difference with biceps and wrist extensors ($p < 0.05$), meaning that mouse design influences the EMG data. Those results were consistent with the findings of Tittiranonda et al. (2000) in that there was a significant difference between input device and muscle activity. The study showed an increase in muscle activity of the flexor digitorum superficialis (FDS), extensor carpi ulnaris (ECU), extensor indicis prorius (EIP) and upper trapezius (UT) when using the Standard mouse compared to other input devices in their study. Also, the Standard mouse tended to create higher loads on the upper trapezius and ECU, leading to increased shoulder elevation and wrist ulnar deviation.

In this study, it could be seen that the results were divided between significant difference and non-significant difference for the average and maximum voltage. The main reason for the conflicting reasons could be as stated in Chapter 4 section 4.11.4, in that this study explored different mice designs, and this might have caused these changes in the muscle activity.

With the average and maximum voltage results with the Penguin mouse, it was found that the average and maximum voltage of biceps increased with the Penguin mouse. In contrast, the average and maximum voltage of triceps decreased with the Penguin mouse. Also, the average voltage of wrist extensors decreased with the Penguin mouse.

With the Evoluent mouse, it was found that the average and maximum voltage of triceps increased with the Evoluent mouse. However, the average and maximum voltage of brachioradialis and wrist flexors decreased with this mouse. Also, the maximum voltage of wrist extensors was decreased with the Evoluent mouse.

With regards to the Standard mouse, it was found that the average and maximum voltage of wrist extensors and flexors, and the average voltage of Brachioradialis increased with the Standard mouse.

To know which mouse design could increase the risk of WRMSD and lead to pathology, related to the mice used, the researcher looked to the results from the movement data and EMG data and looked at several studies that mentioned how injury occurred with computer mouse users. She understood that using a mouse design would require the computer users to make small exact movements with their hand, fingers and thumb. Also, to perform the task, computer users needed to position their hands, scrolling, travelling and clicking the mouse several times. This would require using the same muscles and these muscles could become overworked and tired. This overuse could lead to pain on the elbow and wrist; numbness and tingling sensations could occur in the thumb and index finger, as well as stiffness and a restricted range of motion (Phinyomark et al., 2012; Tittiranonda et al. 2000).

It was found that the problem with the computer mice users is increased wrist extension activity, as discussed in sections 5.10.1 and 5.10.2. Increases in wrist extension movement would increase the wrist extensors activity and would be clinically important. Using the data from this study indicated that the Standard mouse might increase the risk of injuries because the average and maximum voltage of wrist extensors increased with the Standard mouse.

Increases in the average and maximum voltage of wrist extensors could increase the risk of WRMSD in the long run with computer mouse users. This could then lead to tendonitis in the elbow and wrist. An example of tendonitis in the elbow would be a tennis elbow, also called lateral epicondylitis, an injury characterized by pain at the outer aspect of the elbow and indicating tendon inflammation due to overuse of the forearm extensor muscles; the extensor carpi radialis brevis (ECRB) muscle (McMurtrie and Watts, 2012; Waugh, 2005). The overuse of the ECRB would be associated with repetitive wrist extension. When inflammation occurred, microscopic tearing with scar formation at the origin of the ECRB muscle tendon would occur (Waugh, 2005). This would then lead to a mucoid degeneration, fibrinoid necrosis in tendons and proliferation of fibroblasts (Waugh, 2005).

In addition, wrist tendinitis could occur with computer users. Wrist tendinitis, also called tenosynovitis, a condition characterized by irritation and inflammation of the tendons around the wrist joint, occurred due to repetitive hand movements which could stress the tendons that attach hand and arm muscles to the bone (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). This would then lead to overworking the tendons which, in turn, might lead to tears and irritations occurring. In the long run, tendinitis could progress to CTS because the swelling from tendinitis can end up causing carpel tunnel problems, since the swelling can put pressure on the medial nerve (Lublin et al., 1998; Zetterberg and Ofverholm, 1999). Because of that, any compression to the median nerve could cause atrophy, weakness in these muscles, and sensory loss in the fingers supplied by this nerve (Lublin et al., 1998; Zetterberg and Ofverholm, 1999).

According to the literature, a mouse that allowed less average voltage and/or maximum voltage could be the mouse that could reduce the risk of pathology, consistent with the findings from Chen and Leung (2007) in that the muscle activity of ECU decreased as the slanted angle of the mouse increased and the results were significant ($p < 0.05$) compared to a Standard mouse. This could minimise the risk of WRMSD (Chen and Leung, 2007).

In contrast, a mouse that increased the average voltage and/or maximum voltage would be likely to cause pathology, consistent with Tittiranonda et al. (2000), Szeto and Lin (2011), and Nur et al. (2015). The Tittiranonda et al. (2000) study found increased muscle activity of FDS, ECU, EIP and UT when using a Standard mouse compared to other input devices in their study. Also, they found that the Standard mouse tended to create higher loads on the upper trapezius and ECU, leading to increased shoulder elevation and wrist ulnar deviation. Moreover, Szeto and Lin (2011) found an association between higher muscle activity and the level of discomfort; when muscle activity increased, the level of discomfort would increase, and this could be a sign of muscle fatigue. Also, persistent fatigue could promote muscle damage. Nur et al. (2015) showed that when muscle activity increased whilst performing the task, this could indicate muscle fatigue, thus indicating an associated higher risk of WRMSD.

After reviewing the literature and the EMG results from this chapter, it could be possible that the mouse design with less average voltage and or less maximum voltage would be the mouse that could reduce the risk of WRMSD. This pattern of activity could be seen with the Penguin and Evoluent mice because the Penguin mouse decreased the average voltage of the wrist extensors and the Evoluent decreased the maximum voltage of the wrist extensors. Furthermore, the mouse that increased the average voltage and/or increased the maximum voltage would be the mouse that could increase the risk of WRMSD. This pattern of activity could be seen with the Standard mouse because it increased the average and maximum voltage of the wrist extensors.

It could be important to measure muscle fatigue to know whether or not the experimental task could cause fatigue. However, it was believed that the experimental task could not lead to muscle fatigue This was because it was a low intensity task; the mice designs were light in weight. Also, there was a short duration to perform the task; it took up to 10 minutes with each mouse design. Furthermore, the researcher allowed for many breaks.

To measure muscle fatigue, the raw EMG data measurements should be saved in a data link format to calculate median frequency. Median frequency calculations would help to show evidence of fatigue or not whilst performing the experimental task. In this study, the raw EMG data were saved as a text document, the right format to be used with Matlab software. Because of this, the researcher was not able to calculate muscle fatigue. Also, the idea of checking muscle fatigue came after the data collection and when all the processing and analyses were made.

5.10.4 Rapid Upper Limb Assessment (RULA)

In this section, the discussion concerns the results from RULA, presented in Tables 5.4 and 5.5. The researcher wanted to know whether there was a significant difference in the overall sitting posture whilst using three mice designs: Standard, Penguin and Evoluent mice. This was to give an insight into which mouse design would keep the posture maintained in a more neutral position, such as maintaining the wrist and elbow in a neutral position, in the midline of the body; also, maintaining the neck between 0° and 10° flexion without twisting or side bending, as well as keeping the trunk in a neutral position without twisting or side bending (Dockrell et al., 2012).

RULA was used in the middle of the experiment (Task 3) whilst performing the task with each mouse design. It was preferable to take RULA measurements in Task 3 because the researcher felt that when the participants reached the middle of the experiment, they would feel comfortable and confident in performing the task and in using each mouse design.

The results from Friedman's ANOVA found a significant difference in the overall sitting posture with the three mice designs used ($p < 0.001$). From the Pairwise Comparison, it was found that the significant difference was between the Evoluent and Standard mice ($p < 0.001$), and between the Penguin and Standard mice ($p < 0.001$). This meant that the working posture was significantly different with the Standard mouse from the other two mice. Also, it indicated that mouse design had an influence on the overall sitting posture. Furthermore, from the results of Friedman's ANOVA, it was found that the mean rank of the Standard mouse was the highest in ranking (mean = 2.70). Possibly, this mouse allowed further deviation of the overall posture from the neutral position.

By looking at the results from the average Grand score, it was found that the Penguin mouse had the lowest average Grand score (Score = 2). This could mean that the other mice may cause a deviation in the posture. Score 2 meant that there was a low risk in the overall posture and the work posture was acceptable.

By looking to the results from taking the mean in each part of the body from RULA, it was found that there was no cause for concern with the Penguin mouse (mean = 1 in each part of the body). This meant that there was no posture deviation away from the midline position in each body part. However, there was a cause for concern with the Evoluent mouse because the posture deviated in the neck and trunk (mean = 2 in the neck and trunk). This meant that the neck was either flexed by 0˚-10˚ with twisting or side bending, or the neck was flexed by 10˚-20˚. The trunk was either flexed by 0˚-20˚ or in no flexion but with twisting or side bending.

Moreover, there was a cause for concern with the Standard mouse because the posture deviated in all parts of the body. In the upper arm, the mean = 2 and this meant that the shoulder was extended by more than 20˚ or the shoulder was flexed between 20˚-45˚.The mean in the lower arm = 2 and this indicated that the elbow was flexed by less than 60˚ or more than 100˚ or the elbow was flexed by 60˚-100˚ and the working posture was outside the midline of the body. The wrist posture (mean = 3) was extended or flexed by more than 15˚. Also, the wrist was twisted at or near the end of twisting range (mean = 2). The neck was either flexed by 0˚-10˚ with twisting or side bending, or the neck was flexed by 10˚-20˚ (mean = 2). The trunk was either flexed by 0˚-20˚ or in no flexion but with twisting or side bending (mean = 2). Also, the legs and feet were not well supported and not in an evenly balanced posture.

RULA was an easy tool to use and it was believed that RULA was able to pick up changes in the overall posture. It was found in Dockrell et al. (2012) and Hixson (2006) that RULA was an effective tool to be used as part of ergonomic assessment to check whether the participants' posture was at risk whilst performing the task and as an observation method of posture analysis.

Furthermore, Meksawi et al. (2012) showed that RULA can be considered a useful tool to assess different body parts. It would show any ergonomic risk factors related to work posture by allocating a RULA score to each body part, and by using a RULA Grand score, it would have the ability to show whether the work habits of each worker needed to be changed immediately or not. This was consistent with the study of Kee and Karwowski (2007) and Meksawi et al. (2012) in that RULA had a Grand score that could help in indicating whether the working posture was acceptable or required immediate change.

RULA was found to be the most appropriate tool for assessing risk regarding WRMSD when sitting at a desk (Kee and Karwowski, 2007). A study by Kee and Karwowski (2007) compared three different observational tools, RULA, Ovako Working Posture Analysis System (OWAS) and Rapid Entire Body Assessment (REBA), for assessing posture in 301 manufacturing industry workers. This study resulted in that it would be more advantageous to use RULA to assess working posture because it tended to overestimate the potential risks factors of WRMSD, unlike OWAS and REBA, which tended to underestimate the postural risks.

Although RULA was an easy tool, it was found from the literature that it was a reliable and valid tool (Dockrell et al. 2010; McAtamney and Corlett 1993). Also, RULA could be used without the need for any additional equipment and without the need for training (Chen et al., 2013, Dockrell et al., 2012; McAtamney and Corlett 1993). This was consistent with the results from Chen et al. (2013) in that there was no significant difference in the mean grand RULA score and action level between novice and experienced assessors.

In conclusion, the results from RULA showed that the Standard and Evoluent mice may raise a cause for concern because they deviated the posture away from the neutral position. This could increase the risk of WRMSD. Maintaining this overall posture for the workday could cause extra load on the muscles and allow a tensed posture of the forearm and then fatigue could develop. However, the Penguin mouse was found to be the mouse that kept the posture close to the midline position. In this study, the midline position was considered as the safe distance range for comfortable hand movements with computer users. This would then promote musculoskeletal health and prevent from pathology with the computer users.

5.10.5 Questionnaire

In this section, the discussion concerns the results from the quantitative and qualitative questions from the usability questionnaire. The quantitative questions were to help the participants choose the response that best represented their opinions on and degree of satisfaction with each mouse design. This would help to know if there was a significant difference in the participants' response with each mouse design by carrying out further analysis: Friedman's ANOVA test. The Friedman's ANOVA test would help to see whether there was a genuine preference from one mouse design over another in one sample. The qualitative questions would help to have a better perception of each participant's true feelings on each mouse design.

The results from Friedman's ANOVA found firstly that there was a significant difference between the Standard, Penguin and Evoluent mice in terms of how comfortable they were to use ($p < 0.01$). It was found that the significant difference was between the Evoluent and Standard mice ($p < 0.01$), meaning that mouse design had an influence on participants' response with each mouse design in terms of how comfortable they were to use. The Evoluent mouse was found to be the most comfortable to use by 56% respondents. In contrast, the Standard mouse was the least comfortable to use, according to 48% respondents, in comparison with the other mice used.

The participants felt that the Evoluent mouse did not allow much arm movement and because of the way their fingers were placed on the mouse. Also, because of the sensitivity, they felt that the control was better; it was easy to glide on the desk and because of the thumb support due to the thumb rest area.

The participants felt that the Standard mouse did not fit to the shape of the hand as the other mice designs used. Moreover, they felt that it needed more arm movements and did not glide easily on a desk. Some participants stated that they felt pain at the end of the task with the Standard mouse and it caused discomfort. Also, it was difficult after using the other mice.

Second, the Friedman ANOVA results showed that from the 50 participants, pressing the mouse buttons significantly changed with the three mice designs ($p < 0.01$). However, Pairwise Comparison showed no significant difference between the Evoluent and Penguin ($p > 0.05$), the Evoluent and Standard ($p > 0.05$) and between the Penguin and Standard mice ($p > 0.05$). This could be because, as stated in section 5.9.5.1, referring to Question 5, the significant values were adjusted by the Bonferroni correction for multiple tests, as stated in Field (2016). Although there was no significant difference from the Pairwise comparison, most participants selected the Standard mouse as the easiest for pressing the buttons (25 responses), and the Evoluent mouse was selected as the least easy for pressing the buttons (11 responses).

The participants preferred the Standard mouse over the other mice used because of the familiarity with this type of mouse design. The Standard mouse was the most common mouse used with the 50 participants. They used it at home or at work or both. Because of that, they were already familiar with pressing the buttons. Some participants mentioned: "It is straightforward; there is no need to remind ourselves how to operate this mouse, and our reaction is quicker".

The reasons why the Evoluent mouse was least easy in terms of clicking was because the participants felt that the buttons were bigger and wider. Also, the right button was too far down, and they needed to use their ring fingers for the right click, which they were not used to. They thought they required more thought because of the right button position.

According to mouse preferences, 29 participants preferred the Evoluent mouse; 13 participants preferred the Penguin mouse; and 8 participants preferred the Standard mouse. This showed that the Evoluent mouse was the most preferred mouse and the Standard mouse was the least preferred mouse.

The researcher totally understood that there was a difference in the results from usability questionnaire data and from the parametric and non-parametric data. The majority preferred the Evoluent mouse. However, with the parametric data results and RULA, a concern was raised with the Evoluent mouse with wrist extension at rest and during movement because it positioned and moved the wrist outside the mid-ROM, which could then increase the risk of injury. Also, the Evoluent mouse deviated the posture of the neck and trunk outside the neutral position. Moreover, a concern was raised with the Standard mouse because it positioned the wrist into ulnar deviation. Although the amount of ulnar deviation was small, several studies mentioned that positioning the wrist into wrist pronation, extension and UD would increase the risk of injury because the combination of this working posture would allow a non-relaxed posture of the forearm. Also, with the Standard mouse, it was found that it deviated the posture outside the neutral position in each part of the body.

Even though the participants preferred the Evoluent mouse, that did not mean that this mouse design could prevent from pathology. They had the opportunity to be familiar with each mouse design, but they performed the main experimental task with each mouse within up to 10 minutes. Possibly, if the task had been longer in duration, their response about mice preference might have changed.

5.11 Limitations of the study

It would be better to take the range of motion measurements (ROM) prior to the experiment using a standard goniometer. This could help to see how much they normally flexed/extended their elbow and wrist and how much they normally did a radial/ulnar deviation and it could also help to compare their normal ROM with their working ROM whilst performing the task. Even with healthy participants, there might be a difference in the ROM from one healthy participant to another. The researcher assumed that their ROM in wrist and elbow were within the normal ROM because of the inclusion criteria of healthy participants with no musculoskeletal symptoms such as pain, spasm and stiffness, and with no musculoskeletal injury or surgery.

5.12 Conclusion

In conclusion, the aim of this study was to know how the design of a computer mouse influenced the posture, biomechanics and muscle activity of the forearm. It appeared that several factors could increase the risk of WRMSD with computer mouse users: first, when there was a posture deviation, forearm and overall body posture, away from the neutral position; second, when the wrist posture was on ulnar deviation; And third, when there was an increase in the average and or maximum voltage of wrist extensors. Because of this, a cause for concern was raised with the Evoluent and Standard mice.

The Evoluent mouse showed a cause for concern because wrist extension was significantly greater with this mouse both at rest and during movement. Furthermore, it deviated the neck and trunk posture away from the neutral position. Although the Evoluent mouse showed a cause for concern, most of the participants preferred this type of mouse design. The Standard mouse showed a cause for concern because it was the only mouse design that positioned the wrist into UD. It also deviated the overall posture in each body part away from the neutral position, and the average and maximum voltage of wrist extensors increased with this mouse. This could show that the Standard mouse might be the mouse design that might increase the risk of WRMSD in terms of movement and EMG data.

The Penguin mouse was found to show no cause for concern, possibly showing that the Penguin mouse might be associated with a more relaxed, neutral posture at rest and during movement. With regard to EMG data, it was found that there was no clear difference between the Evoluent and Penguin mice; they were fairly similar.

Finally, as exposure rates are high with mouse users, improving the upper extremity posture and the overall body posture while using the mouse is very important. This could be by choosing a mouse design with the right characteristics that could minimise or prevent the risk of injury. Those characteristics would be: a mouse design that allowed a relaxed posture of the forearm at rest and during movement by allowing less posture deviation; keeping and moving the joint into mid-ROM or less, maintaining the overall posture close to the neutral position, and less muscle activity would help to minimise the chance of injuries.

6 Chapter 6: Overall Discussion

6.1 Discussion

In this section, the discussion concerns all the key findings found from the preliminary studies (Chapters 2, 3 and 4) and from the main experimental study (Chapter 5) to generate a better understanding of how mouse design could affect the wrist and elbow posture, the overall sitting posture, the forearm muscle activity, and participants' preferences regarding mouse design. The section also examines whether a particular mouse design could increase or decrease the risk of WRMSD.

First, the discussion concerns WRMSD and gives an overview of injury as well as factors related to injury with computer mouse users. Second, there is a summary and conclusion from the previous preliminary studies (Chapters 2, 3 and 4). Third, the discussion relates to the answers to the four main questions of this overall research study. Finally, there is ergonomic guidance and tips for designing a computer workstation with suggestions to prevent WRMSD. To recap, the four research questions for this thesis are:

1. How does the design of a computer mouse affect the posture and movement of the elbow and wrist during typical use?

2. How does the design of the computer mouse influence the muscle activity of the forearm during typical use?

3. How does the design of the computer mouse affect the overall posture during typical use?

4. How does the design of a computer mouse affect the usability during typical use?

6.1.1 Overview of how musculoskeletal injury occurs

Before discussing the meaning of the results of this research, a complete understanding of the meaning of the musculoskeletal system, injury and how injury occurs should be acknowledged. Musculoskeletal systems include: bones, muscles, tendon, ligaments, cartilage, and nerves. Any injury to any of these structures is called a musculoskeletal disorder.

Results from several experimental and clinical studies specify that WRMSD occurs due to workplace and non-workplace factors that could increase the chance of injury (Blatter and Bongers, 2002; Cook et al., 2000; Fagarasanu and Kumar, 2003; Flodgren et al., 2007; Ortiz-Hernandez et al., 2003; Jensen et al., 2002; Ming and Zaproudina, 2003; Muller et al., 2010; Kaliniene et al., 2013; Ardahan and Simsek, 2016). Understanding these factors is the key to an effective early intervention and prevention of WRMSD. These factors are explained in Figure 6.1, and it is worth noting that the focus of this study is only on the physical workplace factors.

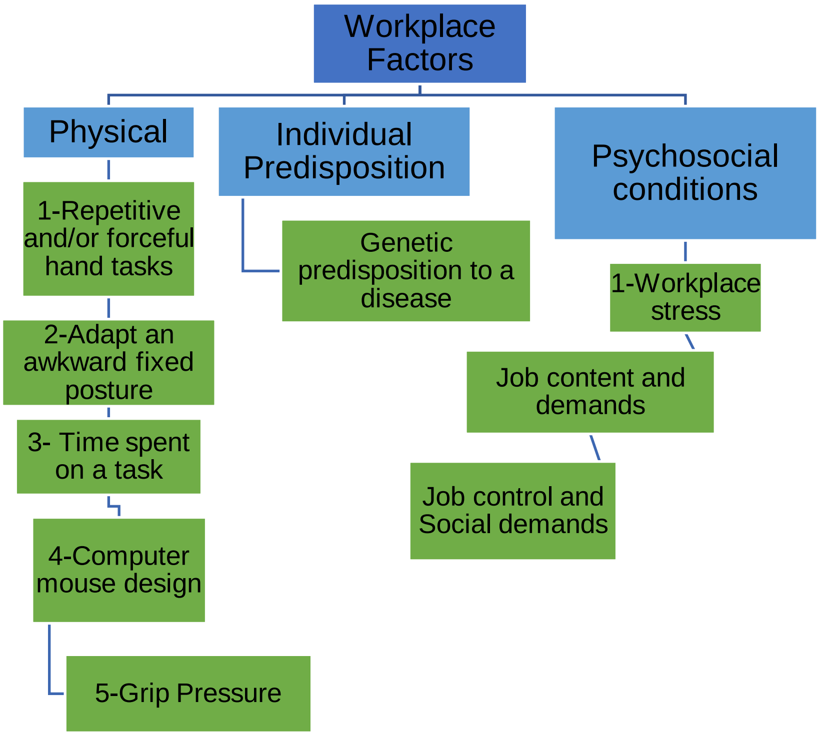


Figure 6.1 *Workplace factors associated with WRMSD (Source: Author's own).*

The pathophysiology of WRMSD is based on the soft and nervous tissues adapting to the stresses placed on them over time, and these stresses include tension, compression, impingement, vibration, and contraction. This then leads to mechanical and physiological fatigue within tendons, ligaments, neural tissue, and other soft tissue (O'Neil et al., 2001; Zetterberg and Ofverholm, 1999). Mechanical fatigue is defined as tissue disruption due to repetitions, and the physiological fatigue is defined as the depletion of energy supplies within the muscles (O'Neil et al., 2001; Zetterberg and Ofverholm, 1999). The main causes of WRMSD with computer mouse users are repeated manual tasks. A manual task can be defined as any activity that needs a person to use his or her musculoskeletal system to perform the work required (O'Neil et al., 2001; Zetterberg and Ofverholm, 1999) and includes any work that needs the use of force for lifting, pushing, pulling, carrying, moving and holding. Furthermore, it includes the work that involves repetitive movements and sustained awkward posture (O'Neil et al., 2001; Zetterberg and Ofverholm, 1999).

Ergonomically, these manual tasks can be hazardous when they include certain characteristics that increase the risk of injury. In general, ergonomic hazard lists of manual tasks are listed as follows:

1- Repetitive or sustained application of force.
2- Repetitive or sustained awkward postures.
3- Repetitive or sustained movement.
4- An application of high force occurs when users find the task difficult because of the effort required.

Understanding the underlying causes of the injury and risk factors could help to understand the meaning of the injury and assist in finding simple preventative manoeuvres to minimise the risk of WRMSD. Figure 6.2 illustrates the cycle of injury.

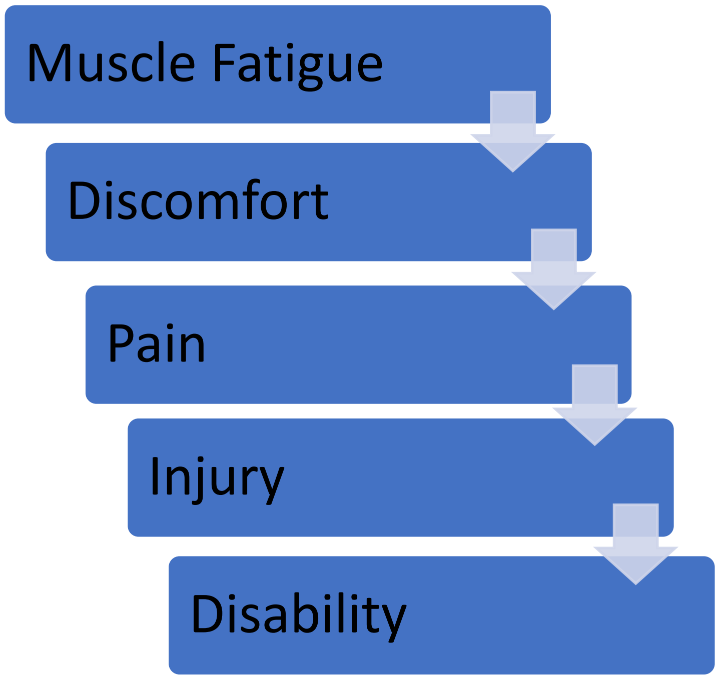


Figure 6.2 *The cycle of injury (Source: Author's own).*

When considering the ergonomics of computer mouse use as a manual task, the hazard list found in the previous paragraph can be considered. However, an application of high force as a risk cannot be linked with computer mouse use because using a computer mouse is a low intensity task. The hazards listed, relating to computer mouse use, are first, the repetitive or sustained application of force, with repetitive meaning using the force repeatedly over a period of time, and sustained, whereby maintaining the same position or making the same movement continually for a period of time. When using a mouse, repetitive use of muscles to produce stereotypical movements could lead to physiological fatigue of the muscles, which has been shown to increase risk of repetitive strain injury (RSI). Second is repetitive or sustained awkward postures which means when the whole body or any part of the body is in an uncomfortable or twisted position. The whole body twisted posture should be addressed by workplace design in terms of a decent chair with adjustable height, and a well-designed mouse. However, the mouse design may lead to local problems such as the sustained awkward posture of the wrist if they held towards the end range. Third is repetitive or sustained movement which means using the same parts of the body to repeat or to maintain the same movements over a period of time. Mouse use can lead to repetitive movements of the fingers and wrist joint, particularly with clicking and scrolling. These small repetitive movements could lead to joint pathologies due to mechanical fatigue of the joint and cartilage. This shows that repetitive movements are a feature of mouse use and it is a risk that increases the likelihood of injury.

Finally, there is prolonged duration of computer and mouse use (Blatter and Bongers, 2002; Cook et al., 2002; Jensen et al., 2002; Ortiz-Hernandez et al., 2003). This could be a prolonged duration of any computer action generally, which is prohibited in several studies and with a recommendation to take breaks to avoid the risk of injury (Blatter and Bongers, 2002; Cook et al., 2002; Jensen et al., 2002; Ortiz-Hernandez et al., 2003). Also, it could be a prolonged duration of sustained awkward posture which could increase the risk of injury. With a well-designed workspace and a well-designed mouse, this could support the arm in a position where prolonged duration of sustained awkward posture should not increase the risk of injury. However, some mouse designs could increase the risk of WRMSD.

In summary, after reviewing the literature and analysing the results of this research, the major factors worth consideration for the discussion are first, repetitive movements of the joint; second, repetitive movements of the muscles; third, positioning the forearm in a sustained awkward posture at rest, and in the working posture where the joint deviates away from the neutral position, i.e. more than the mid-ROM, and it could also be due to positioning the wrist into ulnar deviation. It could be attributed to increasing the ROM as this could be linked to deviating the joint away from the neutral position (Flodgren et al., 2007; Gustafsson and Hagberg, 2003).

The computer mouse size and shape could be other factors that leads to injury. The mouse designs used in this study were light in weight, but the shapes were different: two vertical and one pronated. The size and shape of the mouse could be important factors in positioning the forearm in a relaxed or tensed posture. Also, the size and shape of the mouse could affect the grip pressure. In this research, grip pressure was not measured since the focus of this research was joint movement and muscle activity, but it could be a component that leads to injury as if the mouse design does not fit the computer user's hand, it could lead to a forceful grip while holding the mouse. This will then bring about a co-contraction of the muscles, influencing the vascularisation and blood flow in the tendon (Finneran and O'Sullivan, 2013). Tendinitis could then occur. Furthermore, a forceful grip might be due to the user's habit in the way she or he grips and moves the computer mouse. Understanding the underlying causes and the anatomy of the site of injury could help to understand the meaning of the injury and assist in finding simple preventative manoeuvres to minimise the risk of WRMSD. It should be mentioned that mouse use might not lead to tearing or severely overstretching muscles directly. However, because mouse use is repetitive, it could be problematic in the long run and show that repetitive movement is a component that could lead to injury. Repetitive hand movements could lead to increased risk of injury such as carpal tunnel syndrome, as stated in You et al. (2014). Repetitive movements lead to increased pressure on the median nerve, which then leads to persistent tissue oedema. In turn, this leads to the obstruction of venous outflow and nerve compression, which brings about sensory loss, muscle atrophy and nerve ischemia (You et al., 2014).

In conclusion, these were the major factors that would increase the risk of WRMSD due to its major consequences with the musculoskeletal system, as discussed above.

6.1.2 Summary and conclusion of the previous preliminary studies

The aims of the previous preliminary studies were first, to investigate the validity of the measurement tools FASTRAK and Electrogoniometer in the measurements taken on the artificial rig at known angles, Second, to test the reliability of the range of motion data of the elbow and wrist joint, and the reliability of the forearm muscle activity whilst performing a computer hyperlink task, using three different computer mouse designs. Third, to determine the experimental set-up design to carry out the main experimental study to investigate the influence of three different computer mice designs on the posture, biomechanics of the elbow and wrist, and on the muscle activity of the forearm (biceps, triceps, brachioradialis, wrist flexors and wrist extensors).

The accuracy of both FASTRAK and Electrogoniometer were found to be comparable, according to the results from the validity pilot study in Chapter 2 with random errors of less than 0.2° at rest with both equipment, and 0.5° during movement with both equipment, and small systematic errors (the largest error being 3.86° undershooting at 0° with the Electrogoniometer, and the largest error being 0.34°overshooting at 20° with FASTRAK). Hysteresis (maximum hysteretic effect was at 10° = 2.92% with the Electrogoniometer, and was at 10° = 1% with FASTRAK), and equivalency (approximately, bias was close to zero with both pieces of equipment) were also comparable. Although both systems were comparable, the Electrogoniometer was found to be the easiest and most convenient to use and it was also a suitably reliable measurement tool.

Considering reliability, within-days reliability data was found to produce more repeatable measurements, according to SEM, when compared to between-days reliability data. This is because less variation was found in the measurements taken in the range of motion of the wrist and elbow and in the forearm muscle activity. This indicated that the measurements taken for future work should be done in one laboratory visit.

Following the early studies, it was concluded that it might be a good idea for the participants to use the mouse for some period of time by having extra time during the laboratory visit to get used to the process. This would help participants to adopt a comfortable posture and become more familiar in using the mouse. The reason for this is because it takes time for a computer user to adopt a normal working posture whilst performing a task using a computer mouse. Also, it would help them become more confident and relaxed and build a technique in using each different mouse design.

In addition, it was found that it would be better for the main experimental work to look at other variables such as looking at posture to capture the differences in the posture of the forearm while using different mice. This is because the ROM might not be a valid variable because it did not address the issues related towards the end range.

6.1.3 Question 1: How does the design of a computer mouse affect the posture and movement of the elbow and wrist during typical use?

Computer tasks have been commonly linked to the development of WRMSD (Donoghue et al., 2003). The position and the movement of the elbow and wrist joints could play an important role in the development of upper extremity disorders (Nordander et al., 2013). To understand the effects of computer mouse use on the upper limb posture, it is important to identify the movements involved while participants perform a computer task (Donoghue et al., 2003). To answer this question, three variables were chosen to check the effect of mouse design on the forearm posture and movement: first, the variations between the measurements (magnitude of SEM); second, static posture (static joint position of the wrist and elbow); and finally, the maximum joint position achieved.

For the first variable, in terms of variations (magnitude of SEM), there was no definitive outcome from the analysis of the SEM results between the three mice designs with the ROM data. This is because one mouse design could show higher variability in wrist movements and lower variability in elbow movements and vice versa.

When interpreting the magnitude of SEM, less variation implies a more consistent range of motion. This means that the participants were repeating the same movement every time, whether the task was performed with a large or small range of motion. There is evidence which suggests that moving the hand in precise stereotypical movements every day could lead to WRMSD (Bastani and

Jaberzadeh, 2012; Clark et al., 2016). Usually, stereotypical movements are indicated by lower SEM. According to the SEM results, it could be seen that mainly, the Evoluent mouse had the least variation in the range of movement of wrist flexion/extension and wrist radial/ulnar deviation. Also, the least variations were also found with the Penguin and Standard mice, but only in the measurements taken for elbow flexion/extension.

Individuals who perform repetitive stereotypical movements have been found to be at high risk of developing WRMSD (Cappell, 2006). This is due to mechanical stress at specific joints or tendons (Cappell, 2006), which could lead to Carpal tunnel syndrome, tennis elbow and DeQuervain's syndrome. Repetitive stereotypical movements mean a constant loading pattern within the tendon and the muscles, and because it is repetitive, which can then lead to micro-failure and chronic inflammation (Waugh, 2005). This could also lead to muscle and tendon damage, fatigue within the tendons, ligaments, neural tissue and other soft tissues and then an increased risk of overuse injury (O'Neil et al., 2001; Reilly,1995; Zetterberg and Ofverholm, 1999).

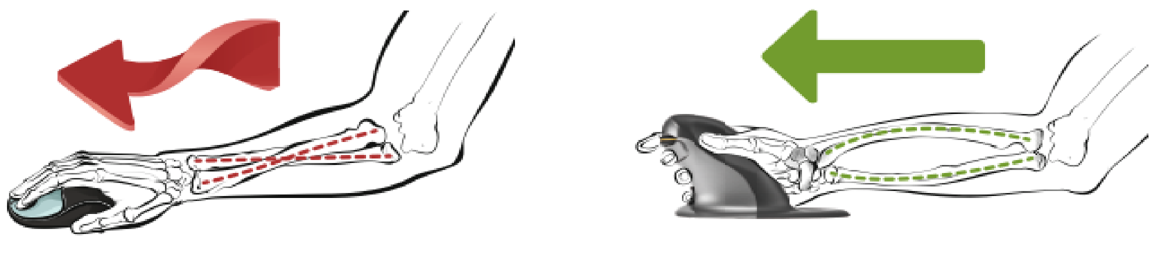
Within joints, it was found that higher variability in kinematics measurements tends to result in a healthier state, while a lower variability is the pathological state (Hamill and Emmerik, 2012). This is because low variability in joint movements causes forces to be constantly distributed across the same small surface area, which may result in overuse of a particular tissue or joint structure (Hamill and Emmerik, 2012). This possibly results in an overuse injury (Hamill and Emmerik, 2012). It was hypothesised that lower variability might be a characteristic of a disease or a dysfunction in a performance (Hamill and Emmerik, 2012). On the other hand, higher variability in joint movements allows the tissue or joint forces to be distributed over a larger area, thereby reducing the chance of having an overuse injury (Hamill and Emmerik, 2012). The findings from the Hamill and Emmerik (2012) study are consistent with the findings of Farana et al. (2015), who stated that higher variability in the elbow joint movement leads to wider distribution of loads between different tissues. This possibly reduces the loads on internal structures of the joint and then reduces the risk of injury. Movement variability can play an important and functional role in the performance of any task (Farana et al., 2015). Understanding the nature of variability of biological systems whilst performing the task can deliver very useful information related to the risk of injury (Farana et al., 2015).

For the second variable, static posture measurements, the results for static joint position of wrist and elbow when using the different mice were compared. This variable was chosen because it would give an insight into how each mouse design positioned the forearm, whether in a relaxed posture or in an awkward sustained posture. From the static posture results, a concern was raised with the Standard and Evoluent mice. The Standard mouse positioned the wrist into ulnar deviation. With the Evoluent mouse, the amount of wrist extension was more than the mid-ROM. This could show that both the Evoluent and Standard mice might be associated with positioning the wrist into a fatiguing, non-neutral posture at rest.

After reviewing the literature and the results from this study, it was found that two factors might be associated with increasing the risk of injury at rest when holding the computer mouse, the first being when the wrist posture is in ulnar deviation. Positioning the wrist into ulnar deviation regardless of the amount of ulnar deviation has been a major concern in several studies (Cook et al., 2000; Bamac et al., 2014; Ortiz-Hernandez et al., 2003). Two studies were found whereby positioning the wrist into pronation, extension and ulnar deviation increases the likelihood of injury with computer mouse users (Cook et al., 2000; Ortiz-Hernandez et al., 2003). This finding was consistent with the Bamac et al. (2014) study, which found that computer mouse users have a tendency to develop ulnar and median sensory nerve damage in the wrist, possibly due to sustained wrist extension and ulnar deviation during computer mouse use.

The second factor increasing the risk of injury at rest is adopting an awkward sustained posture. The awkward sustained posture refers to positions of the body that deviate significantly from the neutral position while performing work activities. When the joint is in an awkward position, muscles operate less efficiently, and more force must be expended to do the task. Working in this posture is a common contributing factor to musculoskeletal disorders. The more the joint departs from the neutral position, the greater the likelihood of musculoskeletal injuries (Carey and Gallwey, 2002). This is because keeping the arm in a tensed, fatiguing position whilst holding the computer mouse will lead to a co-contraction of the muscles, increasing the force applied on the tendon; then microtrauma will occur within the tendon followed by tendinitis. An example of sustained awkward posture with computer mouse users is when the wrist is either in an extreme position in one plane of motion or two planes of motion, which would increase the level of discomfort and that could be a sign of increased risk of WRMSD (Carey and Gallwey, 2002).

The Carey and Gallwey (2002) study indicated a strong association between wrist posture and the level of discomfort whilst performing the task, a finding consistent with the finding from Polovinets et al. (2017), which measured the ground reaction forces (GRFs) with 14 healthy participants when performing the push-up into two different wrist positions: neutral wrist position and hyperextended wrist. This study supported doing push-up in a neutral wrist position due the force being transferred widely through the wrist and forearm and onto the articular surface of the distal radius. This possibly helped to prevent or minimise the risk of wrist ligamentous injury. In contrast, working on a hyperextension wrist position with the forearm pronated might increase the risk of injury. This is because of the force being transferred ulnarly and dorsally into a small area, which may not be able to absorb such forces. This then might increase the risk of wrist ligamentous injury. Figures 6.3 and 6.4 illustrate the differences in hand posture when holding a specific mouse design and how sustained awkward posture occurs.



The hand is in an unnatural position when using a standard mouse

When using a Penguin Mouse the wrist remains in the neutral position

***Figure 6.3** The hand posture when holding the Standard mouse and the Penguin mouse (Posturite,1991).*

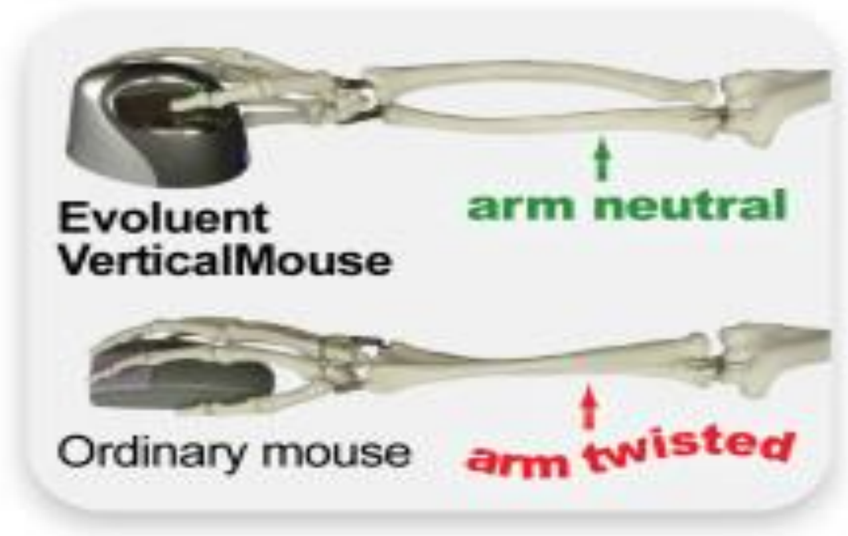


Figure 6.4 *The hand posture when holding the Standard mouse and the Evoluent mouse (Body Support Store (n.d.)).*

The third variable studied was the maximum joint position achieved, which was investigated to compare the computer mice. This variable was chosen because it would provide information on how far the wrist and elbow are moving from the anatomical neutral position, thereby giving an insight into which mouse design moves the wrist and elbow farthest away from the neutral position. After reviewing the literature and the results from this study, it was found that a mouse design that deviates the joint away from the neutral position could increase the musculoskeletal symptoms such as pain and muscle fatigue and then lead to an increased risk of WRMSD (Cook et al., 2000; Carey and Gallwey, 2002). This could be due to the joint being in an at-risk position or in an unbalanced position (far away from neutral position), leading to increased stress on the joint and muscles. Then muscle-tendon fatigue and strain could occur (Aarås et al., 2002; Delisle et al., 2004; Flodgren et al., 2007; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). Figure 6.5 shows the difference when the wrist working position is in a neutral position or in an extreme position. This study (Carey and Gallwey, 2002) indicated a strong association between wrist posture and the level of discomfort whilst performing the task. If the wrist was either in an extreme position in one plane of motion or two planes of motion, this would increase the level of discomfort, which could then be a sign of mechanical fatigue. Fatigue could then be a sign of increased risk of WRMSD.

Figure 6.5 *The correct and incorrect wrist working posture when working in a neutral position or in an extreme deviation from the neutral position (Dachis, 2014).*

Donoghue et al. (2003) found that the wrist posture results for a motion in one plane and two planes showed that the most frequent position for computer users was in wrist extension and ulnar deviation during a typing task. This finding was similar to the findings of this study, as discussed in Chapter 5, in that the most common or frequent wrist position was in extension with the three mice designs and in ulnar deviation with the Standard mouse.

From the results of this study, a concern was raised with the Evoluent and Standard mouse: the wrist extension was significantly greater with the Evoluent mouse ($43.0^{\circ} \pm 11.9^{\circ}$, $p < 0.001$). It was more than the mid-ROM of wrist extension of about 8˚. Also, the wrist was positioned into ulnar deviation with the Standard mouse. Even though the maximum amount of ulnar deviation achieved was still small, positioning the wrist into ulnar deviation was a major concern with several studies as discussed above and in Chapter 5.

6.1.4 Question 2: How does the design of the computer mouse influence the muscle activity of the forearm during typical use?

The EMG data were analysed in terms of variations in the average and maximum voltages, and in terms of the average and maximum voltage during mice comparison. In terms of variation, no variations were found for any muscle ($\pm 0.00\ \mu VSEM$) when the results for each muscle were analysed for each mouse design. Less variation implies a more consistent EMG measurement. In this case, SEM equals zero (to two decimal places), meaning that the measurements taken for the average and maximum voltage for the five muscles during the elbow and wrist hyperlink task were perfectly reliable with the 3 mice designs because no variations were found. This shows that the EMG variables tested in this study (maximum and average voltage) were reliable and can be used for a clinical decision, as discussed in Chapter 4. However, clinically, this could lead to an increased risk of WRMSD because of no variations being found ($\pm 0.00\ SEM$) with each muscle and with each mouse design (Hamill and Emmerik, 2012). This means that the participants used the same amount of muscle activity, and the muscles exerted the same amount of force every time they performed the task. Therefore, it is possible that using the same amount of muscle activity and exerting the same amount of force everyday could lead to muscle fatigue and then increase the risk of overuse injury in the long run. Muscle fatigue means that there is a decline in the ability of the muscles to generate force (Nur et al., 2015). Nur et al. (2015) and Phinyomark et al. (2012) found that muscle fatigue usually occurs due to prolonged repetitive tasks. Also, Nur et al. (2015) mentioned that muscle fatigue occurs due to static low load tasks. Muscle fatigue could be indicated by lower SEM. Muscle fatigue occurs due to the depletion of glycogen, a source of energy for muscle cells, and lactic acid accumulation, which interfere with the release of calcium or with the ability of the calcium to stimulate muscle contraction (Nur et al., 2015; Phinyomark et al., 2012). Muscle fatigue could lead to pain, weakness, discomfort, numbness and hand tremors (Nur et al., 2015; Phinyomark et al., 2012; Tittranonda et al., 2000; Szeto and Lin, 2011).

Overuse muscle injury usually occurs with computer users because of frequent and repeated use of the same muscles and an example would be if the computer task is applied in such a way that adaptation cannot occur. The excessive overload on the muscles might cause microscopic (overuse) injuries, leading to inflammation, the body's response to injury (Nur et al., 2015; Phinyomark et al., 2012). Overuse muscle injuries include strained muscles, small tears in the fibre and connective tissue of the muscles, and overstretched tendons and symptoms include swelling, pain, muscle weakness and numbness, and stiffness of the joints (Tittranonda et al., 2000; Szeto and Lin, 2011).

In terms of the average and maximum voltage with the mice comparison data, and to understand which mouse design could increase the risk of WRMSD and lead to pathology related to mice used, the researcher looked to the results from the movement data and EMG data as well as looking at several studies that mentioned how injury occurred with computer mouse users. Using a mouse design will require the computer user to make small precise movements with their hand, fingers and thumb. Also, to perform the task, computer users need to position their hands, scrolling, travelling and clicking the mouse several times. This requires using the same muscles, which can become overworked and tired. This overuse could lead to pain in the elbow and wrist; numbness and tingling sensations could occur in the thumb and index finger, as well as stiffness and a restricted range of motion (Phinyomark et al., 2012; Tittiranonda et al. 2000).

The problem for the computer mouse users was found to be increased wrist extension activity because wrist extension activity linked to the mouse design made an increase in the level of wrist joint into extension (Chen and Leung, 2007; Dennerlein et al., 2002; Qin et al., 2013; Tittiranonda et al., 2000), as discussed in sections 5.8.1 and 5.8.2. Increases in wrist extension movement will increase the wrist extensor activity. The data from this study indicates that the Standard mouse might increase risk of injury because the average and maximum voltage of wrist extensors increased with it. Increases in the average and maximum voltage of wrist extensor with the Standard mouse could be due to the wrist posture being into ulnar deviation and extension, not only because of increased wrist extension. This is because the wrist extension was significantly greater with the Evoluent mouse than the other mice used, and the maximum voltage of wrist extensors decreased with the Evoluent mouse.

Increases in the average and maximum voltage of wrist extensors could increase the risk of WRMSD in the long run with computer mouse users. Generally, muscles are less efficient at producing force when they are shortened which occurs when the joint is in an extreme position compared to normal ROM or in an awkward sustained position. This will then lead to co-contraction of the muscles, influencing the vascularisation and blood flow in the tendon, possibly leading to tendonitis in the elbow and wrist.

It should be mentioned that the three mice designs were similar in terms of variations. No variations were found in the measurements taken for the average and maximum voltage with the wrist extensors whilst using the Standard, Penguin and Evoluent mice. However, the Evoluent and Penguin mice were different from the standard mouse in terms of the average and maximum voltage with the mice comparison data. Both Evoluent and Penguin mice were fairly similar, and there is no clear difference between them. Figure 6.6 illustrates the wrist extension activity and wrist extensors and flexors.

Wrist Extension Activity (LeClair, 2017)

Wrist Extensors and Flexors ,No More Pain Ergonomics (2016)

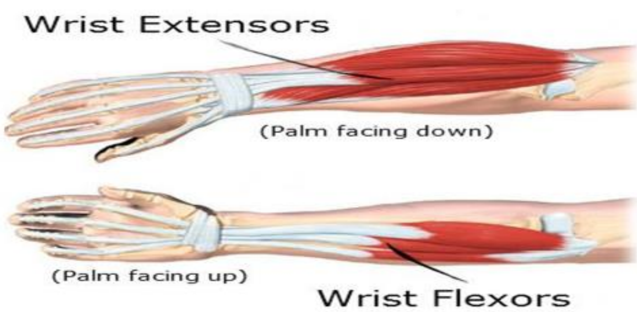


Figure 6.6 *Wrist extension activity and wrist extensors and flexors.*

A study by Szeto and Lin (2011) showed that an association between higher muscle activity and level of discomfort: when muscle activity increased, the level of discomfort could increase, as seen with symptomatic participants. Also, Tittiranonda et al. (2000) found an increase in muscle activity of the FDS, ECU, EIP and UT when using the Standard mouse compared to other input devices used in their study. It also showed a significant difference in the muscle load of the EIP, ECU and upper trapezius across the four different pointing devices, finding that a standard mouse tends to create higher loads on the upper trapezius and ECU, leading to increased shoulder elevation and wrist ulnar deviation. In contrast, using an ergonomic mouse design could promote a more neutral posture of the forearm whilst performing a computer task, which could be through the mouse shape and the location of the buttons, the thumb and fingers. Also, two studies were found which stated that lower muscle activity was generated with the wrist in neutral position compared to muscle activity in all wrist deviated postures, which could increase the muscle load; deviated joint posture causes the muscle to be overused and overstretched and lead to muscle tension (Dennerlein et al., 2002; Qin et al., 2013). Those findings were consistent with the findings from Chen and Leung (2007), whereby the muscle activity of the ECU decreased as the slanted angle of the mouse increased and it was significantly lower when using the 30° slanted mouse ($p = 0.041$) compared with using the non-slanted mouse.

In summary, the Standard mouse showed a cause for concern because the average and maximum voltage of wrist extensors increased with this mouse design. This could increase the risk of WRMSD with computer mouse users.

6.1.5 Question 3: How does the design of the computer mouse affect the overall posture during typical use?

To answer this question and to check whether there was a genuine difference in the overall sitting posture while using three mice designs (Standard, Penguin, and Evoluent), RULA was used to give an insight into which mouse design would maintain the posture in a more neutral position throughout the experimental task. In this study, the midline position was considered the safe distance range for comfortable hand movements with computer users. This will promote musculoskeletal health and prevent pathology in computer users. If a mouse design maintained the overall posture close to the neutral position throughout the whole task, this could be the mouse for pathology prevention. In contrast, a mouse design that causes a deviation in the overall posture or parts of the body away from the midline position could be a mouse design that will increase the risk of pathology. A neutral or midline position could be defined as maintaining the wrist and elbow in a neutral position, in the midline of the body; also, maintaining the neck between 0° and 10° flexion without twisting or side bending, as well as keeping the trunk in a neutral position without twisting or side bending (Dockrell et al., 2012).

The results showed that the working posture with the Standard mouse was significantly different from the other mice because the Standard mouse had the highest mean rank (mean = 2.70˚). This means that this mouse allows further deviation of the overall posture from the neutral position. Moreover, there was a cause for concern with the Standard mouse because the posture deviates in all parts of the body and also with the Evoluent mouse because the posture deviated in the neck and trunk. The Penguin mouse showed no cause for concern, which might mean that this is the mouse design that keeps the overall posture close to the midline position.

In comparing the RULA results taken in the middle of the experiment with the movement data taken at the end of the experiment, the wrist posture with the Penguin mouse was still maintained close to the neutral position from the middle to the end of the experiment. From RULA, the mean rank of the wrist was equal to one (to one significant figure), and from the movement data, the amount of wrist extension and radial deviation whilst performing the task was the lowest with the Penguin mouse. In contrast, the wrist posture with the Evoluent mouse was maintained close to the neutral position in the middle of the experiment, but then deviated away from the neutral position by the end of the experiment. The wrist extension and radial deviation were significantly higher with the Evoluent mouse during movement. For the Standard mouse, the wrist position was at or near the end of twisting range during task three i.e. the middle of the experiment. The twisting range means when the wrist position is in ulnar or radial deviation. The wrist position was still twisted during task five i.e. the end of the experiment. This twisting was due to the wrist being in ulnar deviation.

In summary, the results from RULA showed that the Penguin mouse is the one that maintained the overall body and forearm posture close to the neutral position. This also means that this mouse design could allow a relaxed and neutral posture of the forearm, which then could prevent or minimise the risk of WRMSD. However, the Standard and Evoluent mice may be a cause for concern because they deviate the posture away from the neutral position. This could increase the risk of WRMSD. Maintaining this overall posture for the workday can cause extra load on the muscles, allowing a tensed posture of the forearm and then fatigue could develop. In comparing the Evoluent and Standard mice, it could be seen that the RULA results with the Evoluent were better than the Standard mouse because with the Evoluent, the posture deviated only in the neck and trunk, whereas with the Standard mouse, the posture deviation was with each body part. This could demonstrate that the vertical mouse has a better impact on the overall and forearm posture than the Standard mouse.

6.1.6 Question 4: How does the design of a computer mouse affect the usability during typical use?

A usability questionnaire was distributed at the end of the experiment to answer this question. It was a combination of quantitative and qualitative questions. The questionnaire helped the participants to choose the response that best represented their opinions about and degree of satisfaction with, each mouse design. Furthermore, it facilitated a better record of each participant's true feelings on each mouse design.

The Evoluent mouse was found to be the most comfortable mouse design and the most preferred mouse. The Penguin mouse was the second preferred mouse design, and the Standard mouse the least. This is in contrast to the results of the parametric data and the RULA assessments which raised a concern with the Evoluent mouse. With the parametric data results, a concern was raised with the Evoluent mouse with wrist extension at rest and during movement because it positioned and moved the wrist outside the mid-ROM, which then could increase the risk of injury. With RULA assessment results, the Evoluent mouse deviates the posture of the neck and trunk outside the neutral position. Even though the participants preferred the Evoluent mouse, that does not mean that this mouse design could prevent pathology. The participants had the opportunity to be familiar with each mouse design, but they performed the main experimental task with each mouse for up to 10 minutes. Possibly, if the task had been longer in duration, their response about mice preference might change.

It should be noted that the questionnaire results point towards the participants preferring the ergonomic/vertical mouse design over the Standard mouse. This could confirm that the vertical mouse design has a good influence or a better impact on the posture when compared with the Standard mouse. The participants felt the differences in their posture from how their hands were positioned and moved throughout the task. Several participants expressed interest in obtaining either a Penguin or Evoluent mouse for personal use. They stated a preference for the reduced arm movement and relaxed arm posture achieved using the alternate mice designs. They complained of slight pain and discomfort after using the Standard mouse in this study. They also felt the Standard mouse needs more muscle work and it does not fit properly to the shape of their hand.

6.1.7 Ergonomic guide and tips for computer-based workstations

The goal of ergonomics is to design the job to fit the workers so that they have a safer job with less injury, to increase efficiency and productivity and to improve the quality of the work (Shariat et al., 2017; Westgaard and Winkel, 1997). Also, ergonomics aims to find ways to make repetitive or strenuous work less likely to cause injury at the same time as doing the job effectively (Shariat et al., 2017; Westgaard and Winkel, 1997). This can be achieved by eliminating the potential causes of hazardous manual tasks and includes applying ergonomic specifications into the design of the workplace, equipment and tools to prevent injury for computer mouse users (Aarås et al., 2002; Chen and Leung, 2007; Cook et al., 2000; Delisle et al., 2004; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999). By applying ergonomic interventions, the risk of WRMSD could be reduced by allowing the overall posture to be close to the neutral position (Aarås et al., 2002; Chen and Leung, 2007; Cook et al., 2000; Delisle et al., 2004; Gustafsson and Hagberg, 2003; Houwink et al., 2009; Keir et al., 1999) and by allowing the individuals to sit comfortably to increase their comfort and reduce the chance of injury (Shariat et al., 2017; Westgaard and Winkel, 1997). Applying ergonomic intervention = injury prevention (Shariat et al., 2017; Westgaard and Winkel, 1997).

In setting up the workstation, ergonomists suggest that an acceptable and well-supported seated position means the following. First, sitting with the body close to the desk where the head and neck are in a midline position (the neck between 0° and 10° flexion without twisting or side bending). Second, the shoulders are relaxed and symmetrical and elbows slightly closer to the side of the body. Third, the back is supported by the chair backrest. Fourth, the knees should be at a height lower than or at hip level, ensuring a gap of 2-3 finger widths between the front of the chair and the back of the knees. Fifth, the feet should be flat and well supported on the floor or footrest. Sixth, an adjustable office chair should be used to allow a well-supported posture. Seventh, the screen monitor height should be according to the eye level and the screen distance should be according to the arm length to reduce visual fatigue. Eighth, the computer mouse should be kept at the same height and as close as possible to the keyboard. Dockrell et al. (2012) and the ergonomic guide to computer-based workstation (Workplace Health and Safety Queensland, 2018) outlined those eight suggestions. Figure 6.7 illustrates an acceptable sitting position at the computer workstation.

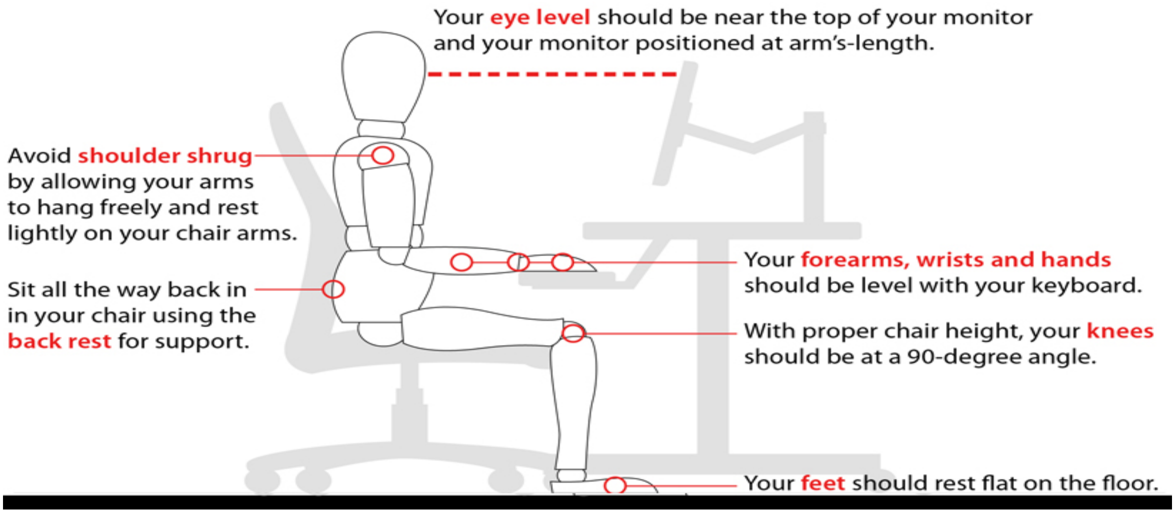


Figure 6.7 *An acceptable sitting position at the computer workstation (Versatables, 2011).*

In conclusion, to avoid overuse injuries of the hand or the arm for computer mouse users, several ergonomic tips that can be followed to avoid such risk (Workplace Health and Safety Queensland, 2018; Dockrell et al., 2012; Shariat et al. 2017; Westgaard and Winkel,1997): first, ensure that the computer mouse fits the hand comfortably to reduce any excessive pressure on the wrist and forearm; second, set the pointer tracking speed to suit the computer user and the computer task; third, ensure the computer workstation is set according to ergonomic guidelines and have enough space and a flat surface to keep the forearm straight; fourth, the hands should be taken off the mouse and keyboard when not in use, which will help to reduce muscle fatigue; fifth, take regular breaks from the computer; and finally, computer tasks should be mixed to avoid long and continuous muscle stretches from computer use.

6.1.8 Clinical recommendations arising from this study

After an overview of how injuries could occur, what the factors are that could heighten risk of injury, the results and ergonomic guidelines and tips to avoid risk of injury, addressing future suggestions of how to avoid WRMSD is most important. These suggestions come after gaining a full understanding of the thesis results, how they relate to what exists in the literature and how they contribute to knowledge.

It could be suggested that the ideal scenario regarding mouse design and office workers' overall posture is to use a mouse design with higher variability, small range close to the neutral position and with lower magnitude of the muscle activity. However, when considering the three mice used in this research it is difficult to recommend the use of any one mouse since the EMG findings were different to the findings from the movement data. With movement data, there was no clear picture leading to a recommendation, as discussed in section 6.1.3. The Penguin mouse could show a better impact on the overall posture and the wrist posture because no overall posture deviation was found; the wrist posture at rest and during movement was close to the neutral position, and higher variability was found with the Penguin mouse for the measurements taken of wrist radial/ulnar deviation, and higher variability was found as a second place in the measurement of wrist flexion/extension. The Evoluent mouse was found to have a better possible impact on elbow posture because of higher variability being found with the measurements taken of elbow flexion/extension. The Standard mouse demonstrated that the overall posture cannot be maintained close to the neutral position in each part of the body, and the wrist posture was significantly different with this mouse, being into ulnar deviation at rest and during movement, a major concern with several studies.

With regard to EMG data, no variations were found in the average/maximum voltage of the forearm muscles with the three mice designs. Furthermore, the Standard mouse was possibly found to be the mouse that would increase risk of injury because the average and maximum voltage of wrist extensors were increased with this design and this is clinically important. Because of this finding, no clear difference was found between the Penguin and Evoluent mouse because the average voltage of wrist extensors decreased with the Penguin mouse, and the average/ maximum voltage of wrist flexors and maximum voltage of wrist extensors decreased with the Evoluent mouse.

Because of all these findings, it is difficult to suggest a particular mouse design that will do all that is required to prevent injury. However, it can be seen from the results that a vertical mouse has a better impact on the posture of computer users, as discussed in this chapter. Thus, it is suggested that the ideal scenario for computer mouse users is to interchange between the vertical mouse designs to help protect from injury by allowing the posture of the upper limb to change throughout the day. Also, this will prevent the forearm from being positioned in an awkward sustained posture. When posture is changed many times throughout the day, it helps to use different muscles. Being in the same posture for extended periods of time can lead to muscle fatigue, pain, spasms, stiffness or overworking parts of the body, which can contribute to WRMSD. By interchanging the mouse design throughout the day, this could enhance higher variability in the posture and muscle activity, thereby promoting musculoskeletal health by positioning and moving the forearm into a relaxed and neutral position. Also, the force applied on a joint or muscles will be distributed more widely to prevent overloading in some body parts and prevent overuse of the muscles. This means that lower muscle activity can be generated with the wrist in neutral position compared to muscle activity in all wrist deviated postures; a deviated joint posture causes the muscle to be overused and overstretched (Fagarasanu et al., 2004).

This suggestion could help physiotherapists in their clinical reasoning and decision-making process with patients with WRMSD who work at a computer-based workstation. Clinical decision-making in musculoskeletal physiotherapy focuses on the nature of patient problems, physiotherapeutic intervention and interaction, and subsequent evaluation. By knowing one of the causative factors of injury with office workers as addressed in this study, physiotherapists can build effective treatment strategies to reduce such risk. This research can be used in the education of musculoskeletal physiotherapists and provide them with a basis through careful analysis of their decision-making. This study would also seem to help clinicians with strategies to minimise the risks of WRMSD and might also help computer users to identify and manage risks within their workplace. Moreover, it will help ergonomists in designing a non-keyboard input device that could reduce such risk and allow the forearm to be in a neutral position.

6.2 Limitations and future research suggestions

This research used convenience sampling, chosen because of the limited time and being the easiest to reach the required sample size. The inclusion criteria were healthy participants. It might be useful to also analyse the influence of different mouse designs on a patient population as well. This would help to see the influence of mouse designs on the symptoms of WRMSD such as pain reduction. A patient population was not tested in this research because of the researcher's limited time to complete her data collection and research. Although this research was done only on healthy participants, it has been useful to understand influence of mouse designs on posture, biomechanics and muscle activity of the forearm. If this were done on a patient population in the first place, it might have been difficult to generate a better understanding of the influence of different mice designs on computer users and have the ability to answer the research questions. In future research, it would be better to compare the influence of mouse designs on the posture, biomechanics and muscle activity of the forearm on healthy participants and a patient population to see whether they have the same effect on healthy participants and the patient population.

In addition, as stated in Chapter 4, it would be better if different variables were tested in terms of variations in conjunction with the ROM in the reliability study, for example, the static posture and maximum joint position achieved as this will give a clear idea about the type of variables that should be chosen for the final study and also enable the researcher to see which mouse design has higher or lower variability in the measurements taken for the static posture and maximum joint position achieved. Testing different variables could help to find the right variable that could relate to WRMSD. Also, it might give an idea about other variables for testing in the final study rather than the static posture and maximum joint position achieved. For example, grip pressure could be a causative factor related to WRMSD. To grip a computer mouse, there is a right and a wrong way. The combination of force and posture during the grip, if not accomplished correctly, may result in increased risk of injury to the hand. When using a computer mouse, it should be held loosely with the wrist in a neutral position and operated by moving the entire arm and shoulder. Also, a light touch should be used when clicking the mouse button. This will help to reduce the risk of injury. Some computer users tend to have a forceful grip which increases the risk of injury and this could be due their personal habit in the way they hold the mouse or any tool, and not due to the design of the computer mouse. Grip pressure was not tested in this research because minor modifications would need be done in the experiment, for example, using sensors on a mouse to measure the amount of pressure. This tool is called a finger switch or finger tactile pressure sensor system, designed to measure the pressure exerted on an object by the human hand during gripping. Also, validity and a reliability study would need to be done for this tool.

This research was exploratory and not hypothesis driven and so this might mean pros and cons in choosing the right variables to answer every research question. However, exploratory research would help to develop a hypothesis that can be tested at the end of the study.

6.3 Contribution to knowledge

This research study constitutes a new contribution to knowledge by looking at the influence of three different mouse designs on the posture and muscle activity of the elbow and wrist joints and how this relates to WRMSD. Previous experimental studies looked at the following: wrist posture only and WRMSD (Flodgren et al., 2007; Gustafsson and Hagberg 2003; Keir et al., 1999); elbow and wrist posture and WRMSD (Delisle et al., 2004; Houwink et al., 2009); and the influence of vertical mouse design on pain reduction with patients with musculoskeletal symptoms (Aarås et al., 2002).

Regarding muscle activity and how it relates to WRMSD, three studies only were found. One assessed muscle activity and range of motion of the wrist joint only (Szeto and Lin, 2011); one assessed muscle activity of the forearm (Qin et al., 2013); and one looked at the influence of different mouse designs on muscle activity of the forearm only and how it related to WRMSD (Chen and Leung, 2007). This research could also establish a contribution to knowledge by finding the computer mouse design to reduce the risk of WRMSD is the mouse that has higher variations, in contrast to reliability study results and what was found in the literature.

This doctoral research is exploratory research and not hypothesis driven because the researcher does not have enough research on which to base her hypothesis;

thus, part of the contribution to knowledge is the intention to develop a hypothesis to test at the end of her PhD, and at the same time, this will help anyone who would like to carry out similar research. Two hypotheses were driven from this doctoral study. First, a mouse design that has higher variations, in joint movements and muscle activity, will lead to reduce the incidence of WRMSD. Second, interchanging between the vertical mice designs while using the computer throughout the day will lead to reduce the incidence of WRMSD.

Finally, this research is the only study that has compared two pieces of equipment alongside each other to determine their accuracy and found the accuracy of the Electrogoniometer to be better than the manufacturer claims. With the availability of this study and its comparison, it will hopefully help future research.

6.4 Conclusion

To conclude, this research was designed to assess the influence of different mouse designs on the elbow and wrist joint posture and biomechanics specifically to help to minimise the symptoms of musculoskeletal injuries as well as to minimise the risk of WRMSD such as carpal tunnel syndrome. The study also focused on how the design of a computer mouse influenced the muscle activity of the forearm and how it affects the overall posture and computer users' usability.

This study found a significant difference on the posture and muscle activity of the forearm and the overall posture between the three different mice used. Vertical mice allowed a more relaxed posture whilst performing a computer task compared with a Standard mouse. This research found that interchanging the mouse design while using the computer throughout the day could be the key in reducing the risk of WRMSD.

This study may help physiotherapists working with patients with WRMSD, and physiotherapists and physical therapy students interested in mouse design, WRMSD and ergonomics, as well as clinicians working in ergonomics to gain more information about mouse design and how the computer mouse affects the posture and muscle activity of the elbow and wrist joint. It could also help the understanding of the mechanism of injury related to the computer mouse usage and how it leads to WRMSD. Furthermore, it could help computer mouse designers learn how mouse design affects the posture and biomechanics of the elbow and wrist joint for them to improve future mouse design.

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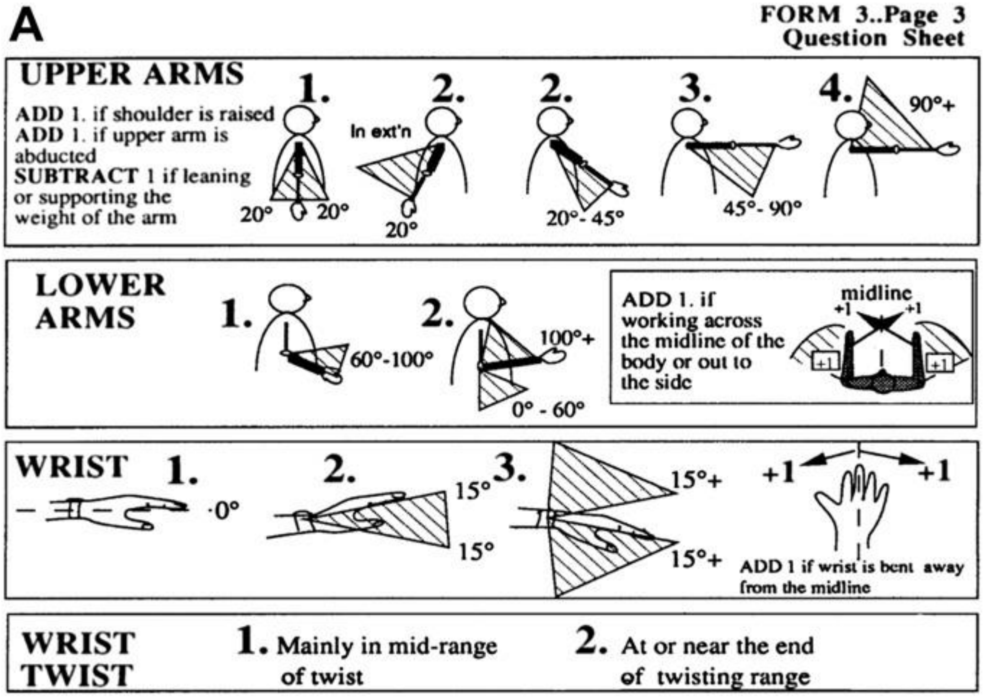
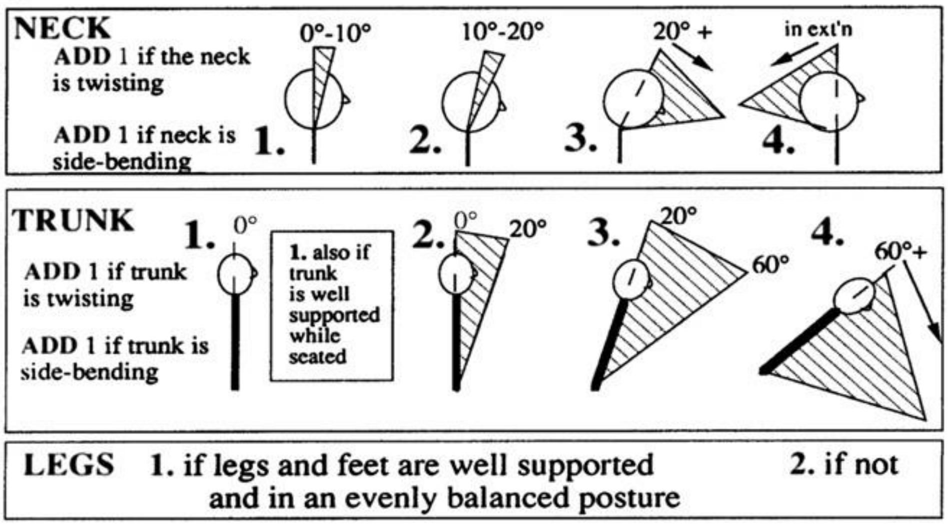
8 Appendices

Appendix 1: RULA (Dockrell et al., 2012)

A



B

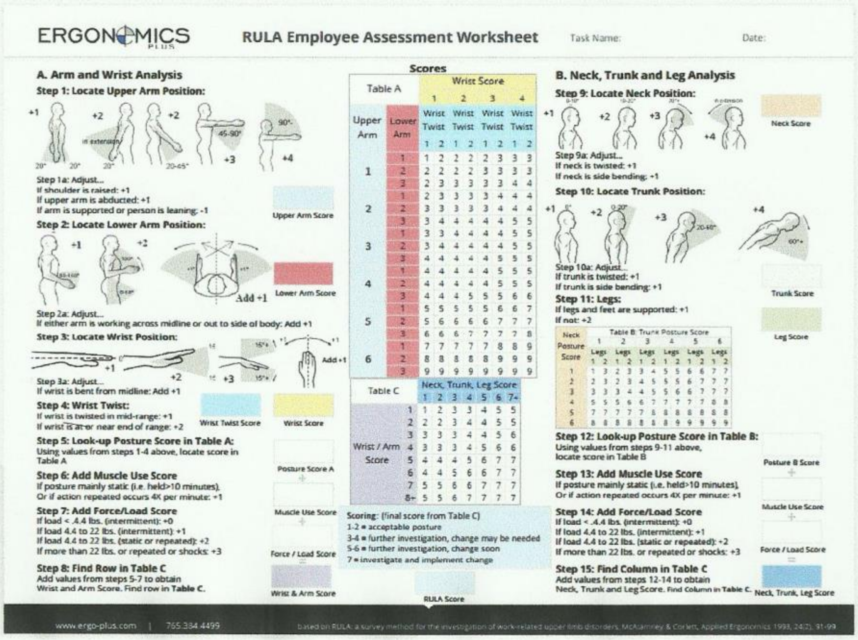


-How to generate a RULA Grand Score (www.ergo-plus.com):

ERGONOMICS PLUS | RULA: A Step-by-Step Guide

Rapid Upper Limb Assessment (RULA)

RULA was developed to evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity MSD. The RULA ergonomic assessment tool considers biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities. A single page worksheet is used to evaluate required body posture, force, and repetition. Based on the evaluations, scores are entered for each body region in section A for the arm and wrist, and section B for the neck and trunk. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk.



-RULA Grand Score (Meksawi et al., 2012)

1. The posture risk score ranges from 1 to 4, as shown in Figure 3.2; a score of 1 indicates the best or the most neutral posture; higher scores show a more unbalanced position.

2. The RULA grand score is produced by a combination of risk scores in the upper arms, lower arms, wrists, neck, trunk and legs and it ranges from 1-7.

2.1 A range from 1 or 2 (low) means that the work posture is acceptable.

2.2 A range from 3-4 indicates that further investigation is needed and work habit changes may be required.

2.3 A range from 5-6 (warning) indicates that an investigation and changes in work habits are required.

2.4 A score 7 indicates that work habit changes are required immediately.

Appendix 2: OWAS scores and action levels (Kee & Karwowski, 2007)

Table 1 The OWAS score for each body position

Body part	OWAS score	Description of position
Back	1	Straight
	2	Bent
	3	Twisted or bent to one side
	4	Bent *and* twisted or bent *and* bent to one side
Arms	1	Both arms below shoulder level
	2	One arm at or above shoulder level
	3	Both arms at or above shoulder level
Legs	1	Sitting, legs below seat level
	2	Standing, legs straight
	3	Standing on one leg, leg straight
	4	Standing on both legs, legs bent
	5	Standing on one leg, leg bent
	6	Kneeling on one or both knees
	7	Walking or moving
Weight or strength requirement	1	Less than 10 kg
	2	Over 10 kg but less than 20 kg
	3	More than 20 kg
Head	1	Free
	2	Bent forward
	3	Bent to the side
	4	Bent backwards
	5	Turning to the side

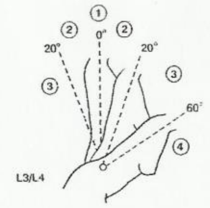
Table 2 The OWAS classes of action required for each body position (after Stoffert, 1985)

OWAS score	Class
214	class 3
212	class 2
112	class 1
132	class 1
133	class 1
224	class 3/4 depending on weight carried
120	climbing is not classified
213	class 2/3 depending on weight carried
235	class 4
110	climbing is not classified

Appendix 3: REBA (Kee & Karwowski, 2007)

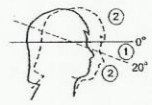
Trunk

Movement	Score	Change score:
Upright	1	+1 if twisting or side flexed
0°–20° flexion 0°–20° extension	2	
20°–60° flexion >20° extension	3	
>60° flexion	4	



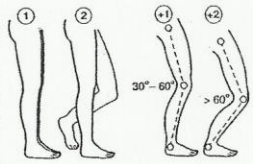
Neck

Movement	Score	Change score:
0°–20° flexion	1	+1 if twisting or side flexed
>20° flexion or in extension	2	



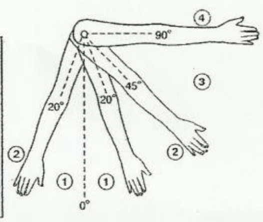
Legs

Position	Score	Change score:
Bilateral weight bearing, walking or sitting	1	+1 if knee(s) between 30° and 60° flexion
Unilateral weight bearing Feather weight bearing or an unstable posture	2	+2 if knee(s) are >60° flexion (n.b. Not for sitting)



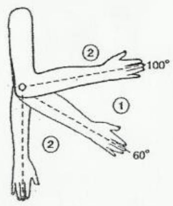
Upper arms

Position	Score	Change score:
20° extension to 20° flexion	1	+1 if arm is: • abducted • rotated
>20° extension 20°–45° flexion	2	+1 if shoulder is raised
45°–90° flexion	3	−1 if leaning, supporting weight of arm or if posture is gravity assisted
>90° flexion	4	



Lower arms

Movement	Score
60°–100° flexion	1
<60° flexion or >100° flexion	2



Wrists

Movement	Score	Change score:
0°–15° flexion/ extension	1	+1 if wrist is deviated or twisted
>15° flexion/ extension	2	

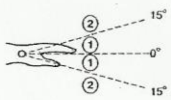


Fig. 1. Group A and B body part diagrams.

Table 4
REBA action levels

Action level	REBA score	Risk level	Action (including further assessment)
0	1	Negligible	None necessary
1	2–3	Low	May be necessary
2	4–7	Medium	Necessary
3	8–10	High	Necessary soon
4	11–15	Very high	Necessary NOW

A B C

Appendix 4: Ethics Approval

From: onbehalfof+J.Scholes+brighton.ac.uk@manuscriptcentral.com <onbehalfof+J.Scholes+brighton.ac.uk@manuscriptcentral.com> on behalf of J.Scholes@brighton.ac.uk <J.Scholes@brighton.ac.uk>
Sent: Thursday, October 24, 2013 11:30 AM
To: Bashaer Alhay; Lucy Redhead (staff)
Subject: Faculty of Health and Social Science Research Ethics and Governance Committee - Decision on Manuscript ID FREGC-13-044
24-Oct-2013
Dear Mrs. alhay:
Application ID FREGC-13-044 entitled "The influence of computer mouse design on the muscle activity, movement and position of the elbow and wrist joints." which you submitted to the Faculty of Health and Social Science Research Ethics and Governance Committee, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter.
The reviewer(s) have recommended that subject to minor revisions to your application, the proposal be approved. Therefore, I invite you to respond to the reviewer(s)' comments and revise your application according to their recommendations. The amendments you make should be listed against each comment made by the reviewer.
To revise your application, log into http://mc.manuscriptcentral.com/fregc and enter your Author Centre, where you will find your application title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.
You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using bold or coloured text.
Once the revised application is prepared, you can upload it and submit it through your Author Centre.
When submitting your revised application, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original

manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

IMPORTANT: Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely approval of applications submitted to the Faculty of Health and Social Science Research Ethics and Governance Committee, your revised application should be uploaded as soon as possible. If it is not possible for you to submit your revision in a reasonable amount of time, we may have to consider your paper as a new submission.

Please note, you may not start your research, or forward your proposal to external agencies until the application has been finally approved by FREGC.

Sincerely,

Prof. Julie Scholes

Chair, Faculty of Health and Social Science Research Ethics and Governance Committee

J.Scholes@brighton.ac.uk

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments to the Applicant

attached

Reviewer: 2

Comments to the Applicant

A clear proposal of what will be an interesting and useful study.

abstract is fine but I advise a change of wording in the benefits section "this study will provide information to help the manufacturer ...."

page 5 purpose of research point 1.....".find reliability... "

perhaps you should use the term validity as this doesn't quite tie into p6 line 15 "The preliminary work........study 1 will be about the validity of the measurements......". and the following descriptions of stage 1 and 2

p8 experimental procedures

line 7 - should this be most suitable instrument ?

p9 paragraph 2

line 11/12 - you address reliability of consumer questionnaire but you should include some comment on the validity of the questionnaire

p10 experimental procedure

it would be useful to state the nature of the task that will be performed

p11 lines 7 & 8 repetition

p 12 exclusion criteria

why exclude the allergic - can you use hypoallergenic tape ?

excellent range of references

appendix 1 Consumer product questionnaire

This is currently laid out over 5 pages which maybe expensive to duplicate and somewhat overwhelming ! I would recommend a more condensed layout before you present this to participants

appendix 3

p 28 line 34 study requirements

It currently reads as though the activities mentioned should not be carried out before or after the experiment but surely this is only on the day before participating ?

This section is not clear - needs adjustment should not drink tea coffee etc ...... on the day of participation before taking part in the study. A similar phrase needs to be added to explain exercising before the experiment on the day.

This should also be adjusted on p32, p36 study requirements

appendix 4

line 42 Should read the selected arm or an arm ?

Fwd: Faculty of Health and Social Science Research Ethics and Governance Committee - Decision on Manuscript ID FREGC-13-044

BA

Bashaer Alhay

Reply all |

Tue 10/27/2015 11:48 AM

To:

Tue 10/27/2015 11:48 AM

Inbox

Inbox

Alhay

Begin forwarded message:

From: Julie Scholes <J.Scholes@brighton.ac.uk>
Date: 29 October 2013 at 2:49:06 p.m. GMT
To: Bashaer Alhay <B.Alhay1@uni.brighton.ac.uk>
Subject: Re: Faculty of Health and Social Science Research Ethics and Governance Committee - Decision on Manuscript ID FREGC-13-044

Apologies - the comments from reviewer one were as follows:
Microsoft Word - 15840031_File000002_324276867.doc

FREGC 13 044
This is very promising PhD proposal and I hope the research goes well. I have just a few comments on it. The page numbers apply to the PDF submitted to FREGC.
In terms of your submission to FREGC, I assume the application excludes the final phase as this has yet to be designed, based on this pilot work. Further ethical approval needs to be sought at that stage.
Scientifically, it would be helpful in the Introduction to comment on trends towards greater use of laptops and touch pads, compared to mouse use. This would help to strengthen the case for the study: I was wondering whether in the rapidly changing world of IT whether mouse use would disappear during the 5 years of your PhD studies. It would good to have positive data to show that the study will still be relevant in 5 years¹ time.
Page 2, Para 1- Œcomputer input device¹ seems an odd term to use.
Page 4, para1, line 4: do you mean patients or healthy adults here?
Page 10: sampling and participants: I don¹t understand why you are using a patient / hospital population to obtain a sample of healthy participants. Please explain.
Would a purposive sample be more rigorous and informative than a convenience sample? You do not simply need a large enough sample size, you could either select a sample for maximum homogeneity of heterogeneity? Would that not be more informative?
PIS : comments apply to all the PIS submitted, as relevant.
The language of the PIS is a little formal and would benefit from proof-reading by a lay reader.
I found it somewhat confusing to have a Study title at the top, and then later on to have a different ŒPurpose of the study¹. Why not use a sub-heading under the study title eg ŒPhase 1 To explore the equipment...¹
P26, What will happen ..section: I suggest re-wording first sentence You will be invited to attend [the University campus??] for one session lasting one hour. The date of the visit will be agreed with you.
t would be helpful to say what the photography will be aiming to show.
P26, Study requirements section: line 1: delete Œall Œ ; amend Œallowed¹.
Line 3: how many days prior to attendance should they avoid these things?
P27, What will happen to the results section: add Œwriting up my PHD thesis¹ and Œpublish the results of the study in scientific journals¹.
The above PIS edits should be considered in the PIS for each of the other phases.
In addition, there was one sentence in the second PIS,(p 30) where I found the explanation about

attendance confusing. It might be clearer to say ŒWe would like you to
take part in two experiments,
each one hour long. In the hour we will ask you to do 10 trials each
lasting 5 minutes (with rests in
between?). You can choose whether you would prefer to attend for two hours
on one day or to
attend for one hour on two separate occasions, at dates to suit you.[1]
I hope this helps.
Kind Regards
Prof Julie Scholes
Chair, FREGC HSS

Response to reviewers' comments

Reviewer 1

Thank you for your very useful comments

I can confirm that I will be submitting a separate application for the final, patient, phase of this study

I understand your concern about the changing technology of computers. It is not possible to find references that confirm that the computer mouse will still be the most frequently used input device in 5 years' time, however for desktop computers it is still used by 97% of users and this is the population that is most likely to develop musculoskeletal problems from hours of computer use. Presently there is no alternative available to the mouse for desktop computers.

To clarify the sampling for this study: the first 2 phases will use healthy participants which will be recruited through the University. Patients will only be used for the final phase and these are the only participants to be recruited through a hospital population. A separate application will be put into FREGC for this final phase. A purposive sampling method will be used to recruit these patients as we are aiming for a homogeneous sample, however, a convenience sample is going to be used to recruit the healthy adults for the early phases as there is no specific requirement in the inclusion criteria.

All the other comments have been addressed in the proposal and the changes highlighted.

Reviewer 2

Thank you for your useful comments.

In answer to your question about hypoallergenic tape, the tape used will be hypoallergenic however some individuals still respond to any tape and these individuals will know that they cannot use plasters or tape on their skin. It is these individuals that we are aiming to exclude from the study.

The consumer questionnaire enclosed with the proposal is a validated tool and my supervisors have recommended that I do not adjust it in order to make it shorter. I will however look at condensing it onto fewer sites of paper to make it feel less overwhelming to the participants.

All the other comments have been addressed in the proposal and the changes highlighted.

Appendix 5: Emails & Flyers

Dear Student
RE: The Influence of Computer Mouse Design on the muscle activity, Movement and Position of the Elbow and Wrist Joints.

I am undertaking the above research as part of PhD. Physiotherapy degree at the University of Brighton. The project is a quantitative experimental study, investigating the influence of computer mouse design on the elbow and wrist movement, position and muscle activities.

Please find attached a detailed information sheet. If after reading this you think you may be willing to participate in this study, please contact us via email or telephone number.

Thank you for your help

Kind Regards

Bashayer Alhay
PhD. Physiotherapy students
School of Health Sciences
University of Brighton

Supervisor names:

-Dr. Lucy Redhead l.redhead@brighton.ac.uk

-Dr. Martin Bailey M.P.Bailey@brighton.ac.uk

-Dr. Derek Covill D.Covill@brighton.ac.uk

Student name: Bashayer Alhay ba64@uni.brighton.ac.uk

Tel: 07507259508

Appendix 6: Participant information sheet (Reliability Study)

University of Brighton
School of Health Sciences

Course Title: MPhil. Physiotherapy

Date: -------------------------

Main Study Title: The influence of computer mouse design on the muscle activity, movement and position of the elbow and wrist joints.

Phase two title: Exploring the reliability of the measurements.

Invitation

I would like to invite you to take part in a research study. Before you decide whether you would like to participate or not, you need to understand why this research is being done and what it would involve for you. Please take your time to read the following information carefully. You are allowed to talk to others about the study and do not hesitate to ask us if there is anything that is not clear or if you would like to know more information

Purpose of the study: - To look at the repeatability of the measurements taken in the elbow and wrist joints.

Why have I been invited?

You have been invited to take part in this study because you have matched the inclusion criteria of this study. Unfortunately you will not be able to take part in the study if you are not familiar with using a computer mouse, if you have a problem in the neck, shoulder, elbow or wrist joint, if you complain from pain in the neck, shoulder, elbow or wrist joint and if you have had any surgical history in the neck, shoulder, elbow and wrist joint.

Do I have to take part?

It is up to you to decide whether you would like to take part in the study or not; taking part in the research is entirely voluntary. Go through this information sheet which I will describe the study and then I will ask you to sign a consent form to show you have agreed to take part. You will have a copy of the information sheet and the consent form. You are free to withdraw at any time without giving a reason.

What will happen to me if I take part?

We would like to invite you to take part in two experiments, each one hour long. In the hour we will ask you to do 10 trials each lasting 5 minutes with 5 minutes rests in between. You will attend for one hour on two separate occasions, at dates to suit you.

Some measurements will be taken of your elbow and wrist movements and muscle activity and some photographs will be taken but your face will not be shown for confidentiality issues. Photographs will be taken to help the researcher in writing the thesis and will be used in thesis appendix. Also, photography will help to show how you are holding the computer mice. Prior the experiment, you will have the opportunity to become familiar with the task. In addition, a warm up task such as a computer game task will be used prior to the experiment to allow you to become familiar with using the particular computer mouse.

Study requirements:

We need your attendance at the allowed agreed scheduled visits and you are allowed to drink tea or coffee, smoke or take routine exercise on the day of participation before taking part in the study. In addition, any excessive exercise such as squash should not be done on the day before participation or on the day of participation before taking part in the study to avoid any muscle fatigue. To allow measurement equipment to be attached effectively it may be necessary to shave some small areas of the arm.

The possible risks of taking part:

During this study a non-invasive instrument to measure the elbow and wrist movements and muscle activity will be attached to the skin using a medical tape. It is possible that some people may develop a mild allergic reaction to this tape; if this happens I will remove the tape immediately and use some ice on the affected area. I will ask about possible allergies prior the study.

What are the possible benefits of taking part?

You will not benefit from taking part in this research directly, but you will help the researcher to know if the measurements taken by the instrument used in this experiment is reliable or not.

What if there is a problem?

If there is any complaint about the way you have been dealt during the study or any possible harm you might have suffered can be addressed by contacting my supervisors. See the bottom of the information sheet for contact details.

Will my taking part in the study be kept confidential?

The research data will be stored securely using a coding scheme, for example, participant 1, participant 2, no names will be added in the data to ensure confidentiality. Also, this data could be used for future studies. No one can access this data except for the researchers and the supervisors.

What will happen if I don't want to carry on with the study?

If you would like to withdraw from the study, you can withdraw at any time and without giving a reason. If this happen, we may ask you to use your data in our study, but you have the right to decide whether that can be used or not.

What will happen to the results of the research study?

This data will be used in the writing up my PhD thesis and we could have the chance to publish the results in scientific journals. An email will be sent to each participant to know the results of the study. You will not be identified in any report or publication. You are not allowed to give your individual results to anyone else.

Who has reviewed the study?

This study has been reviewed and approved by the Faculty of Research Ethics and Governance Committee, School of Health Sciences, University of Brighton.

Kind Regards

Bashayer Alhay
MPhil. Physiotherapy student
School of Health Sciences
University of Brighton

Supervisor names:

-Dr. Lucy Redhead l.redhead@brighton.ac.uk

-Dr. Martin Bailey M.P.Bailey@brighton.ac.uk

-Dr. Derek Covill D.Covill@brighton.ac.uk

Student name: Bashayer Alhay ba64@uni.brighton.ac.uk
Tel: 07507259508

Appendix 7: Consent Form

Title: The influence of computer mouse design on the muscle activity, movement and position of the elbow and wrist joints.

I agree to take part in this research which is to look at the influence of computer mouse design on the muscle activity, movement and position of the elbow and wrist joints.

The researcher has explained to my satisfaction the purpose of the study and the possible risks involved.

I have had the procedure explained to me and I have also read the information sheet. I understand the procedures fully.

I am aware that I will be required to answer questions and expose the selected arm for sensor attachments.

I understand that any confidential information will be seen only by the researchers and will not be revealed to anyone else.

I understand that I am free to withdraw from the investigation at any time.

Name ....

Signed...

Date..

Appendix 8: Participant information sheet (Final Study)

University of Brighton
School of Health Sciences

Course Title: PhD. Physiotherapy

Date: ------------------------

Study title: The influence of computer mouse design on the muscle activity, movement and position of the elbow and wrist joints.

I would like to invite you to take part in a research study. Before you decide whether you would like to participate or not, you need to understand why this research is being done and what it would involve for you. Please take time to read the following information carefully. You are allowed to talk to others about the study and do not hesitate to ask us if there is anything that is not clear or if you would like to know more information.

You have been invited to take part in this study because you have matched the inclusion criteria of this study. Unfortunately, you will not be able to take part in the study if you are not familiar in using a computer mouse, if you have a problem in the neck, shoulder, elbow or wrist joint, if you complain from pain in the neck, shoulder, elbow or wrist joint and if you have had any surgical history in the neck, shoulder, elbow and wrist joint. It is up to you to decide whether you would like to take part in the study or not; taking part in the research is entirely voluntary. Go through this information sheet which I will describe the study and then I will ask you to sign a consent form to show you have agreed to take part. You will have a copy of the information sheet and the consent form. You are free to withdraw at any time without giving a reason.

Purpose of the study: - To investigate the influence of computer mouse on the posture of the elbow and wrist joints and on the muscles activity of the Forearm in order to minimize the risk factors associated with Work Related Musculoskeletal Disorders (WRMSD).

What will happen to you if you take part?

You will be invited to attend the University campus in Eastbourne for one session lasting one hour. The date of the visit will be agreed with you. Some measurements will be taken to your elbow and wrist movements and muscle activity and some photography will be taken but your face will not be shown for confidentiality issues. Also, photography will help to show how each participant is holding the computer mice, whether participants are holding each computer mouse in a correct way or not.

Prior the experiment, you will have the opportunity to become familiar with the task and with each mouse design used in this study by a familiarisation session. This session will include playing a computer game with each mouse design and this will take 30 minutes only.

Study requirements:

We need your attendance at the allowed agreed scheduled visits and you are allowed to drink tea or coffee, smoke or exercise on the day of participation before taking part in the study. In addition, any excessive exercise such as squash should not be done on the day before participation or on the day of participation before taking part in the study to avoid any muscle fatigue.

The possible risks of taking part:

During this study a non-invasive instrument to measure the elbow and wrist movements and muscle activity will be attached to the skin using a medical tape. It is possible that some people may develop a mild allergic reaction to this tape; if this happens I will remove the tape immediately and use some ice on the affected area. I will ask about possible allergies prior the study.

What are the possible benefits of taking part?

You will not benefit from taking part in this research directly, but you will help to show which mice could have positive impacts with the mouse users such as reducing the risks of musculoskeletal disorders in the neck and upper extremities.

What if there is a problem?

If there is any complaint about the way you have been dealt during the study or any possible harm you might have suffered can be addressed by contacting my supervisors. See the bottom of the information sheet for contact details.

Will my taking part in the study be kept confidential?

The research data will be stored securely using coding scheme, for example, participant 1, participant 2, no names will be added in the data to ensure confidentiality. Also, this data could be used for future studies. No one can access this data except for the researchers and the supervisors.

What will happen if I don't want to carry on with the study?

If you would like to withdraw from the study, you can withdraw at any time and without giving a reason. If this happen, we may ask you to use your data in our study, but you have the right to decide whether that can be used or not.

What will happen to the results of the research study?

This data will be used in the writing up my PhD thesis and we could have the chance to publish the results in scientific journals. An email will be sent to each participant to know the results of the study. You will not be identified in any report or publication. You are not allowed to give your individual results to anyone else.

Who has reviewed the study?

This study has been reviewed and approved by the Faculty of Research Ethics and Governance Committee, School of Health Sciences, University of Brighton.

Kind Regards
Bashayer Alhay
PhD. Physiotherapy students
School of Health Sciences
University of Brighton

Supervisor names:

-Dr. Lucy Redhead l.redhead@brighton.ac.uk

- Dr. Martin Bailey M.P.Bailey@brighton.ac.uk

-Dr. Derek Covill D.Covill@brighton.ac.uk

Student name: Bashayer Alhay ba64@uni.brighton.ac.uk

Tel: 07507259508

Appendix 9: Usability Questionnaire

The instructions and Items of the questionnaire are:

This questionnaire gives you an opportunity to tell us how satisfied you were with the different mice you used. Your response will help us understand what aspects of the mouse are particularly positive or negative.

Please try to relate your responses to the task that you have done with the different mice.

After you have completed this questionnaire, we will review your answers with you to make sure we understand all of your responses.

Thank You.

Bashayer Alhay,
University of Brighton.

Usability Questionnaire:

Q1) Put these mice in order according to which mouse is the most comfortable to use and the least comfortable to use?

Standard mouse Penguin mouse Evoluent mouse

Q2) Why did you find them comfortable/ not comfortable?

Q3) Put these mice in order according to which mouse is the easiest to move around?

The easiest to use: Standard mouse Penguin mouse Evoluent mouse

Q4) Why did you find this mouse is the easiest to move around?

Q5) Put these mice in order according to which mouse is the easiest to operate with in terms of pressing the buttons?

Standard mouse Penguin mouse Evoluent mouse

Q6) Why did you find this mouse is the easiest to operate?

Q7) Put these mice in order according to which of these mice you find it easy to become familiar with? Put them in order.

Standard mouse   Penguin mouse   Evoluent mouse

Q8) why did you find it easy to become familiar with it?

Q9) Can you give three words to describe each mouse used?

Q10) From the three mice, which one do you prefer? And what do you prefer about it and why?

Q11) Is there any other feedback you would like to give me that we have not covered?

Appendix 10: Summary of the 50 participants' responses from the usability questionnaire

- Question 2: Why did you find them comfortable/uncomfortable?

Evoluent (Comfortable):

- Because it does not allow much arm movement.

- Because how their fingers were placed on the mouse and the clicking was easier.

- More supportive and it positioned their arm in a natural way. Also, their hand fit comfortably around the mouse and they did not have to adjust or move it around much to move the cursor.

- Less friction against the surface.

- The control felt better.

- Sensitive, easy to glide and manoeuvre. Also, it was lightweight.

- Easy to use. They were relaxed and did not have to lift their hand (smooth movement).

- They did not feel pressure around their hand (effortless).

Evoluent (Uncomfortable)

- Difficult to control.

- Too fast (sensitive).

- The right click seemed out of reach; not at comfortable position to click.

- Difficult to get used to.

- Less comfortable.

- Because it was a new mouse design, they felt it would take some time to get used to it.

- Big size to hold; it would be better smaller or in a different size, similar to a Penguin mouse.

- Straining (fatigued).

Penguin (Comfortable):

- Supportive.

- More comfortable in the hand.

- More stable (less sensitive), easier to control and easy to use.

- More natural to use.

- The feeling of the silicone pad felt the nicest; the buttons were closer together and that made it easier to use.

- Easy to click.

- Lighter, easy to curve the hand around.

- Because of the arm position not putting any stress on the hand. Positioned the arm in a more natural way.

- Easy to hold (because participants were choosing the right size for their hand).

Penguin (Uncomfortable)

- More arm movements.

- Buttons felt cheap and chunky to press.

- Quite rigid and felt that the arm getting tired.

- More effort to move.

- Chunky, bulky.

- The least comfortable because it was heavy under the hand and wrist, and pad felt sticky.

- Not smooth in movement.

- The right click was little too low.

- Difficult to click.

- Felt strange position.

Standard (Comfortable)

- The most comfortable because they were used to it (familiar). They use it every day in their daily life.

- Because they are more used to it, they felt that their arm was positioned in a more natural way.

- Less movement compared to Penguin.

Standard (Uncomfortable)

- Felt uncomfortable after trying Penguin and Evoluent mice.

- Felt pain by the end of the task and needed more arm movements. It caused strain.

- The least sensitive and so it required more arm movements. More movements in the elbow and shoulder.

- Too much friction and not easy to glide on surface (stiff). More muscle work.

- Does not fit the shape of the hand like another mice design used.

- Difficult after using the other mice.

Question 4: Why did you find this mouse the easiest to move around?

Evoluent (Easy):

- Because of how the hand rested on it and it seemed very natural (how it positioned the hand).

- Less arm movement.

- More sensitive and more fluid. More reactive to their movements. Responsive to movements.

- Easier and smaller during movement.

- Glided easier. Not as restrictive to hand/arm.

- More responsive, less friction against the surface. Very smooth and felt right.

- Because it was easy to press the buttons.

- They could push and pull more easily and faster with real synchronisation of movement on the screen. Easy to navigate the screen.

- Light, rested and comfortable. Had moved 360 degrees.

- Because of the shape of the mouse.

Evoluent (Not easy):

- Too sensitive and almost slipped around a bit.

- It could be the easiest after more use.

- Because it was sensitive, it was felt difficult to be accurate.

Penguin (Easy):

- Because of the wrist support during movement.
- No friction.
- More control.
- Easier, freedom of the elbow.
- Sensitivity was good, and the shape made it easy to control.
- Movement of the mouse and function of it with ease.
- More ergonomic.

Penguin (Not easy):

- Did not enjoy moving the mouse at all and felt friction.

- Sweated a lot on hand (because of the rubber material).

- Was sticky sometimes (not a smooth movement). Some participants tended to move the mouse up sometimes to move it around.

Standard (Easy):

- The right size for the hand.

- Familiar.
- Better handling.
- The position of the hand was more comfortable, and the movement was smaller.
- Because they had more experience of it.
- More direct control.
- Easy to use.

Standard (Not easy):

- The least sensitive.

Question 6: Why did you find this mouse the easiest to operate?

Evoluent (Easy to operate):

- The buttons are near to each other, which provided comfort whilst clicking.
- The mouse shape.
- Fingers fit more naturally on this mouse.
- Need slight touch.
- Liked how it felt and the way it positioned the hand.
- Position of the buttons fit the hand.
- Lighter response.
- Comfortable and smooth.
- Nicer wrist position.

Evoluent (Not easy to operate):

- The buttons were bigger and wider.
- The right button was too far down. Needed to use the third finger for the right click and not used to this. (Difficult to right click because the buttons were too low.) It required more thought for the right click.

Penguin (Easy to operate):

- Fit the hand better.
- Buttons close to each other. The design of the button position (easy to reach).
- Because of the mouse design and size, it made it easy to operate.
- Easier to click.
- Resting the hand on the side of the mouse using the buttons with ease.
- The most ergonomic of them all.

Penguin (Not easy to operate):

- The most difficult one as was not responding to the clicks.

- It took longer to get used to.

Standard (Easy to operate):

- It needed a very light press. Little pressure needed.

- Buttons were exactly in the right place for the fingers. Fingers stayed on a button and it was easier to click.

- Familiar. They did not have to think where to click like the other mice.

- Straightforward. No need to be reminded how to operate this mouse. Reactions quicker. More tolerance.

- The most comfortable.

- Normal, small (compact), flexible.

- No need to move the fingers much or change their position intensively.

- Gravity assisted.

Standard (Not easy to operate):

- Buttons are not as close.

Question 8: Why did you find it easy to become familiar with it?

Evoluent (Easy):

- The ease to coordinate.
- Easy.
- You can see the buttons at the side if you have forgotten how to operate it (button position).
- Liked the mouse and with practice, I will be more familiar.
- More comfortable.
- Fits to hand.
- Lighter touch.
- Similar to Standard but more comfortable and responsive.
- It moves freely, and I assimilated the finger movements.
- More natural grip.

Evoluent (Not easy):

- Three buttons to get used to (confusing).

- Because of the sensitivity, it would take a bit of getting used to.

Penguin (Easy):

- Button position is clear to see and identify. Close to each other, straight under my fingers when I gripped the handle.

- The mouse design, shape and size. Everything in the right place.

- Once I used Penguin, I found it strange going back to Standard.

- Easy to adjust and to use.

- Although I am already familiar with the Standard mouse, the Penguin was the next easiest to become familiar with because pressing the buttons was the next easiest and comfortable and I didn't need to move my fingers a lot.

Penguin (Not easy):

- The weight of arm on the Penguin mat was a distraction and required me to adapt the use of hand much more.
- The grip could be difficult.

Standard (Easy):

- Familiarity and the most common to use in daily life (experience).

- Simple.

- A straightforward design; suits the flat hand.

- More natural to go to hand position for the mouse.

- Easy to use.

Question 9: Can you give 3 words to describe each mouse used?

Evoluent:

- Sensitive, comfortable, ergonomic.

- Supportive (thumb rest area), fast, difficult, complicated, hard (in texture).

- Relaxed, not easy (to move), weird.

- Awkward, painful, erratic, quick, useful.

- Smooth, irritating, dynamic, precise.

- Natural, efficient, modern.

- Big, frustrating.

- Clunky, accurate, effortless, nice shape.

- Fun, modern, light, easeful.

- Imprecise, unusual, uncomfortable.

- Stylish, too big, unfamiliar, very flexible, tiring (after long use).

- Fits well, unique, straining, responsive, excellent.

- Clumsy, rapid.

Penguin:

- Comfortable, fast, hand well supported.

- Easy, big, chunky, movable.

- Strange, uncomfortable, difficult.

- Annoying, supportive, fluid.

- Normal (feelings), slow (speed), controlled.

- Fun design, odd, frustrating.

- Precise, ergonomic, fitting, sleek.

- Hard (to manoeuvre), Gamers, rigid, tiring.

- Awkward, lighter, optimum, unrecognisable (clicking), not good design.

- Nice shape, less tiring (when compared to Standard).

- Difficult, heavy, glides easily.

- Sweat a lot, too sensitive, unnatural.

- Jerky, accessible, unfamiliar, barely comfortable.

- Smooth, not practical, adaptable, manoeuvrable.

- Excellent, bulky, sticky, rigid.

- Relaxing, normalised grip, unusual, large, different, interesting, clumsy, clunky.

- Fiddly.

Standard

- Most common, difficult to move, awkward.

- Rough, small, basic, heavy, hard.

- Easy, looks good, comfortable.

- Visual, familiar, most common.

- Simple, uncomfortable, moves well, adaptable.

- Tiring, appropriate speed, odd, slow.

- Bulky, old fashioned, precise, relatively comfortable.

- Clumpy, sticking (to surface), unresponsive.

- Overshoots, boring, comfortable, controllable.

- Movable, cumbersome, average, too much friction on surface.

- Felt sweaty, light, smooth.

- Restrictive, straining, stress.

- Compact, normal, flexible, unergonomic.

- Useless, painful, usual, nice in size, layout (buttons).

- Smooth, less supportive, clumsy.

Question 10: From the three mice, which one do you prefer? And what do you prefer about it and why?

Evoluent:

- Fast in movement, and comfortable. Also, I felt that my hand was well supported while holding the mouse.

- Because of the shape and because it positioned my hand in a nice position, a more natural way.

- The hand fits naturally on the mouse.

- Less arm movement and comfortable.

- Less tiring, precise and ergonomic, good for my health in the future.

- No restraining in the hand.

- Because it feels like with practice, it would be the fastest and most accurate.

- I did not have to use it much to move the cursor.

- Because of the sensitivity; very sensitive so does not need harsh movements to be effective.

- Because it's modern.

- It was easy to use and easier to adapt to once the position of the right click was mastered.

- Because it's fast.

- Reacted well to the movements.

- Quick to respond.

- I prefer it the most as it glided along the surface. It had the right sensitivity for me. The buttons were easy to use, all very natural. After a week using it, I would use myself at home.

- Less friction to move around.

- Better hand position and felt more natural to use.

- Ease of movement around the surface.

- The clicking seems natural.

- Lighter and responded to light touch.

- Can do more with less movement, powerful and easier to use. I did not have to move the mouse as much as the others.

- Required less effort.

- Once you were familiar with it, it was easy to use, smooth and efficient.

Penguin:

- More supportive to the hand and suited their movements.

- Due to the ease and control and the rubber handle makes it comfortable to grab.

- The most comfortable, not as sensitive as Evoluent.

- Due to the ease and control and the rubber handle makes it comfortable to grab comfortably to hold my hand around.

- Because it had a good shape and buttons were accessible.

- Just the right amount of friction.

- After this experiment, I preferred the Penguin because it was the most relaxing for me and it does not need many movements, considering the position of the buttons.

- Allowing a relaxed posture to the arm.

- Positioned the arm in a more natural way.

- Smooth and becomes easier to operate with time.

Standard:

- Prefer the shape because it positioned the hand in a natural way.
- Fits well to the hand. Moving around easily; No need to use the whole hand.
- More familiar with it and used to it; that’s why they are comfortable.
- Comfortable and most controllable.
- It’s the old one.
- Lowest to the table and with good arm position.

Question 11: Is there any other feedback you would like to give me that we have not covered?

Evoluent:

- More difficult with the right click.

- Comfy and I don’t lean on it.

- Position of hand/arm was uncomfortable after a while.

- Evoluent was difficult in pressing the buttons. It had a slippery surface because of the shiny material it used., Could be less slippery if they used a non-shiny surface/material.

- Right click was a new movement to my little finger as I’d never used it in a mouse operation before. It might need more practice for the muscle.

- After more time, it could become the most familiar.

Penguin:

- More difficult to do the left click.

- I found myself leaning on it; I can feel the heaviness of my hand.

- Needs large movements.

- Position of hand/arm was uncomfortable after a while.

- If I used the Penguin, I would like it and prefer it.

- Good for games.

- Felt nicer on the hand and felt more natural.

- My fingers were very sweaty and stuck a lot to the buttons.

- Was not always easy to move around the desk; more suitable for gaming but for personal use it was not always practical.

- Odd button configuration for Penguin.

Standard:

- Some aching to the thumb and wrist when using the Standard.