Kinematics and Muscle Activity of the Upper Extremity While Performing Cleaning Tasks

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Abstract

In Canada, occupations including janitors, caretakers, and building superintendents are the fourth most prevalent occupational group among men in the labour force, while cleaners are the 10th most prevalent occupational group among women (Statistics Canada, 2008). Cleaning tasks, typically labor-intensive, are characterized by a combination of static muscle loads (mainly involving bending and twisting of the back) and repetitive movements of the arms and hands requiring high physical exertion. Tasks such as lifting, mopping, and vacuuming often involve awkward postures with both dynamic and static muscular activities. These types of prolonged static and repetitive muscle activities cause muscle fatigue and may lead to musculoskeletal disorders. Therefore, the purpose of this study was to examine the effects of custodial cleaning tasks on upper extremity muscle activity and to assess changes in kinematics throughout the duration of a shift. Ten custodians employed at Brock University performed six cleaning tasks during two different sessions (pre-shift and post-shift). Kinematics of the upper extremity were collected, and muscle activity was recorded from 8 upper extremity muscles. Our results showed no significant changes in mean joint angles or joint range of motion pre-shift to post-shift. However, significant changes were observed in mean and peak EMG amplitudes as a result of time. Higher muscle activity was observed in the upper trapezius and FDS while lower muscle activity was found in the anterior deltoid, posterior deltoid, and EDC post-shift compared to pre-shift. This suggests that custodians use different muscular strategies to maintain task performance over the duration of a work shift. This may imply they are experiencing fatigue due to insufficient rest. This work acts as a stepping-stone into future investigations of custodial work and the adaptations over time.

Acknowledgements

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1.0 Introduction

1.1 Background

Musculoskeletal disorders (MSDs) are the most common type of workplace injury in Ontario, accounting for 44% of allowed lost time claims accepted by the Workplace Safety and Insurance Board (WSIB, 2019). From 2002 to 2019, MSDs were the leading cause of injury in the workplace for all age groups, genders, and industry sectors, with the exception of forestry in 2014 (WSIB, 2019). Individuals affected by these disorders frequently experience substantial pain and functional impairment. For the employer, these injuries result in loss of productivity and increased costs in the form of higher medical expenses and disability payments for injured workers. The combined direct and indirect costs in Ontario are estimated to be $19 billion from 1996-2006 (IHSA, 2020). Similar to Canada, MSDs are widespread in many countries, resulting in substantial costs to society and impact on quality of life. MSDs are the leading cause of work-related injuries in the United States (US), Nordic countries, and Japan, resulting in more absenteeism and disability than any other group of diseases (Punnett & Wegman, 2004).

In many workplaces, the upper extremities are fundamental to completing daily tasks, but inapt working demands can lead to inefficient performance and workplace injuries. The prevalence of upper extremity MSDs are increasing worldwide. In Ontario, upper extremity injuries accounted for 21.1% of lost time claims during 2019 (WSIB, 2019). In the United States, one third of worker’s compensation costs in the private industry are estimated to be caused by upper extremity MSDs. The direct costs with compensation exceed $20 billion in Washington State alone (Staal et al., 2007). In the Netherlands, there has been a rise in upper extremity MSD complaints from 19% to 28% between 1997 and 2002, resulting in 8% of the whole working population taking time off work (Staal et al., 2007). The Health & Safety Executive, a British institution responsible for the regulation of occupational risks to health, estimated that self-reported work-related MSDs resulted in 4.7 million lost working days in 2003/04 (Staal et al., 2007).

Upper extremity MSDs are highly prevalent in manual intensive occupations, such as cleaning. Cleaning is vital in society, it has an important role in general work and public environments as it enhances feelings of health and well-being (Kumar & Kumar, 2008). Clean work areas promote productivity and quality of output, while unclean environments can lead to accidents and ailments (Kumar & Kumar, 2008). Workers who perform cleaning services form an important proportion of the total working population in Canada. Occupations including janitors, caretakers, and building superintendents are the 4th most prevalent occupational group among men in the labour force, while cleaners are the 10th most prevalent occupational group among women (Koehoorn et al., 2011). Similarly, in the United States, over 4.2 million people work in buildings as cleaning staff (USDL, 2019), and over 8 million cleaners are employed in the European Union (Skills Panorama, 2018). Cleaners employed in the healthcare, education, and hotel sectors have been shown to be at high risk of developing upper extremity MSDs. Despite the high rate of employment in the cleaning industry and the high risk of workplace injury, this occupation is underrepresented in the literature. Of the reported injuries to cleaners, the upper extremities are the most frequent body area injured (21.1% - 41%), followed by the back (20% - 27.9%), although underreporting may be artificially depressing these statistics. (Koehoorn et al., 2011; WSIB, 2019).

The assessment of various tasks such as vacuuming, mopping, and garbage removal have been found to generate high physical demands and likely contributes to the development of MSDs (Cabeças, 2007; Chang et al., 2012; Village, et al., 2009). Cleaners may spend up to 50%

of their time cleaning floors and 25% of their time clearing garbage, although the amount of time allocated to each task varies by work environment (Village et al., 2009; Salwe et al., 2011). The task of mopping has received considerable attention in the literature as it is a high-risk task found to elicit high static loads and poor working postures (Kumar & Kumar, 2008). Generally muscular demands are reported relative to each muscles' maximum activation capacity during a maximal voluntary contraction (MVC). Mopping is associated with high muscle activity in the flexor carpi ulnaris (FCU) (28.2% MVC) and extensor carpi ulnaris (ECU) (33.7% MVC) and non-neutral working postures in the neck (51° flexion) and back (28° flexion) (Søgaard et al., 1996; Cabeças, 2007). During vacuuming, median electromyogram (EMG) amplitude of the upper extremity muscles has been found to range from 4.5% MVC to 47.5% MVC for females and from 2.7% MVC to 23.6% MVC for males and was generally the highest in the upper trapezius. Statistically significant gender differences have been found in the muscle activity of the FCU, brachioradialis, biceps brachii, triceps brachii, anterior deltoid, and posterior deltoid during vacuuming, with women experiencing higher levels of median muscle activity than men (Bak et al., 2018). There is minimal research on garbage removal; however, epidemiological studies suggest it is one of the main tasks associated with injury (14% of injuries) due to poor working posture (trunk flexion >20°) and excessive loads (4.5- 10kg) (Koehoorn et al., 2011; Village et al., 2009).

The most common work-related complaint cleaners report is overexertion due to excessive work rates (Chang et al., 2012; Kumar & Kumar, 2008). If cleaners are exhausted after a work shift, they are likely suffering from some level of muscle fatigue. Muscle fatigue has been shown to alter muscle activation patterns and body segment kinematics (Ebaugh et al., 2005; Dingwell et al., 2008; Zabihhosseinian et al., 2015; Forman et al., 2020). Muscle fatigue is often common throughout the workday in labour intensive occupations, and to the researchers' knowledge, only one study has attempted to quantify changes in muscle activation during cleaning tasks over the course of a work shift (although it was not the primary objective). In this study, muscle activity was only examined from the upper trapezius during workplace floor cleaning (Søgaard et al., 1996). The development of muscle fatigue was evaluated by analyzing the EMG signals obtained during test contractions performed pre- and post-working hours for changes in EMG amplitude and frequency content. As expected, the pre- versus post-shift test contractions for the mopping group showed classic EMG signs of fatigue (e.g. a decrease in mean power frequency and a simultaneous increase in RMS-amplitude of the EMG signal) (Kamen & Gabriel, 2010). Fatigue is often common throughout the workday in labour intensive occupations, resulting in changes to muscle activation and body segment kinematics over the duration of a work shift and is an important topic for future investigation.

1.2 Research Gap

Previous research investigating muscular effort and working postures of occupational cleaners has mainly focused on quantifying the risk associated with certain cleaning tasks. Quantifying the risk of cleaning tasks is important for the modification of occupational health and safety policy and injury prevention methods. However, a high percentage of cleaners (50-75%) have reported to complain about feelings of over exhaustion at the end of their shift, as a result, cleaners likely adopt varied muscle activation patterns, working postures and movement strategies to complete their work (Chang et al., 2012; Søgaard et al., 1996). While the demands on the worker are likely to change over the course of the work shift, the risk associated with each of these exposures is unknown. To date, little research has been conducted to investigate multiple muscles of the upper extremity during cleaning work, especially in combination with kinematic recordings of the upper extremity. Furthermore, despite evidence of fatigue in custodial workers, to the researchers' knowledge, no one has investigated if there are changes in muscle activity and upper extremity kinematics when comparing different cleaning tasks performed at the beginning of a shift to those same tasks performed at the end of a shift.

1.3 Research Questions

Do upper extremity kinematics and/or muscle activity differences exist in custodial tasks performed at the beginning of a shift to those same tasks performed at the end of a shift? If the physical demands of each task remain the same (beginning and end of shift), might changes in upper extremity kinematics and muscle activity indicate an elevated MSD risk?

1.4 Purpose

The purpose of this research was twofold:

1. To assess changes in upper extremity muscle activity and kinematics (posture) during typical custodial tasks. The tasks assessed included:
    - Vacuuming
    - Mopping
    - Garbage removal
2. To determine if differences in pre-shift or post-shift timings create differential task exposures. This included:
    - Mean and peak muscle activity
    - Trunk and neck joint angles

        - Upper extremity joint range of motion

1.5 Hypotheses

1. There will be differences in muscle activity pre-shift compared to post-shift.

   Measurements obtained during a mopping task have shown that the descending part of the trapezius displays EMG signs of muscle fatigue over the duration of a workday. These changes were observed as an increase in RMS amplitude and decrease in mean power frequency (Søgaard et al., 1996). Moreover, upper extremity fatigue has been found to cause an increase in shoulder elevation and a decrease in average shoulder abduction angle during reaching tasks which should lead to compensations and elevated trapezius activity therefore, we hypothesize an increase in upper trapezius activity during the post-shift tasks (Fuller et al., 2009). Additionally, the cleaning tasks in this study are dual motor tasks that require simultaneous hand-gripping and wrist forces. During dual motor tasks, wrist extensors have been found to be active at moderate-to-high levels across all conditions (handgrip and wrist forces of various magnitudes) and demonstrated greater activity than the wrist flexors during handgrip dominant tasks (Forman et al., 2019). The continuous, elevated muscle activity of the wrist extensors predisposes them to an earlier onset of fatigue (Hägg & Milerad, 1997). Thus, we hypothesize that EDC will have sustained muscle activity throughout the shift, resulting in greater activity during the post-shift tasks.
2. During the vacuuming task, the upper trapezius will exhibit the highest muscle activity across all muscles evaluated.

Muscle activity during vacuuming was generally the highest in the upper trapezius regardless of technique, vacuum cleaner model, or participant sex (Bak et al., 2018).

3. There will be a change in joint angles and joint range of motion post-shift compared to pre-shift.

   Custodial tasks have been found to change muscle activity (specifically fatigue related changes) and muscle fatigue has been found to alter body segment kinematics (Søgaard et al., 1996; Fuller et al., 2009; Dingwell et al., 2008).

4. There will be a decrease in shoulder flexion and an increase in trunk flexion post-shift compared to pre-shift.

   Following fatigue of the upper extremity, the average center of mass and center of pressure positions both shift more laterally toward the non-reaching side during reaching tasks. This suggests that individuals may lean toward their non-reaching side when fatigued (Gregory et al., 2008). Additionally, following fatigue, shoulder flexion has been found to decrease over time during an upper extremity task which may result in more trunk compensation to maintain task performance (McDonald et al., 2019).

2.0 Literature Review

2.1 The Upper Extremity

2.1.1 Bones and Joints

The bones of the upper extremity consist of the humerus, ulna, radius, carpal bones of the wrist, and the metacarpal bones and phalanges of the hand. The humerus is the proximal bone of the upper extremity. The head of the humerus articulates with the scapula at the glenoid cavity which forms a ball-and-socket type joint known as the shoulder joint. The shoulder joint permits the greatest angular range of motion of any joint in the body and thus enables the positioning of the hand for a wide variety of functions. At the distal end of the humerus articulations between the trochlea of the humerus and the trochlear notch of the ulna as well as the capitulum of the humerus and the proximal head of the radius form the elbow joint. The elbow joint is a hinge joint which enables flexion and extension of the elbow. The ulna and radius are two parallel bones that comprise the forearm. In the anatomical position, the ulna lies medial to the radius. The ulna and radius form two radioulnar joints at the proximal and distal ends allowing for supination and pronation of the forearm. Lastly, the radiocarpal (wrist) joint involves the distal articular surface of the radius and three proximal carpal bones. The radiocarpal joint is a condylar articulation that permits flexion/extension, adduction/abduction, and circumduction (Martini, Timmons, & Tallitsch, 2012).

2.1.2. Muscles and Actions

Although there are various muscles in upper extremity only the muscles examined in the succeeding study will be mentioned including the flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), biceps brachii, anterior/lateral/posterior deltoid, trapezius (upper fibers), and the cervical extensors. The FDS and EDC form an antagonist/agonist muscle pairing. The FDS lies in the anterior compartment of the forearm and primarily functions to flex the four medial metacarpophalangeal joints but can also act as a secondary flexor of the wrist. The EDC lies in the posterior compartment of the forearm and primarily functions to extend the fourth medial metacarpophalangeal joint but can also act as a secondary extensor of the wrist. The biceps brachii lies anterior to the humerus and functions to flex and supinate the forearm. The deltoid is a proximal muscle of the upper extremity which lies over the glenohumeral joint and can be divided into three distinct parts (anterior, lateral, and posterior). The primary function of the deltoid is abduction of the humerus although the anterior portion also flexes and medially rotates the humerus while the posterior portion extends and laterally rotates the humerus. The trapezius is a large superficial back muscle that extends from the external protuberance of the occipital bone to the lower thoracic vertebrae and laterally to the spine of the scapula. The upper fibers can elevate and upwardly rotate the scapula and extend the neck. The more superficial layer of the cervical extensors consists of the splenius capitus and splenius cervicis which when activated bilaterally act to extend the neck (Martini, Timmons, & Tallitsch, 2012).

2.2 Surface Electromyography

Electromyography is a technique that measures the electric potential generated by the compound muscle action potential (CMAP). Surface EMG (sEMG) involves placing electrodes on the skin directly over the muscle (Figure 1). This approach restricts the recording to superficial muscles, unlike indwelling EMG, where needles or wires are placed within the muscle to record the electrical potential of deep muscles or even individual motor units (Kamen & Gabriel, 2010). The advantage of sEMG is that it is non-invasive and easy to apply.

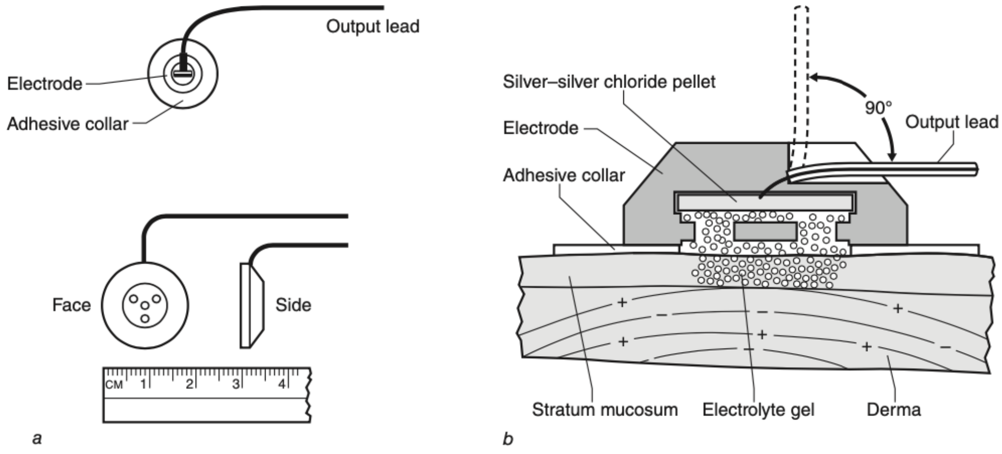

Figure 1. The surface electrode. (a) The dimensions of a typical circular surface electrode and (b) the skin-electrode interface (from Kamen & Gabriel, 2010).

Before surface electrodes are placed, sufficient preparation is required to ensure proper recording. The skin at the recording site should be abraded to remove oils and layers of dead skin. After abrading the skin, the site should be wiped with alcohol to clean the area and reduce any moisture to avoid skin-conducted artifacts. Once the skin is prepared, an electrolyte gel is applied to the recording surface of the electrode and rubbed into the skin. This serves to decrease the recording resistance through the skin by creating an electrolyte bridge to maintain a conductive path between the electrode and the skin (Kamen & Gabriel, 2010). Surface electrodes are made from conductive metals (e.g. gold, silver, stainless steel). Electrochemical reactions between the metal and the electrolyte gel give rise to a dipole layer of charge at the electrode-electrolyte interface, where the electrolyte gel just outside of the electrode surface achieves a different potential that the rest of the surrounding medium (Kamen & Gabriel, 2010). During muscle innervation, the changing potential gradients, along the muscle fibre sarcolemma, associated with the propagating dipole result in electrical currents in the electrode leads (Kamen

& Gabriel, 2010). The currents in the electrode leads are sent to an amplifier to increase the magnitude of the signal so that it is large enough to be digitally recorded (Kamen & Gabriel, 2010). Therefore, surface electrodes convert ionic potentials generated by the muscles into electronic potentials that can be amplified, and digitally recorded for further analyses (Kamen & Gabriel, 2010).

Accurate placement of electrodes is important. For kinesiological applications, bipolar electrodes should be placed 2 cm away from the motor point (Kamen & Gabriel, 2010). Bipolar recordings consist of two recording electrodes placed on the skin directly over the muscle and one ground electrode typically placed on a nearby bony prominence. An interelectrode distance of 5mm to 20mm is recommended as this will help prevent the formation of a salt bridge between the two recording electrodes (Kamen & Gabriel, 2010). Ensuring the electrodes, leads, and cables are secure can help minimize movement artifacts during dynamic movements. Anatomical guidelines have been published that outline recommended electrode placements for various muscles based on anatomical landmarks (Perotto, 1994). An acceptable sampling rate is specified by the Nyquist theorem which suggests a minimal acceptable sampling rate of at least one hertz more than twice the highest frequency content of the signal (Merletti, 2017). The typical frequency band present in a bipolar sEMG signal is 10-500 Hz and a conservative sampling rate is 2000 Hz.

Surface EMG allows for the determination, at each moment, whether a muscle is active or inactive and the degree of activity exhibited during periods of activation. Surface EMG allows for the examination of multiple muscles synchronously. EMG techniques are used to measure sensory nerve, motor nerve or muscle fibre conduction velocities, gross muscle activation patterns, coactivation, and fatigue. In a clinical setting, EMG techniques are useful for diagnosing neuromuscular disorders and movement disorders (e.g. tremor, myoclonus, dystonia, dyskinesia) as well as aid in rehabilitation processes (e.g. post-treatment evaluations) (Pullman et al., 2000). EMG has also been used to improve performance in occupational and sports settings by improving movement economy and preventing injuries (Türker & Sözen, 2013).

2.2.1 Analysis

A raw sEMG signal is a mix of biologically relevant signal and noise. With the presence of too much noise, the signal is no longer representative of the muscle activation characteristics. The signal must be processed to minimize the impact of noise on EMG analysis and interpretation. Noise contamination comes from two basic sources: inherent noise and interference (Kamen & Gabriel, 2010). Sources of inherent noise occur from the measurement system (i.e. electrode, amplifier) and are responsible for observed direct current (DC) bias. Removal of the DC bias is performed by calculating the signal average and subtracting this value from each data point, ensuring the data oscillates at a true zero (Kamen & Gabriel, 2010). If the signal is contaminated with interference noise sources (i.e. electronics, fluorescent lights) a notch filter can be applied to eliminate signal power at 60 Hz. Another source of noise contamination, particularly in musculature surrounding the torso, is electrocardiographic (ECG) activity. Removal of ECG activity can be accomplished by using a high-pass filter at 30 Hz (Drake & Callaghan, 2006). The signal is then linear enveloped by applying full-wave rectification and a low-pass filter in order to generate normalized linear enveloped EMG as an outcome measure. Full-wave rectification consists of changing the amplitude of the signal to all absolute values as this allows for the application of standard amplitude parameters (i.e. mean, peak, area) to the signal (Konrad, 2005). A Butterworth filter is often applied as it has a good frequency response and a steep roll-off without pass band ripple, although other filters (e.g. Bessel, Chebyshev) may be used depending on nature of the study, and desired frequency response characteristics. Commonly a 2nd order Butterworth filter with a cut-off frequency of 6 Hz is used and applied recursively in order to minimize phase shift (Konrad, 2006). Higher order filters can be imposed onto the dataset to attenuate filter roll-off or to approximate an ideal brick wall response. A residual analysis can be performed to determine the cut-off frequency in the absence of any *a priori* criteria (Kamen & Gabriel, 2010). Once the signal has been smoothed it must be amplitude normalized as this allows for intraindividual and interindividual comparisons (Kamen & Gabriel, 2010). The most common method of normalization is called maximum voluntary contraction (MVC) normalization. This method requires the recording of an MVC for each muscle, recommendations for MVC positions are published (Konrad, 2005). Each data point of a linear enveloped EMG time series is divided by the MVC value obtained from a similarly linear enveloped EMG trace, thereby converting the signal to a relative value ready for analysis and comparison. The signal is ready to be analyzed upon completion of the signal processing.

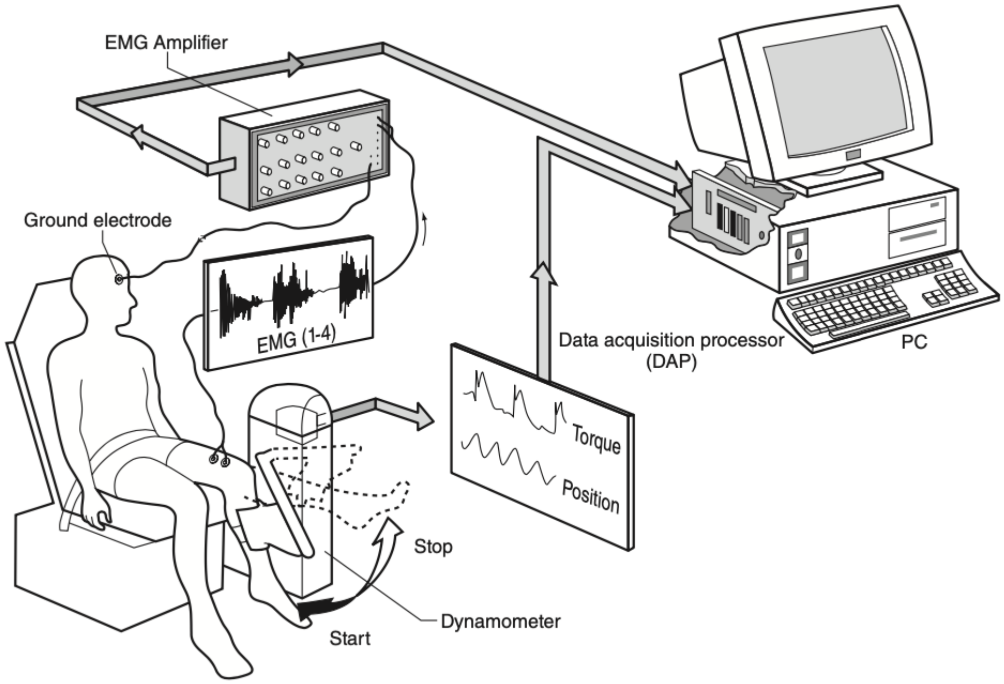

Figure 2. The essential components of an analog-to-digital data acquisition system in EMG (Kamen & Gabriel, 2010)

Electromyogram analyses can be performed in the amplitude domain and/or the frequency domain. The signal amplitude provides information on the activity of the muscle (active or resting), the duration of muscle activity, and the intensity of muscle activity (Türker & Sözen, 2013). Two common analysed amplitude parameters are the mean and peak values, with the mean value representing the average muscle activity over time and the peak value representing the highest amplitude value recorded over a specified time window. These values can be used to compare tasks demands, for example, a task that elicits a higher mean value implies that it requires more muscular effort therefore suggesting that the task is more physically demanding and potentially increases the chance of developing a musculoskeletal disorder. An amplitude probability distribution function (APDF) is an analysis method that reports the probability in which the myoelectric signal is lower than or equal to a specific contraction level and can be expressed as a fraction of the total duration that the signal is within a certain level (Jonsson, 1988). APDF is helpful for analyzing muscular strain during occupational work. The “static level” may be defined as the level of muscular contraction corresponding to the probability level P=0.1. This definition means that for 10% of the time, muscle activation is at a certain level or lower. The median level (P=0.5) and peak level (P=0.9) is the contraction level under which the muscle activity is found to occur for 50% and 90% of the time respectively (Jonsson, 1982). Based on previous research, the following limit values have been suggested for constrained work with a duration of one hour or more: the static load level should not exceed 2% of MVC and must not exceed 5% of MVC; the median load level should not exceed 10% of MVC and must not exceed 14% of MVC; and the peak loads should not exceed 50% of MVC and must not exceed 70% of MVC (Jonsson, 1982). Another method is to analyze the distribution of short spontaneous EMG gaps in the data. The gaps are defined as time periods with contraction levels consistently below 0.5% MVC (Veiersted, 1990). The gaps represent the muscle is “rested” therefore, gaps analysis can be used to quantify the work-to-rest ratio of muscles during tasks (Veiersted, 1990). The relationship between endurance time and relative force of contraction for a continuous dynamic contraction without any intervening rest period and with a constant muscular load has been found to be approximately the same as a sustained isometric contraction (Jonsson, 1988). These results indicate that short rest periods are more important for optimum endurance time than the type of contraction.

2.2 Kinematics

2.2.1 Human Motion

The movement of physical bodies has been of interest for many years. More than 3000 years ago, Babylonian astronomers studied the problem of planetary positions (Lu & Chang, 2012). Progression in this field ultimately laid the foundation for the development of classical mechanics published by Isaac Newton in 1687. Classical mechanics outlines the law of universal gravitation and the three laws of motion which can be applied to the motion of planets and all forms of movement on earth. Later research examining the mechanical interactions within the biological systems and with the environment have helped to form the discipline of research called biomechanics (Lu & Chang, 2012).

Human movement is achieved by a complex and highly coordinated mechanical interaction between bones, muscles, ligaments, and joints within the musculoskeletal system (Lu & Chang, 2012). Any injury or lesion of any of the individual elements of the musculoskeletal system will change the mechanical interaction and cause degradation, instability or disability of movement. To address this, proper modification, manipulation and control of the mechanical environment can help prevent injury, correct abnormality, and speed healing and rehabilitation (Lu & Chang, 2012). Therefore, the analysis of human movement has clinical, research, and sports performance applications.

Vision-based motion analysis involves extracting information from sequential images to describe movement (Colyer et al., 2018). This technique was pioneered by Eadweard Muybridge, dating back to 1878, where he used 24 cameras and an increased shutter speed to capture the movement of a horse while galloping. Through this work, titled “The Horse in Motion”, Muybridge proved that at certain points while galloping, all four legs of a horse are airborne

(Figure 3). This eventually led to the recording of human movement and paved the way for the future. With the help of technological advancements, modern motion capture systems allow for the recording of movement in three dimensions and can be used in combination with electromyography and force transducers. Human motion analysis has become a useful investigative and diagnostic tool in many research and clinical areas. It can be used to determine deviations from normal movement, help identify and evaluate neuromuscular disorders as well as help with treatment planning and/or assess the efficacy of treatments (Lu & Chang, 2012). It has also seen many applications in assistive technology such as prosthetics and orthotics. In sport science, applications include athletic performance, technique expertise, injury mechanisms, injury prevention, and rehabilitation (Pueo & Jimenez-Olmedo, 2017). Recent applications include entertainment, augmented reality, and the development of marker-less motion capture using recent advancements in computer vision and machine learning (Merriaux et al., 2017).

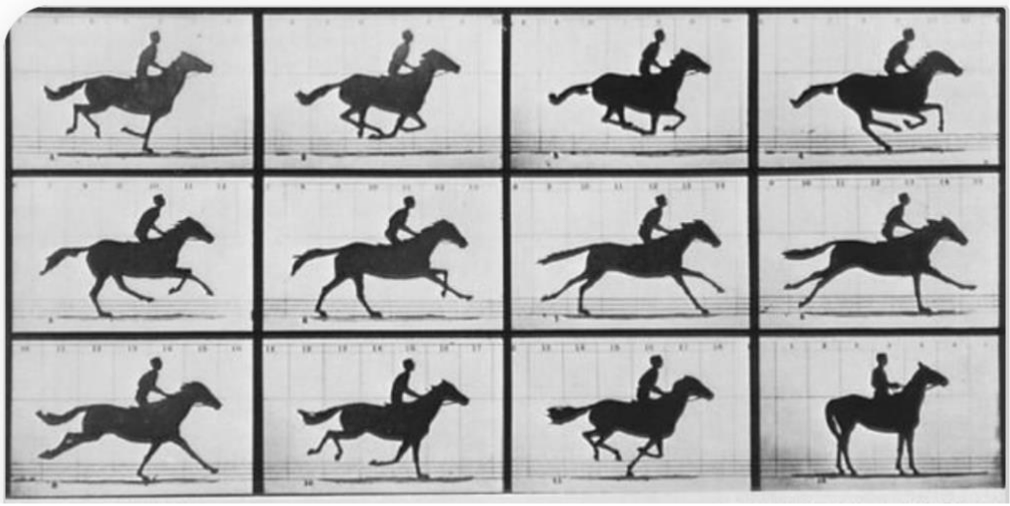

Figure 3. *The Horse in Motion* by Eadweard Muybridge, 1878.

2.2.2 Motion Capture

Biomechanical tools have developed considerably from manual annotation of images to marker-based optical trackers, inertial sensor-based systems and marker-less systems using sophisticated human body models, computer vision, and machine learning algorithms (Coyler et at., 2018). A wide range of motion analysis systems allow movement to be captured in a variety of settings, which can broadly be categorised into direct (devices affixed to the body, e.g accelerometry) and indirect (vision-based, i.e. video or optoelectronic) techniques (Coyler et al., 2018). A large number of commercial optoelectronic systems are available for the study of human movement such as those developed and manufactured by Vicon. These systems utilize multiple cameras that emit invisible infrared light and retroreflective markers that reflect the infrared light back to the cameras. A marker must be visible by a minimum of two cameras in order for its 3D position to be triangulated. Accurate quantification of whole-body motion can be difficult as the human body is an extremely complex, highly articulated, self-occluding and only partially rigid entity (Coyler et al., 2018). To make this process more tractable, the structure of the human body is usually simplified as a series of rigid bodies connected by frictionless rotational joints (Coyler et al., 2018). Rigid bodies define body segments and must remain fixed throughout the entire process (calibration and recording). For 3D reconstruction of a rigid body at least three non-collinear markers must be affixed to each segment to specify six degrees of freedom (DOF). Markers defining joint centers are necessary for calibration, though they can be removed before data recordings. Calibration allows for the position of markers to be reconstructed into real-space coordinates, most commonly via direct linear transformation (Coyler et al., 2018). These “calibration markers” are precisely placed to specific anatomical landmarks for accurate reconstruction and proper definition of joint coordinates (Wu et al., 2005). In addition to marker placement, the capture area should be optimized to the type of movement being examined. The first consideration is how large the capture area should be. If the movement is small (e.g. facial expressions) each camera can be aligned to capture the same relative area. If the movement is large (e.g. walking) the space can be split into multiple capture zones if necessary. In this circumstance, a certain number of cameras (at least 2) are dedicated to capture markers only in that zone (Roesler, 2011). The second consideration is with regards to quality, as the cameras must strike a balance between resolution and sampling rate. A higher resolution is ideal for precise movements but at the expense of sampling rate. Alternatively, a higher sampling rate is superior for fast movements but at the expense of resolution (Roesler, 2011). Factors that might affect measuring error include marker size, marker roundness, reflection capacity, calibration velocity and duration, and lighting conditions (Windolf et al., 2008).

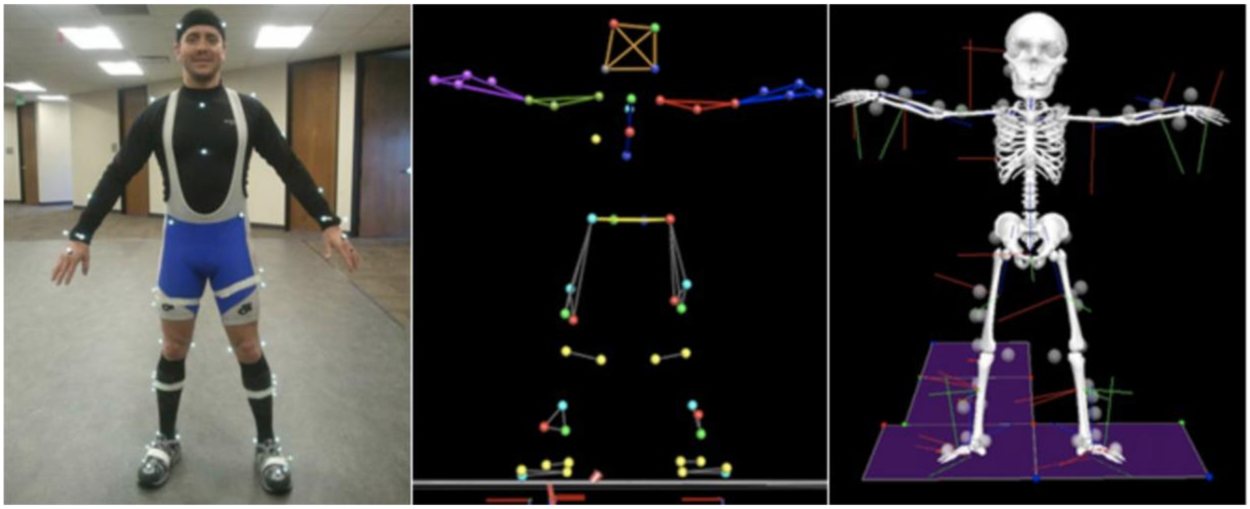

Figure 4. 3D motion capture. Marker placement (left), marker projection in recording software (middle), and modeling of a skeleton (right) (https://experiment.com/).

2.2.3 Joint Coordinate Systems

The Standardization and Terminology Committee of the International Society of Biomechanics have defined joint coordinate systems (JCS) for the shoulder, elbow, wrist, and hand. The standardization of motion is only described for right shoulder joints. Whenever left shoulders are measured, it is recommended to mirror the raw position data with respect to the sagittal plane ($z = -z$). Then, all definitions for right shoulders are applicable (Wu et al., 2005). Rotations are described using Euler angles. For a clearer interpretation of these angles it is suggested that the coordinate systems of the proximal and distal body segments are initially aligned to each other by the introduction of 'anatomical' orientations of these coordinate systems. The rotations of the distal coordinate system should then be described with respect to the proximal coordinate system (Wu et al., 2005). Properly defined JCS help provide consistent and accurate reporting of data.

JCS and motion of the torso may be represented relative to the global coordinate system in which the torso rotation sequence is Z-X-Y with positive Z_t rotation representing extension, positive Y_t rotation representing axial rotation to the right, and positive X_t rotation representing lateral bend to the right (Figure 5). The torso coordinate system is as follows:

$+Y_t$ is the line connecting the midpoint between the xiphoid process and T8, and the midpoint between the suprasternal notch and C7, pointing upward.

$+Z_t$ is the line perpendicular to the sagittal plane, pointing to the right.

$+X_t$ is the line commonly perpendicular to the Z_t- and Y_t- axis, pointing forward.

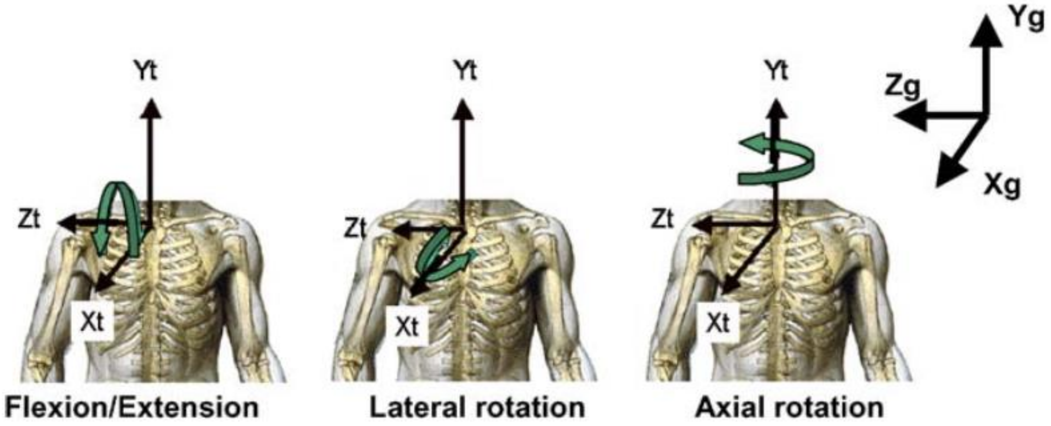

Figure 5. Thorax coordinate system and definitions of motion (Wu et al., 2005).

The humerus coordinate system quantifies humeral angle of elevation, plane of elevation, and axial rotation relative to the torso. The rotation sequence for the humerus is Y-X-Y’, with rotation around the Y_h axis determining the plane of elevation and rotation about the X_h axis determining the angle of elevation. The humerus coordinate system is as follows:

$+Y_h$ is the line connecting the glenohumeral rotation center and the midpoint of the epicondyles, pointing toward the glenohumeral rotation center.

$+Z_h$ is the line perpendicular to the plane formed by Y_h and Y_f (the line connecting the most caudal-medial point on the ulnar styloid and the midpoint of the epicondyles, pointing proximally), pointing to the right.

$+X_h$ is the line commonly perpendicular to the Z_h- and Y_h- axis, pointing forward.

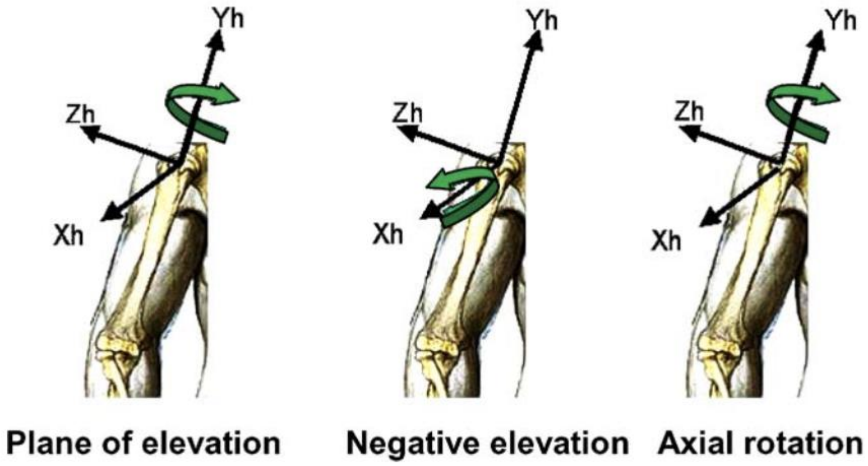

Figure 6. Humerus coordinate system and definitions of motion (Wu et al., 2005).

Joint rotations of the forearm are relative to the humerus. The rotation sequence of the forearm is Z-X-Y, with positive Z_f rotation representing flexion, positive X_f rotation representing the carrying angle (rarely reported), and positive Y_f rotation representing pronation. The forearm coordinate system is as follows:

$+Y_f$ is the line connecting the ulnar styloid and the midpoint between the epicondyles, pointing proximally.

$+X_f$ is the line perpendicular to the plane through the ulnar styloid, radial styloid, and the midpoint between the epicondyles, pointing forward.

$+Z_f$ is the line commonly perpendicular to the X_f- and Y_f- axis, pointing to the right.

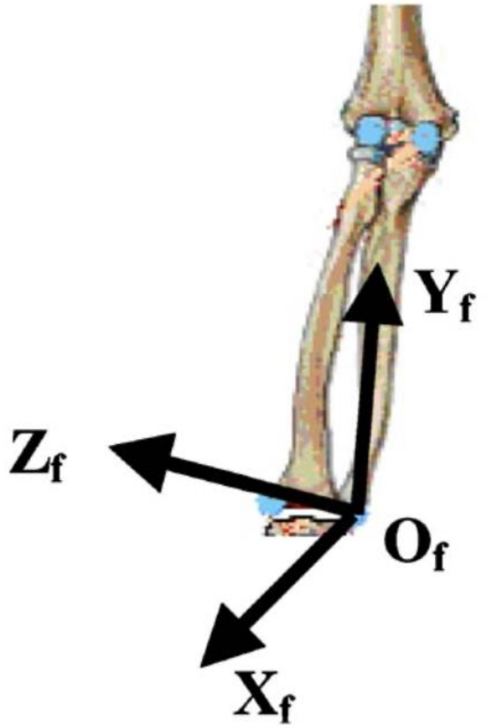

Figure 7. Definition of forearm coordinate system (Wu et al., 2005).

Global wrist motion is typically considered as the motion of the second and/or third metacarpal with respect to the radius. If only general motion of the wrist is of interest, one can use the forearm and third metacarpal to create a simplified wrist joint. The rotation sequence for the hand is Z-X-Y, with positive Z_h rotation representing wrist flexion, positive X_h rotation representing ulnar deviation, and positive Y_h rotation representing pronation. The hand coordinate system is as follows:

$+Y_h$ is the line parallel to a line from the center of the distal head of the metacarpal to the midpoint of the base of the metacarpal.

$+X_h$ is a sagittal plane formed by the X_h- and Y_h- axis, which splits the metacarpal into mirror images.

$+Z_h$ is a line commonly perpendicular to the X_h- and Y_h- axis.

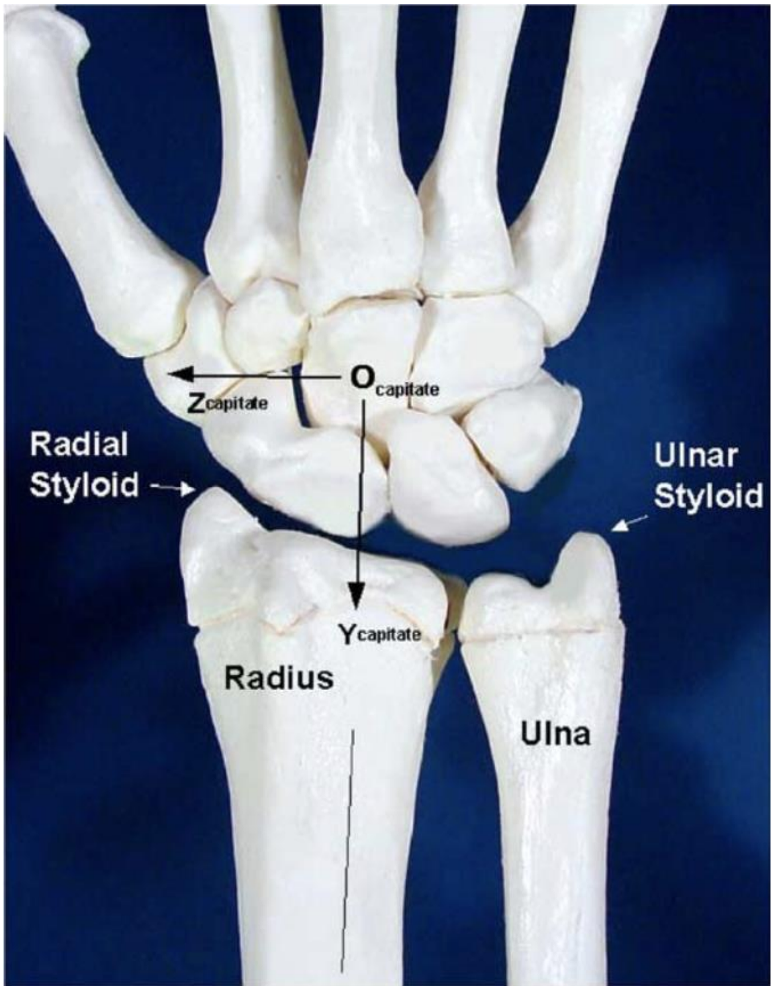

Figure 8. Dorsal view of a right wrist joint illustrating the capitate coordinate system as an example of the carpal coordinate systems (Wu et al., 2005).

2.3 Fatigue

2.3.1 Characteristics

According to Enoka and Duchateau (2016) fatigue should be defined as a symptom in which both physical and cognitive function may be limited through interactions of perceived fatigability and performance fatigability. Performance fatigability refers to the decline in an objective measure of performance over a discrete period of time and perceived fatigability refers to the changes in the sensations that regulate the integrity of the performer (Enoka & Duchateau, 2016). Performance fatigability can manifest experimentally as decreased movement accuracy, impaired proprioception acuity, decreased co-contraction during precision movements, and decreased peak contractile speed and torque generation (Forman et al., 2020). The consequences of performance fatigability can contribute to the development of MSDs and impair kinematic performance.

According to Enoka and Duchateau (2016), defining the mechanisms of fatigue is situational and depends on the rate of change of the two measures of fatigability (performance and perceived), which themselves depend on the status of 4-7 modulating factors (Figure 9). For example, the decline in maximal voluntary contraction force that develops during sustained low-intensity activity is largely attributable to a reduction in the activation signal generated by the nervous system, whereas the reduction in MVC force after high-intensity activity is more likely due to a decline in contractile function (Enoka & Duchateau, 2016). Additionally, the level of fatigue reported by individuals with known pathologies is positively correlated with the level of depression, illustrating the influence of psychological state on fatigability level (Enoka & Duchateau, 2016). Regardless, classical measures of fatigue such as the time to complete a prescribed task, the reduction in MVC force, and the decline in power production can be used to quantify performance fatigability but may not provide a measure of the intensity of the symptom.

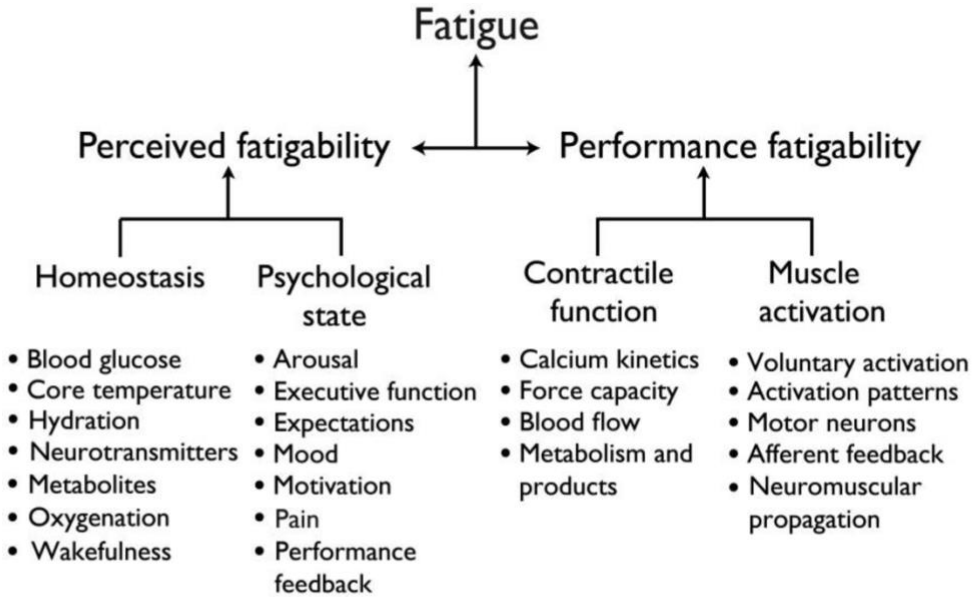

Figure 9. Proposed taxonomy by Enoka & Duchateau suggesting that fatigue be defined as a self-reported disabling symptom derived from two independent attributes: perceived fatigability and performance fatigability (Enoka & Duchateau, 2016).

2.3.2 Fatigue and Electromyography

In the field of ergonomics, researchers and practitioners are concerned with workplace fatigue and the extent to which occupational tasks may result in muscular fatigue. Muscular fatigue can lead to injury, therefore, efforts to investigate and mitigate workplace fatigue are of interest. EMG is a technique commonly used to examine muscular activity and may also be used to investigate muscular fatigue. Changes in EMG parameters during fatiguing efforts have demonstrated the EMG signal changes with fatigue (Kamen & Gabriel, 2010). EMG amplitude decreases over time during a sustained maximal isometric contraction, however, EMG amplitude increases over time during a sustained submaximal isometric contraction (Kamen & Gabriel, 2010). The decrease in EMG amplitude during a maximal isometric contraction is likely due to the decrease in motor unit firing rate, possible neuromuscular propagation failure, or the slowing of conduction velocity produced by the potassium ions and the depletion of sodium inside the muscle fiber (Kamen & Gabriel, 2010). Contrarily, the increase in EMG amplitude during sustained submaximal isometric contractions is likely due to an increase in motor unit recruitment, and the increase in firing rate of those already recruited to maintain the required force (Kamen & Gabriel, 2010).

A number of studies have noted that the frequency-based EMG variables are less dependent than amplitude on the instantaneous force level of a muscle, and are therefore, more sensitive to fatigue-related changes (Potvin & Bent, 1997). The frequency of the EMG signal decreases during fatiguing contractions (Kamen & Gabriel, 2010). The mean power frequency has been found to decline during sustained maximal isometric contractions regardless of limb (left or right) or participant sex with respect to the elbow flexors. Similar changes have been found for sustained submaximal isometric contractions (Kamen & Gabriel, 2010). The mean power frequency of the EMG signal has been reported to decline in both static and dynamic contractions (Kamen & Gabriel, 2010).

With respect to the forearm, it has been proposed that the wrist extensors function primarily as joint stabilizers while the wrist flexors are highly task dependent and function primarily as the prime mover in most hand related tasks (Forman et al., 2020). This is supported in the literature as the wrist extensors have been found to contribute more to joint rotational stiffness than the wrist flexors during external wrist perturbations, greater co-contraction during both hand-grip force and wrist exertions than the flexors, and they exhibit increased muscle activity regardless of task-parameters (Holmes et al., 2015; Forman et al., 2019). Continuous activity and insufficient rest are both risk factors in the development of early onset fatigue and chronic overuse injuries; therefore, the wrist extensors are likely more susceptible to injury than the flexors (Forman et al., 2020). This is relevant for occupations involving repetitive use of the forearm and wrist. Furthermore, tasks with low motor variability continually stress the same muscles, increasing fatigue and susceptibility to injury (Tat et al., 2014). Increasing the frequency and load during a pushing task was found to significantly alter muscle activity during the rest phase, ultimately reducing the work-to-rest ratio (Tat et al., 2014). This suggests that task demands not only influence muscular fatigue during the work phase but also during the rest phase. Additionally, the effects of forearm muscle fatigue on MVC force have been found to last up to 10 minutes post-fatigue, illustrating prolonged effects of fatigue on force production (Forman et al., 2020). With the development of fatigue, the force requirements to perform a task are increased, relative to a muscles maximal force generating capacity, thus increasing the risk of developing MSDs.

2.3.3 Effects of Fatigue on Electromyography and Kinematics

Muscle fatigue has been shown to alter body segment kinematics. Fatiguing of muscles around the shoulder girdle have been found to alter scapulothoracic and glenohumeral kinematics, cervical extensor fatigue has been found to alter upper limb kinesthesia, and wrist flexor/extensor fatigue has been found to alter precision movements of the hand and wrists (Ebaugh et al., 2005; Zabihhosseinian et al., 2015; Forman et al., 2020).

Dingwell and colleagues (2008) examined changes in muscle activity and kinematics of highly trained cyclists during fatigue. Throughout the fatiguing protocol, cyclists exhibited non-monotonic variations in both EMG fatigue related outcomes and joint kinematics. This suggests studies employing “pre vs. post” experimental designs do not accurately document the time course over which these changes occur. This is not suggesting that studies employing “pre vs. post” experimental designs do not accurately document the changes that occur, but rather the time course over which they occur. Almost immediate decreases in EMG median frequency were observed with sustained muscle fatigue evident across all cyclists for the biceps femoris and gastrocnemius. Most subjects also exhibited shifts toward greater trunk lean angles early in the fatigue protocol and all subjects displayed decreasing ankle angles, possibly resulting from fatigue of the gastrocnemius. The significant cross-correlation time lags demonstrated that muscle fatigue preceded changes in mean trunk lean joint angle, mean hip joint angle, and trunk lean range of motion (Dingwell et al., 2008). This demonstrates that cyclists altered their torso position in response to muscular fatigue. Kinematic changes were adopted to maintain performance, despite muscular fatigue, by potentially taking advantage of the length-tension characteristics of muscle to generate increased down-stroke force (hip extension) from the gluteus maximus (Dingwell et al., 2008).

Effects of shoulder fatigue caused by repetitive overhead activities have been examined with respect to scapulothoracic and glenohumeral kinematics. Immediately after a fatiguing protocol of the shoulder muscles, subjects exhibited decreased glenohumeral motion and increased scapulothoracic motion, although the mechanisms for how this occurred were not reported (Ebaugh et al., 2005). It was hypothesized that changes in scapulothoracic motion was a direct result of fatigue in the external rotator muscles, and that subjects compensated for reduced glenohumeral motion by using greater scapulothoracic movement. However, this may indicate that the fatigue protocol isolated muscles involved in glenohumeral motion to a greater extent compared to those for scapulothoracic movement. Regardless of the mechanism, fatigue resulted in altered kinematics and were preceded by EMG fatigue related outcomes, although the time progression was not examined. Altered body segment kinematics as a result of muscle fatigue has also been demonstrated in a study examining hand-tracking accuracy following fatigue of the forearm muscles (Forman et al., 2020). Results from this study showed that isometric fatigue significantly impaired hand-tracking performance immediately after the cessation of the fatigue trials. Interestingly, tracking deficits mostly recovered within 1-minute post-fatigue, however, MVC force was still significantly reduced from baseline up to 10 minutes post-fatigue. This relates back to Enoka and Duchateau (2016) proposed definition of fatigue by demonstrating that one fatigue related measure (hand-tracking accuracy) does not necessarily provide a full understanding of fatigue.

Neck muscle fatigue is often experienced in the workplace and may impair upper limb proprioception. Fatigue of the neck extensor muscles with a submaximal fatigue protocol (70% MVC) has been found to influence the accuracy of elbow joint position sense (Zabihhosseinian et al., 2015). Although a complex mechanism, muscle fatigue is known to alter afferent feedback from muscles (Zabihhosseinian et al., 2015). This mechanism emphasizes the changes in sensory feedback from the mechanoreceptors (i.e. muscle spindles, Golgi tendon organs) and changes in firing of muscle afferents, consequently altering proprioception, thus joint reposition sense.

Muscle fatigue is a complex and multifaceted adaptation. The literature demonstrates how muscular fatigue can be induced (i.e. maximal, submaximal, isometric, dynamic) and the resulting changes in the EMG signal (i.e. amplitude domain, frequency domain) and kinematics (i.e. joint angles, ROM, JPS). The changes in EMG fatigue states precedes kinematics changes however, the recovery of kinematic performance does not imply recovery at the muscular level (Forman et al., 2020). Muscular fatigue can cause local changes in muscle activation patterns and/or body segment kinematics as well as more global changes (as seen with Zabihhosseinian et al., 2015). This has relevance for manual-intensive occupations where fatigue may manifest from the task demands (i.e. repetitive, varying loads, awkward postures).

2.4 Occupational Cleaning

Upper extremity MSDs in cleaning work develop from the complex interaction of many risk factors. Several studies have shown that cleaning tasks in demand a high level of physical effort including high static muscular loads, repetitive movements, and high frequency of unsatisfactory postures (Weigall et al., 2005; Buchanan et al., 2010). The workload of cleaning work has been found to influence cleaners perceived psychological demands through a combination of individual and work attributes that ultimately contribute to job stress (Kumar & Kumar, 2008). These include factors such as high perceived workload, time pressure, job dissatisfaction, monotony of work, limited job control, and lack of social support which are all related to musculoskeletal symptoms (Bernard, 1997; Bongers et al., 1993; Kumar & Kumar, 2008; Weigall et al., 2005). The risk associated with the physical and psychosocial risk factors are also influenced by the individual characteristics of the worker. Individual risk factors that have been identified as affecting the development of MSDs include being female, older age, less experienced, poorer general health, and anthropometrics that produce less suitable worker-tool interactions (Weigall et al., 2005; Scherzer et al., 2005; Woods & Buckle, 2005).

2.4.1 Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels (Punnett & Wegman, 2004). The risk of developing MSDs increases with an insufficient balance between load and physical capacity, activities that involve repeated movements, and prolonged periods spent with one or more body parts in a fixed position (Staal et al, 2007). Types of MSDs include nerve compression disorders (e.g. carpal tunnel, thoracic outlet syndrome, sciatica), soft tissue rheumatic syndromes (e.g. epicondylitis, bursitis, tenosynovitis), and osteoarthrosis, as well as low back pain and other regional pain syndromes not attributable to known pathology. The most commonly involved body regions are the low back, neck, and upper extremities (shoulder, arms, hands, wrists, fingers) (Potvin, 2014; Punnett & Wegman, 2004). Other terminology commonly used to describe these types of injuries include repetitive strain injuries (RSI), cumulative trauma disorders (CTD), repetitive motion disorders, and occupational overuse syndrome (Potvin, 2014).

MSDs are prevalent in many countries worldwide which places a substantial burden on the economy and negatively impacts the quality of life of persons involved. Despite not being uniquely caused by work, data regarding the compensation of lost time claims demonstrates the correlation between high-risk occupations and the probability of developing an MSD. Recent estimates suggest MSDs affect 11 million Canadians annually over the age of 12. Further, this number is projected to increase with the aging population to up to 15 million in 2031 (Government of Canada, 2019). The combined direct and indirect costs of MSDs are estimated to cost the Canadian economy upwards of $22 billion annually. While the direct costs of MSDs are high (hospital care, physician visits, rehabilitation, prescription drugs), 75% of the overall costs are indirect (absenteeism, loss of earning, reduced productivity) (Government of Canada, 2019). Similar to Canada, MSDs are the leading cause of work-related injuries in the United States, Nordic countries, and Japan. They also cause more work absenteeism or disability than any other group of diseases in the United States, Canada, Finland, Sweden, and England (Punnett & Wegman, 2004). MSDs occur in many industries and occupations with varying rates of injury. Some occupations such as cleaning, have an increased injury rate of four times the national average (Scherzer et al., 2005). High-risk industry sectors include manufacturing, services, healthcare, educational, and construction (WSIB, 2019). Upper extremity MSDs are highly prevalent in manual-intensive occupations such as mining, clerical work, forestry, and cleaning (Punnett & Wegman, 2004).

Professional cleaning is a basic service occupation that is carried out worldwide both indoor and outdoor environments. It is essential for the maintenance of cleanliness and sanitation in public and workspaces. Cleaning workers form an important proportion of the total working population; these tasks employ 3% of the workforce in the United States, 4% in Finland, and 10% of the female working population in Spain (Zock, 2005). About 80% of cleaning work is manual, although the allocation of time spent on particular tasks may vary widely depending on the work environment (Kumar & Kumar, 2008). In the educational sector, cleaners of primary and secondary schools have been found to allocate 0-50% of their time to cleaning floors, followed by general cleaning (0-20%), and clearing garbage (0-10%) (Village et al., 2009). Not only is a high percentage of cleaning work manual, but most cleaning tasks require forceful movements, awkward postures, and are classified as highly repetitive (Søgaard et al., 1996). Manual lifting tasks (e.g. garbage removal, moving furniture) often exceed loads of 10 kg and floor cleaning tasks (e.g. vacuuming, mopping, sweeping) have low cycle times (< 30s) and poor trunk (> 20° flexion) and arm postures (Village et al., 2009). Since the majority of cleaners are older women, the demands of the job present a considerable risk in the development of MSDs as they are generally required to work at a relatively higher intensity than men (Kumar & Kumar, 2008, Bak et al., 2018).

2.4.2 Physical Risk Factors

There is a consistency within the literature that the increased physical demands escalate the probability of developing an MSD. A survey by the National Institute for Occupational Safety and Health (NIOSH) for causal relationships between work/task factors and the development of MSDs identified that the key physical risk factors related to upper extremity MSDs are force, posture, repetition and/or a combination of these factors (Weigall et al., 2005). Unfortunately, the majority of cleaning tasks are repetitive in nature and are often accompanied by awkward postures and high outputs of force.

Researchers have identified a relationship between frequency of repetitions and MSDs (Bekkelund et al., 2001; Bernard, 1997; Kumar & Kumar, 2008). In the educational sector, cleaners spend approximately 50% of their time cleaning floors, 20% doing general cleaning, and 10% clearing garbage (Village et al., 2009). Meanwhile, in the healthcare sector, cleaners have been found to spend 40% of their time cleaning rooms, 25% of their time clearing garbage, and 10% of their time vacuuming (Salwe et al., 2011). The time allocated to perform certain tasks is expected to vary between sectors/buildings and between departments within the same building, however all of the tasks are manual-intensive. High repetitiveness is defined as a cycle time less than 30 seconds or more than 50% of the work cycle time performing the same movement (Potvin, 2014). Tasks included in floor cleaning have short cycle times, for example, mopping has a cycle time of 1.3- 1.9 seconds, scrubbing has a cycle time of 0.8-1.7 seconds, and vacuuming has a cycle time less than 5 seconds (Cabeças, 2007; Choi & Shin, 2016; Søgaard et al., 2001). This demonstrates that occupational cleaners perform highly repetitive tasks for the majority of their workday consequently placing them at high risk of developing upper extremity MSDs. Chiang and colleagues (1993) found a significant association between very short or repetitive cycle times (<30 seconds or > 50% cycle time) and shoulder girdle pain (30.9%), and although this was among workers in the fish-processing industry, the results may be applicable to cleaning work. A study investigating the physical risk factors associated with custodial work in a large school district in British Columbia found that repetitive movements were related to 286 injuries (49.9% of total injuries) over a 4-year observation period (Village et al., 2009). Another study found that MSDs accounted for 59% of all injuries in two healthcare regions over a 1-year period noting that one of the principal reasons was repetitive tasks (Alamgir & Yu, 2008). The risk associated with repetitive tasks during cleaning work is amplified when they are performed in combination with external loads and/or awkward postures (Bekkelund et al., 2001; Gallagher & Heberger, 2013).

Static strength, dynamic strength, trunk strength, and stamina are the top 4 physical demands of interest to the issue of MSDs (physical requirements with respect to the ability to work as a cleaner) as defined by Occupational Information Network (Kumar & Kumar, 2008). Although a list of descriptors potentially used as a screening tool for both employers and potential employees, it clearly emphasizes the regularity of muscle exertion and force production in occupational cleaning. Surface EMG seems to be the most common method to investigate the static and dynamic loads of cleaning tasks. Although most common, cleaning studies using EMG are limited and there is little consistency among the examined muscles. Upon conducting 44 observational ergonomic assessments among a sample of 25 school custodians, Koehoorn and colleagues (2011) compiled a list of the percentage of time cleaners were exposed to certain risk factors. They found that the average worker spent approximately 80% of their work time grasping something with their right hand and 45% with their left hand, 50% of their time pushing/pulling something (14% with moderate force), 4% of their time lifting > 22lbs, 10% of their time lifting > 10lbs, 28% of their time bending > 20 degrees, and 13% of their time with one or more arms raised above their shoulders. A 4-year follow up showed that the main physical demand, as a cumulative exposure over the shift, associated with MSDs and showing a dose-response relationship was pushing and pulling activities (Koehoorn et al., 2011). These activities were generally associated with floor cleaning (e.g. mopping, vacuuming, sweeping), which is consistent with other studies (Alamgir & Yu, 2008; Bekkelund et al., 2001; Cabeças, 2007). Vacuuming has been found to elicit high muscle activity in the upper extremities (median EMG amplitude range from 2.7% - 47.5% MVC), with heavier vacuums associated with higher EMG amplitude values (Bak et al., 2018). Mopping is associated with high muscle activity in the FCU (28.2% MVC) and ECU (33.7% MVC) (Cabeças, 2007). Cleaning studies involving multiple muscles of the upper extremity are limited, especially the muscles of the forearm. This illustrates a gap in the literature when you consider that cleaners spend 80% of their work time grasping objects with their right hand and 45% with their left. Cabeças (2007) examined muscle activity in the FCU and ECU across 14 different cleaning tasks. Results showed no significant differences; however, two intriguing tendencies were identified: (1) for activities using a vertical handle, highest muscle activity was found in the lower positioned arm (35.6 %MVC); (2) for activities using essentially the dominant hand, the greatest muscle activity was found in the wrist extensors (55 %MVC). Results from a study investigating triceps brachii activity were consistent with the first tendency suggesting that the upper hand steers while the lower hand propels in mopping tasks (Chang et al., 2012). Additionally, repetition results in modest increases in the risk of developing MSDs for low-force tasks but rapid increases in risk for high-force tasks suggesting that the lower hand has a higher risk of MSDs during mopping tasks (Gallagher & Heberger, 2013).

Cleaners have been found to use poor working posture, awkward movements, and static workloads while completing daily tasks (Village et al., 2009). This can be a result of poor working technique, inadequate equipment designs, and poorly designed workplaces. Unnatural and static postures have been described as contributing to MSDs in different occupations, as well as in combination with repetitive and forceful movements (Kumar & Kumar, 2008). The shoulder, elbow, wrist, and back are the most common body areas using poor or static posture during cleaning tasks. Static work postures include isometric positions where very little movement occurs, along with cramped or inactive postures that cause static loading on the muscles. High static loads of the upper arm and back muscles have been found in frequent mopping (Kumar & Kumar, 2008). Trunk flexion greater than 20° has been found to occur for 30% of the time when performing tasks such as garbage removal, general cleaning, and moving furniture, and during these tasks, 10% of the time included lifting a load of 4.5-10kg (Village et al., 2009). This resulted in back injuries representing 27.9% of injuries and garbage removal being responsible for 14% of injuries. Although these percentages are representative of all injuries, MSDs accounted for 49.2% of all injuries, therefore roughly half of the injuries to the back caused by garbage removal could be associated to poor/static postures. For tasks such as cleaning boards/walls, windows, and lights, custodians spend 25% of the time with their arms raised (Village et al., 2009). Although specific joint angles are not reported, it was indicated that arms were raised above the shoulders, suggesting shoulder angles greater than 90°. A critical review by NIOSH on MSDs and workplace factors state that there is a continuum of severity from an angle of 30 degrees to a maximally abducted arm and postures with shoulder abduction or flexion past 60 degrees are considered awkward (Bernard, 1997). Therefore, custodians spend 25% of their time in awkward postures during those tasks.

Shoulder and elbow positions during mopping have been more accurately examined. As a result of the vertical handle, the upper positioned arm confines the shoulder to be in continuous abduction (mean 29°, peak 44°) and flexion (mean 22°, peak 37°), meanwhile the shoulder relating to the lower positioned hand is abducted (mean 16°, peak 27°) and flexed (mean 20°, peak 37°) for most of the cycle (Søgaard et al., 2001). Therefore, based on the previous criteria mentioned by Bernard (1997), mopping does not require awkward postures of the shoulder as it does not require shoulder angles greater than 60°, however, it does require unsatisfactory postures that may increase the risk of MSDs. The elbow relating to the upper positioned hand during mopping has been found to be in a continuously flexed position of more than 100° (with a mean of 132°), while the angle of flexion of the lower positioned hand showed a bimodal pattern (an increase, a peak, and a decrease during both the push and pull phase) with a mean of 52°. The high degree of flexion in the upper positioned elbow places the elbow flexors in an unfavourable position, requiring higher relative muscle activity from the biceps brachii or an increased contribution from the synergists (Leedham & Dowling, 1995, Yang et al., 2014). Mopping also requires both wrists to assume a large portion of time in harmful flexion/extension and harmful radial/ulnar deviation (Chang et al., 2012). Additionally, trunk flexion and rotation during mopping is between 20° and 60° and the neck is generally flexed and often rotated (Woods & Buckle, 2005). This is a result of working technique and handle length (Woods & Buckle, 2005; Öhrling et al., 2012).

Movement during mopping and vacuuming is controlled by the wrists and high muscle forces are necessary (Kumar & Kumar, 2008, Bak et al., 2018). Results from Chang and colleagues (2012) on the evaluation of wrist posture during mopping indicate that the time portion of the right wrist in harmful flexion/extension and the left wrist in harmful radial/ulnar deviation exceeded 40%. This was based on criteria suggested by Liu and colleagues (2003) which suggests that wrists are at a greater risk of developing carpal tunnel syndrome (CTS) when angles of radial/ulnar deviation and flexion/extension exceed 18° and 20° respectively. This is consistent with Woods & Buckle (2005) who found that a substantial amount of wrist movement during mopping and vacuuming was greater than 50% of the maximum wrist movement possible in flexion/extension and radial/ulnar deviation. However, they did not mention hand positions for either task, nor did they provide specific wrist angles. Regardless, results from Bekkelund and colleagues (2001) show that compared to a control group, floor cleaners have impaired neurophysiological variables in the median nerve, confirming that they are at risk of developing median nerve dysfunction. This seems to help validate the findings from Chang and colleagues (2012) and Woods & Buckle (2005), concluding that cleaners are at risk of wrist related MSDs due to repetitive forceful use of the wrists, specifically during floor cleaning tasks.

Commonly used cleaning tools were not designed using ergonomic principles. As a result, cleaners may be required to adopt extreme, static or constrained postures, repetitive movements, heavy workload, and high force requirements (Woods & Buckle, 2005). Garbage removal consists of lifting a bag of waste from designated garbage bins and transporting it to a dumpster, often with the use of a cart. The garbage bins come in all shapes and sizes. Shorter bins would result in more trunk flexion than taller bins, however taller bins would require more shoulder flexion to lift the garbage. Shorter bins typically have less volume therefore typically require less force to lift the garbage. Although the size of the bins was not documented, Village and colleagues (2009) found that at least 30% of the time clearing garbage requires trunk bending greater than 20° and at least 10% of the time lifting 4.5-10kg. Garbage bags do not have handles, therefore high grasping forces are necessary. Garbage carts for the transportation of garbage are designed with four sets of wheels and are capable of transporting a large amount of garbage. Cleaners push/pull the carts throughout a shift and as the day progresses the load of the cart increases, thus increasing the physical workload.

There are numerous mopping systems on the market. The most common are round head mops (generally used in conjunction with a plastic or metal bucket with a drain), long tailed mops and flat mops (often used with buckets with wringing systems) (Woods & Buckle, 2005). Mops consist of a vertical handle that comes in an assortment of lengths, material (e.g. plastic, wood), and grip (e.g. rubber, no-grip), and cleaners either use a push/pull technique or a figure of eight technique. The design of the vertical handle requires the user to offset their hands into an upper and lower position. Mopping is entirely manual, requiring the user to perform continuous movement cycles until completion. Since mopping is not automated, the task is a highly repetitive (cycle time <1.7s) which has previously been established as a risk factor. Mopping also requires high force exertions, specifically in the lower positioned hand. The unequal distribution of applied force between arms is due to the asymmetrical placement of the hands arising from the vertical handle (Cabeças, 2007). High forces are also required when operating the squeezing mechanism (approximately 200N for hand lever) and emptying the bucket of water (approximately 10kg) (Woods & Buckle, 2005). Typically, mop buckets are designed with wheels allowing for easier transportation, but it may likely be unstable while operating the squeezing mechanism or while tipping contents down a drain. Conversely, mop buckets without wheels require the user to lift and carry the bucket of water (Woods & Buckle, 2005). Interestingly, in Finland, wet mopping is uncommon as it is believed that the results do not justify the amount of strain placed on the cleaners (Kumar & Kumar, 2008).

Vacuums are also available in multiple designs. The most common are upright vacuums, canister vacuums, and backpack vacuums. Similar to mopping, the task of vacuuming is highly manual, requiring the user to perform frequent movement cycles. Upright vacuums can weigh more than 10kg requiring large forces to manoeuvre (Bak et al., 2018). They have a distinct grip area and if that area is too small it can result in difficulties in obtaining proper grip. The fixed handle also causes frequent wrist flexion/extension and ulnar/radial deviation during operation. Literature on canister and backpack vacuums has demonstrated that the use of backpack vacuums leads to increased trunk flexion, less walking, and increased shoulder activity compared with canister and upright cleaning machines (Bell & Steele, 2012). It is also speculated that backpack vacuums would result in an increased load during trunk flexion and higher static loads while standing.

The design and features of the work environment may also pose a physical risk to cleaners. The work environment may vary between countries, within a country, between work sectors, and even between departments within the same building. It may also vary depending on the season, main user population, and building design. Cleaners generally work in facilities designed for other activities or work processes and how to clean the area is an afterthought rather than part of the design. A study by OSHA (1999) reported that cramped work areas resulted in workers adopting twisted and bent postures, and that furniture and fixtures required awkward postures or excessive force to move. Kumar and colleagues (2005) found that cables on floors and behind desks forced cleaners to squat and crawl to lift the cables when mopping. Binding and attaching the cables to the underside of desks provided an extremely simple but effective design solution. Bell and Steele (2012) investigated the risk of vacuuming across three different sectors (government schools, hospitality, commercial office). Government school cleaners were found to be at greater risk of developing MSDs than cleaners in the other sectors based on the results from observational assessments tools (Manual Tasks Risk Assessment version 2.0, Quick Exposure Check). These results did not provide any specific information on the work environment but rather the work environment as a whole. A report prepared by Health & Safety

Matters Pty Ltd (2005) seems to extrapolate on these results by mentioning work environment factors that may increase risk to school cleaners. Some of these factors include messy children, old building designs, temporary buildings (detached classrooms), classrooms with various desk configurations, outdoor breaks, and high amounts of waste. Results from an epidemiological study on school cleaners elaborates further on these factors which found that the outside grounds were associated with an increased injury risk as more mud and snow are tracked in during inclement weather with grass fields as opposed to gravel or pavement (Koehoorn et al., 2011). This is especially relevant for primary schools as students are provided multiple outdoor breaks throughout the day, thus increasing the frequency of floor cleaning. Detached classrooms usually do not have a separate water supply or a storage cupboard for cleaning supplies and equipment (Koehoorn et al., 2011). Therefore, higher injury rates in schools with detached classrooms can be explained by the additional physical demands associated with walking, carrying, and stair climbing with supplies and equipment, such as buckets of water, mops, and vacuums. Additionally, rental of school space outside of hours in an increasingly popular way to generate additional revenue for school systems however, for custodians who perform a large part of their cleaning in the early evening, rentals increase their workload (Koehoorn et al., 2011).

2.5 Summary

Research surrounding the risk associated with cleaning tasks is extensive, but knowledge gaps persist. Previous work has examined body segment kinematics and muscle activity during the completion of various cleaning tasks. Floor cleaning and garbage removal are common daily tasks that have been identified as being high-risk for the development of work-related MSDs, specifically to the upper extremities. This is consistent with findings from epidemiological studies as well as a Brock University custodial incident report (2015-2017) (Koehoorn et al., 2011). A substantial amount of research utilizes observational assessment methods for determining the risk of associated with cleaning tasks and are therefore dependent on the subjective viewpoint of the observer. Moreover, there is little consistency among the muscles examined of the upper extremity when EMG is utilized and only a few studies examine body segment kinematics in three-dimensions. To the researchers' knowledge, no study has compared body segment kinematics and muscle activity during the completion of cleaning tasks pre-shift versus post-shift. Cleaners often report feelings of exhaustion over the course of the workday as result of fatigue. Therefore, this thesis aimed to extend the knowledge of kinematics and muscle activity during cleaning tasks and determine if differences in pre-shift and post-shift timings create differential task exposures.

3.0 Methods

3.1 Participants

Ten custodians (6 female, 4 male) employed at Brock University (Age: 43.9 ± 12.9 years; Height: 172.6 cm ± 8.0 cm; Mass: 74.8 ± 17.0 kg; Experience: 6.2± 9.2 years) were recruited for this study. Participants were excluded from the study if they had any neurological or musculoskeletal disorders or injuries of the upper limb within the past 12 months that required attention from a clinician. This study received clearance by the Brock University Research Ethics Board (REB# 18-302). The participants first read the informed consent, and upon addressing any questions or concerns the participant signed the informed consent. Additionally, participants were provided the choice to sign a consent to have photographs and video captured.

3.2 Experimental Setup

The laboratory space was optimized for the completion of the custodial tasks used in the study. Participants were familiarized with the three cleaning tasks; 1) vacuuming, 2) static mopping and dynamic mopping, 3) garbage removal (2.26, 4.53, 6.80kg). Once participants completed any necessary familiarization trials, they were prepared for electromyography collection (Figure 10). Muscle activity was recorded using paired monopolar surface electrodes (MediTrace 130, Kendall, Mansfield, MA, USA) from eight muscles of the dominant upper extremity (identified by the subject): flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), bicep brachii (BB), anterior deltoid (AD), lateral deltoid (LD), posterior deltoid (PD), upper trapezius (UT), and the cervical extensor (CE) at 2000Hz. Prior to electrode placement, all recording sites were shaved of hair using a disposable razor and cleansed with an isopropyl alcohol swab. Electrode placement followed guidelines outlined by Perotto (1994); electrodes were placed over the muscle belly in-line with fiber orientation with an inter-electrode distance of 2 cm. A ground electrode was placed on the clavicle of the dominant arm. Tape (Hypafix®, BSN Medical, Quickbornstrasse, Hamburg, Germany) was applied to each pair of electrodes in order to secure the leads and reduce electrode/wire movement artifact. Surface EMG signals were band-pass filtered (10–1000 Hz) and differentially amplified (CMRR >100 dB at 60 Hz; input impedance ∼10 GΩ; AMT-8, Bortec Biomedical Ltd, Calgary, AB, Canada). Following electrode placement, signal quality and gain were reviewed and adjusted. Participants then performed eight muscle specific maximum voluntary isometric contractions (MVC) against the manual resistance of the researcher and included specific grip and joint actions to target individual muscles (Table 1).

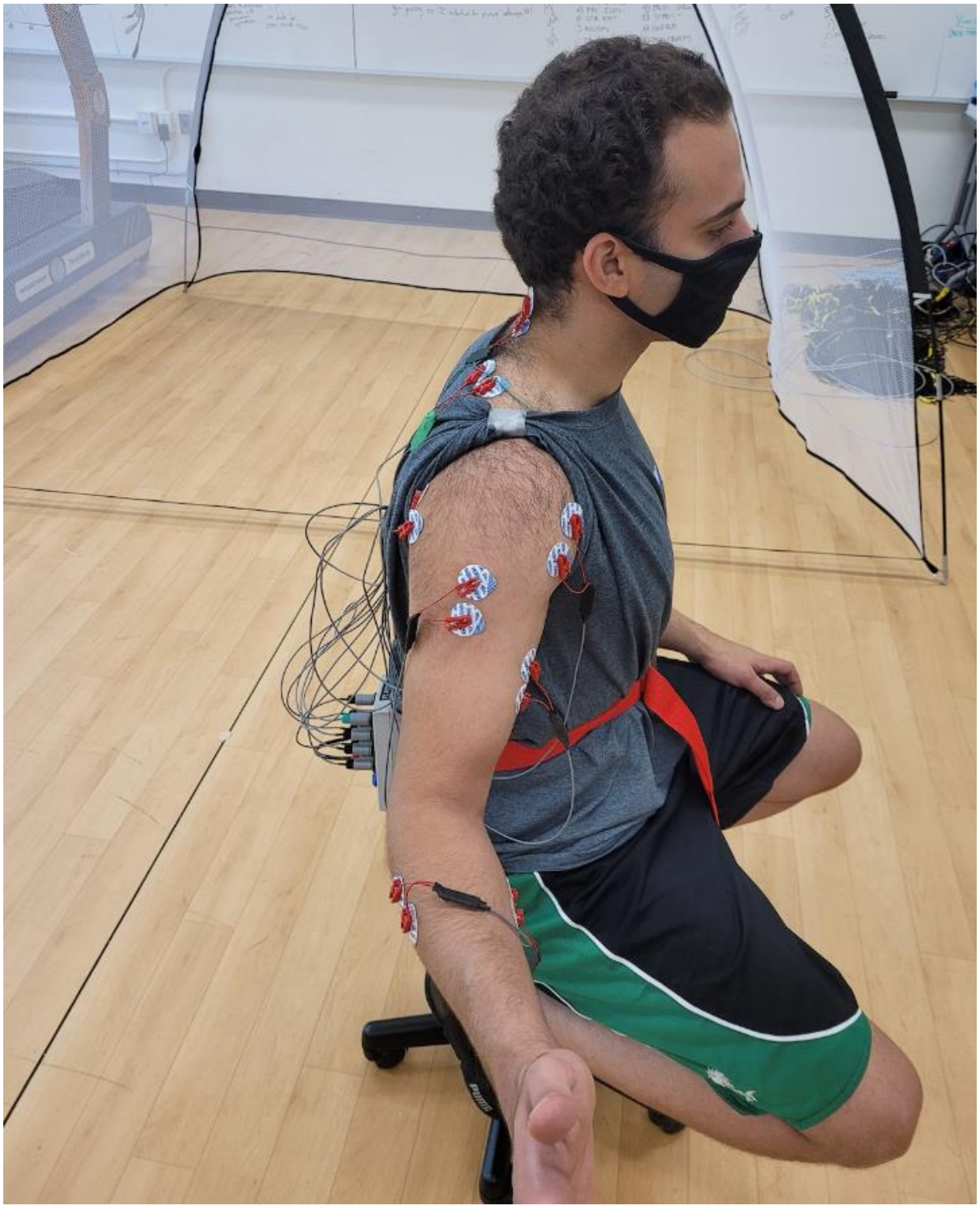

Figure 10. Electrode placements of the upper extremity muscles.

Table 1. Maximum voluntary contraction (MVC) protocol for each of the 8 muscles assessed

Muscle	MVC Protocol
Flexor Digitorum Superficialis (FDS)	Forearm supinated, partially opened hand grasping the hand of the researcher, combined wrist flexion and maximal grip
Extensor Digitorum Communis (EDC)	Forearm neutral, hand partially opened and enclosed with the hand of the researcher, combined wrist extension and maximally opening the hand against resistance
Bicep Brachii (BB)	Elbow flexed to 90º and positioned at the side of the body, hand partially open and enclosed with the hand of the researcher, combined wrist supination and forearm flexion
Anterior Deltoid (AD)	Upper arm flexed to 90º, hand positioned with thumb pointing to the ceiling, researcher applied resistance at the wrist and elbow (to prevent elbow flexion), participant performed shoulder flexion
Lateral Deltoid (LD)	Upper arm abducted to 90º, hand positioned with thumb pointing forward, researcher applied resistance at the wrist and elbow, participant performed shoulder abduction
Posterior Deltoid (PD)	Upper arm abducted to 90º, hand positioned with thumb pointing forward, researcher applied resistance at the elbow, participant performed transverse extension
Upper Trapezius (UT)	Participant was seated, torso in a neutral position, researchers' hand placed on participants shoulder, participant performed shoulder elevation
Cervical Extensor (CE)	Participant was seated, torso and neck in a neutral position, researchers' hand placed on the back of the participants head, participant performed neck extension

Following MVCs, participants were prepared for three-dimensional motion capture (Vicon Industries, Inc, NY, USA). Seven rigid bodies, each consisting of four retroreflective markers, were placed on the participant's thorax at the midpoint between the scapulae, upper arms, forearms, and hands. An additional rigid body, consisting of six retroreflective markers affixed to a headpiece, was placed on the participants head. Retroreflective markers were also affixed to eighteen anatomical landmarks to create anatomical frames of reference for each rigid body and were removed following camera calibration and before experimental trials. The anatomical landmarks consisted of nine bilateral pairs included the acromion, greater trochanter, 2nd distal phalange, 5th distal phalange, ulnar styloid process, radial styloid process, lateral epicondyle of humerus, medial epicondyle of humerus, and the anterior to the external auditory canal for the ear. These anatomical landmarks were digitized and their three-dimensional coordinates were continuously monitored assuming a fixed spatial relationship with the rigid body affixed to the segment. Kinematic data were sampled at 100 Hz.

3.3 Experimental Trials

Participants completed two sessions (pre-shift, post-shift) on separate days (minimum two days apart) for this study. The sessions were randomized, and participants arrived at the laboratory for the first two hours (pre-shift) or the last two hours (post-shift) of their regularly scheduled shift at Brock University. This ensured that participation in this study did not increase their daily workload. Each session consisted of the participant performing two trials for each task (6 tasks), for a total of 12 trials. The trials were performed in a fully randomized order. The cleaning tasks include: 1) Vacuuming, 2) Static mopping, 3) Dynamic mopping, 4) Garbage removal- 2.26kg, 5) Garbage removal – 4.53kg, 6) Garbage removal – 6.8kg (Figure 12). The tasks were selected based on data from a Brock Custodial Manual Materials Handling Incident Report (2015-2017) which identified these tasks as the most likely contributors to injury risk. Participants were requested to complete each task as they normally would during a typical work shift. The time to complete a task was not controlled for, with the exception of static mopping where participants performed the task continuously for 15 seconds. The vacuuming task was performed moving backwards and completed on a standard floor rug (3.5 m by 1.1 m). Mopping trials were performed using a wet mop without water. The dynamic mopping trial was performed over the same area of space as the vacuuming trial, without the rug, with the participant moving backwards. Static mopping was performed in the center of the space for a duration of 15 seconds. Garbage bags were positioned inside of a wire frame (simulating a garbage bin) with the appropriate weight placed inside the bag. Three 2.26 kg plates were used to control for the weight of the garbage. Participants received two minutes of rest in between each trial to prevent any influence of muscle fatigue and allow for the researchers to setup the next trial.

Figure 11. The vacuuming (top left), mopping (top right), and garbage removal (bottom) tasks performed in the study.

3.4 Data Analysis

Muscle activity and kinematic variables were calculated from the EMG and kinematic data. Muscle activity from all eight muscles was full-wave rectified after bias was removed by subtracting the simple mean. Muscle activity was filtered (6 Hz cut-off, fourth order, single low-pass Butterworth), and all signals were normalized to the respective MVCs. Maximums for normalization were determined as the highest activity recorded from each of the MVC trials. Mean and peak muscle activity for each muscle was determined by determining the maximum and mean EMG amplitude across the entire duration of each task.

Kinematic data was first processed using the Vicon Nexus 2.0 motion capture software (Vicon Industries, Inc, NY, USA). A custom labelling template was created and applied to each trial. Each marker was labelled for every frame of a trial. Gaps were filled using the spline fill (<60 frame gap) in the event that a marker was not captured over multiple frames with the exception of the hand markers during the garbage removal trials in which the markers were obstructed for the majority of the trial and could not be reconstructed. The data was then exported to Visual3D (C-Motion, Inc.) for further analysis, including filtering (6 Hz cut-off, second order, dual low-pass Butterworth). A local axis coordinate system was specified for each rigid body as outlined in Wu and colleagues (2005) (Figure 11). Mean and peak joint angles were calculated along with joint range of motion for each trial. Torso rotations were calculated using a Z-X-Y rotation sequence, humeral rotations will be calculated using a Y-X-Y’ rotation sequence, elbow rotations will be calculated using a Z-X-Y rotation sequence, and wrist rotations will be calculated using a Z-X-Y rotation sequence (Wu et al., 2005).

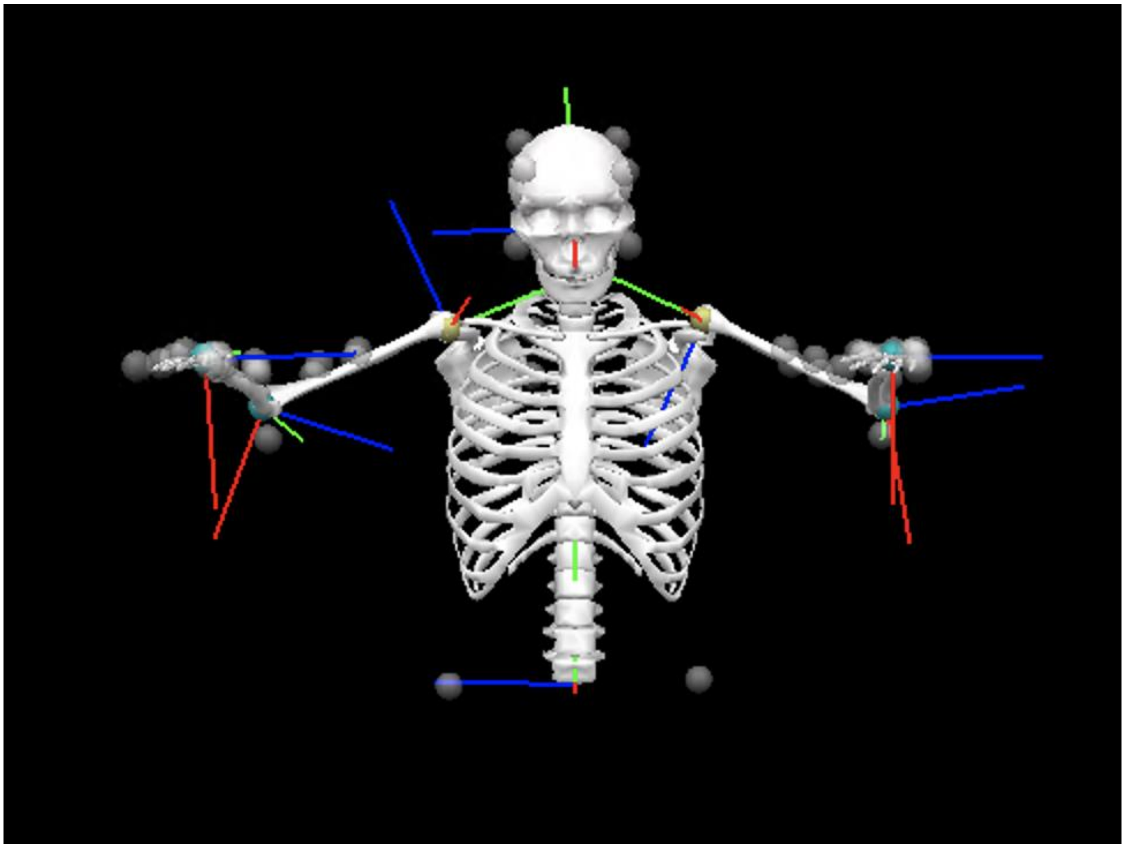

Figure 12. Local coordinate systems for each body segment. The red line represents the x-axis, green line the y-axis, and the blue line the z-axis.

3.5 Statistical Analysis

Statistical analyses examined the effects of task and time point of work shift on muscle activity and kinematic responses. To examine the interactions between task and time point of work shift on changes in muscle activity and kinematics, a two-factor repeated measures analysis of variance (ANOVA) (task*pre-/post-shift) was applied to the dependent variables of mean and peak muscle activity and neck and trunk angles. All statistical analyses were completed using SPSS software (version 25). Statistical significance was set at $p < 0.05$. Assumptions of sphericity were tested with Mauchley's test of sphericity, and in cases where violated, degrees of freedom were corrected with Greenhouse-Geisser. The assumption of normality was assessed with the Shapiro-Wilk test. In cases where a main effect of task was found, post-hoc pairwise comparisons were conducted with a Bonferroni correction.

4.0 Results

4.1 Muscle Activity

4.1.1 Mean Muscle Activity

For all muscles, no significant interactions of task and time point were found for mean muscle activity (CE: $p = 0.91$, UT: $p = 0.93$, PD: $p = 0.41$, LD: $p = 0.93$, AD: $p = 0.96$, BB: $p = 0.86$, EDC: $p = 0.99$, FDS: $p = 0.68$). Figure 13 illustrates mean muscle activity data for all 8 muscles during pre-shift and post-shift timings. Results are reported as means ± standard error. Unless otherwise stated, $p < 0.001$.

For shift time point, a significant main effect was found for the upper trapezius, posterior deltoid, anterior deltoid, EDC, and FDS. Mean muscle activity increased from pre-shift to post-shift for the upper trapezius (pre: 10.33 ± 1.43% MVC, post: 12.57 ± 1.44% MVC) and FDS (pre: 8.66 ± 2.25% MVC, post: 17.13 ± 2.27% MVC) while it decreased for the posterior deltoid (pre: 5.54 ± 0.67% MVC, post: 4.48 ± 0.66% MVC), anterior deltoid (pre: 9.2 ± 1.99% MVC, post: 6.05 ± 1.97% MVC), and EDC (pre: 14.95 ± 2.5% MVC, post: 10.62 ± 2.52% MVC). Regarding shift time point, no significant main effect was found for the cervical extensors ($p = 0.65$), lateral deltoid ($p = 0.41$), and biceps brachii ($p = 0.25$).

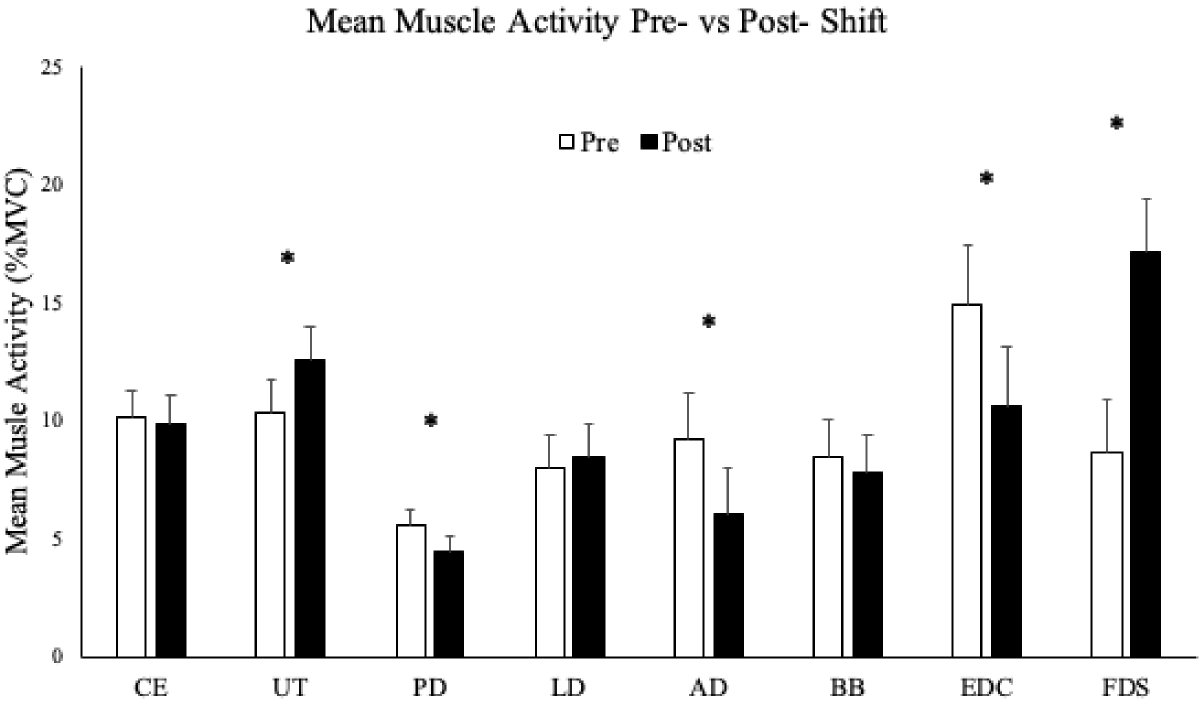

Figure 13. Group averages (n=10) of mean muscle activity (displayed as a % of MVC) recorded pre-shift and post-shift. Muscles include the cervical extensors (CE), upper trapezius (UT), posterior deltoid (PD), lateral deltoid (LD), anterior deltoid (AD), biceps brachii (BB), extensor digitorum communis (EDC), and flexor digitorum superficialis (FDS). Error bars represent the standard error. An alpha level of 0.05 was set for significance (*).

Figure 14 illustrates the mean muscle activity for all 8 muscles across each of the 6 tasks. All muscles demonstrated a significant main effect for task ($p < 0.001$, EDC: $p < 0.05$) with the exception of the FDS ($p = 0.10$). The 6.8 kg garbage removal task elicited the highest mean muscle activity in the cervical extensors (13.54 ± 1.32% MVC), upper trapezius (15.75 ± 1.54% MVC), anterior deltoid (11.89 ± 2.14% MVC), biceps brachii (11.51 ± 1.66% MVC), and EDC (15.34 ± 2.39% MVC) while the vacuuming task elicited the highest mean muscle activity in the posterior deltoid (8.62 ± 0.71% MVC) and the lateral deltoid (10.66 ± 1.51% MVC). Static mopping was associated with the lowest mean muscle activity for all muscles with the exception of the posterior deltoid where 2.26 kg garbage removal elicited the lowest (3.75 ± 0.71% MVC) and the anterior deltoid where dynamic mopping elicited the lowest (4.07 ± 2.14% MVC) although these were not significantly different from the static mopping task.

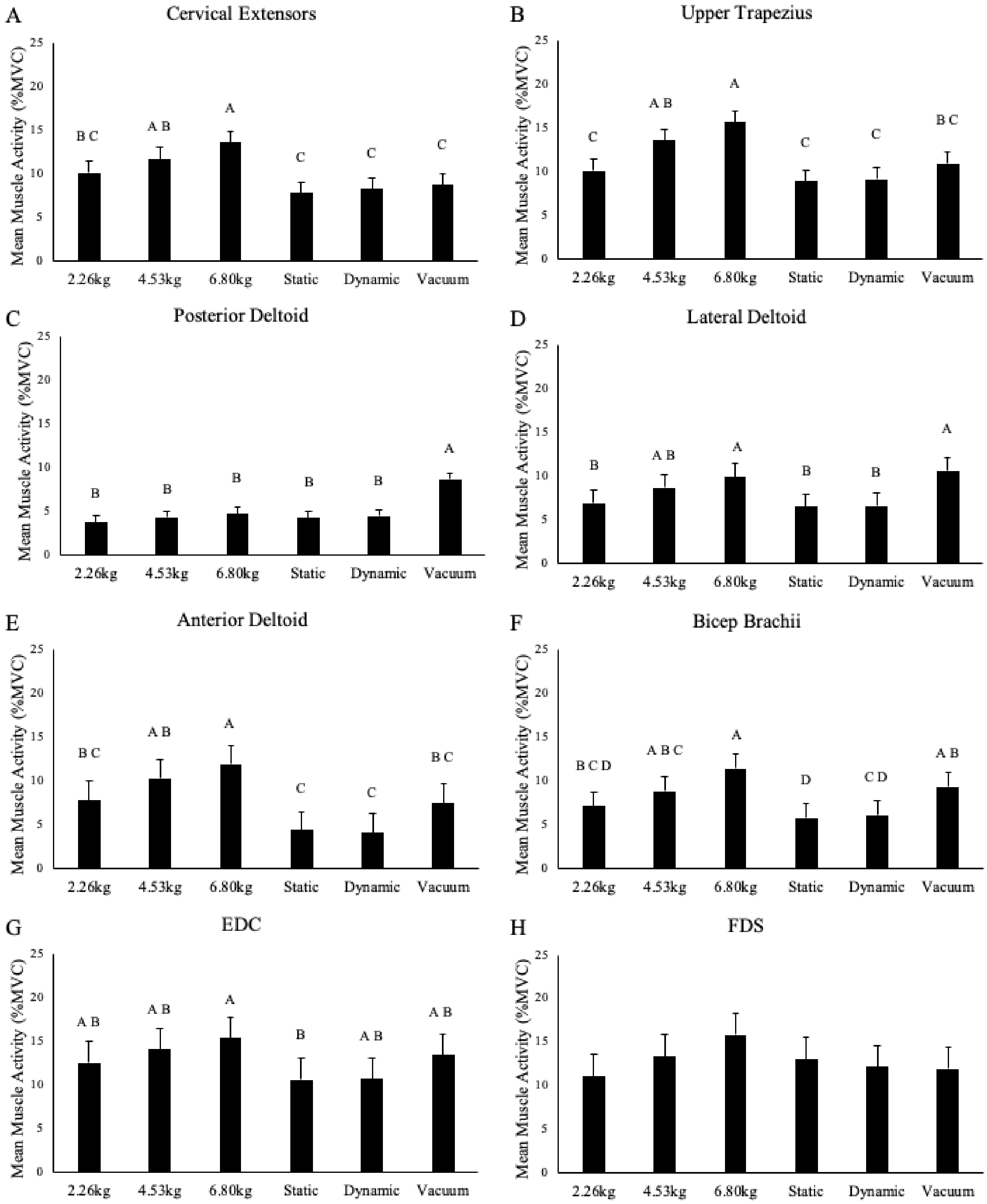

Figure 14. Group averages (n=10) of mean muscle activity (displayed as a % of maximum) during each of the 6 cleaning tasks. Error bars represent the standard error. Letters indicate membership in different statistical groups, ranked from highest (A) to lowest (D). Tasks containing the same letter were not different from each other.

4.1.2 Peak Muscle Activity

For all muscles, there were no significant task by time point interactions for peak muscle activity (CE: $p = 0.69$, UT: $p = 0.93$, PD: $p = 0.85$, LD: $p = 0.96$, AD: $p = 0.99$, BB: $p = 0.57$, EDC: $p = 0.99$, FDS: $p = 0.78$). Figure 15 illustrates peak muscle activity for all 8 muscles during pre-shift and post-shift timings. Unless otherwise stated $p < 0.001$. For shift time point, a significant main effect was found for the upper trapezius, posterior deltoid, anterior deltoid, EDC, and FDS. Peak muscle activity increased from pre-shift to post-shift for the upper trapezius (pre: 52.52 ± 9.06% MVC, post: 63.59 ± 9.13% MVC) and FDS (pre: 42.53 ± 11.36% MVC, post: 81.5 ± 11.47% MVC). Peak muscle activity decreased for the posterior deltoid (pre: 27.84 ± 3.31% MVC, post: 22.04 ± 3.36% MVC), anterior deltoid (pre: 43.97 ± 8.39% MVC, post: 29.76 ± 8.51% MVC), and EDC (pre: 67.38 ± 11% MVC, post: 53.55 ± 11.15% MVC). Regarding shift time point, no significant main effect was found for the cervical extensors ($p = 0.90$), lateral deltoid ($p = 0.24$), and biceps brachii ($p = 0.84$).

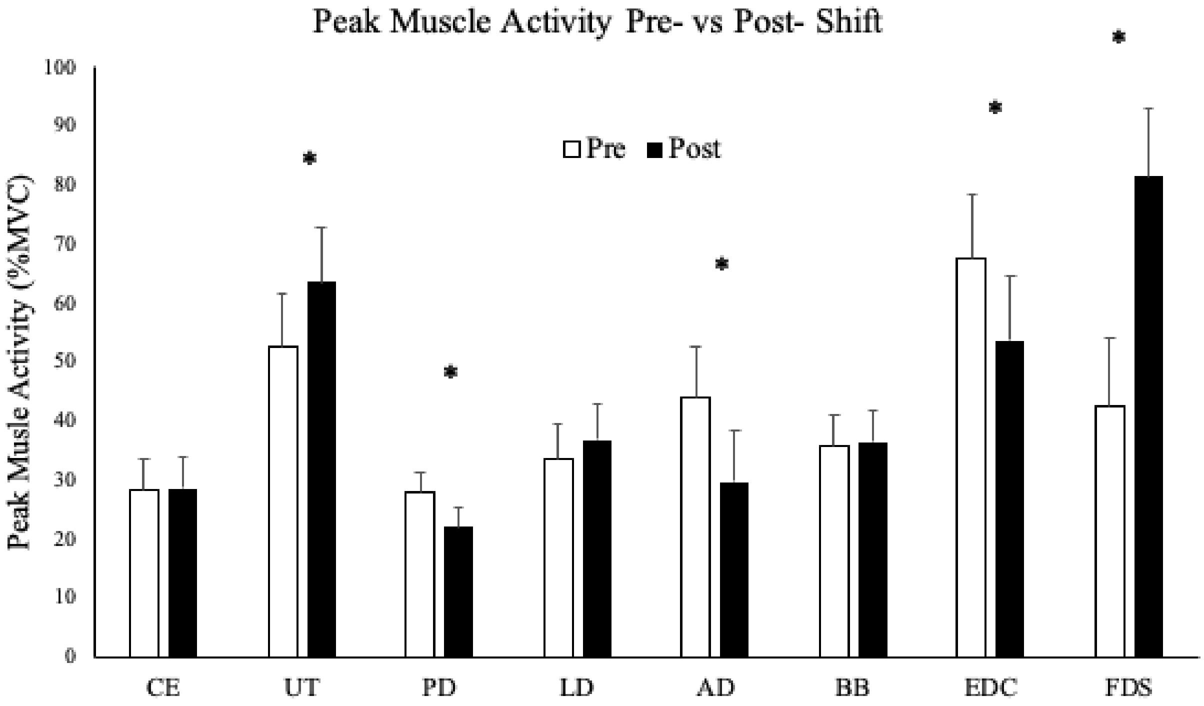

Figure 15. Group averages (n=10) of peak muscle activity (displayed as a % of maximum) recorded pre-shift and post-shift. Muscles include the cervical extensors (CE), upper trapezius (UT), posterior deltoid (PD), lateral deltoid (LD), anterior deltoid (AD), biceps brachii (BB), extensor digitorum communis (EDC), and flexor digitorum superficialis (FDS). Error bars represent the standard error. An alpha level of 0.05 was set for significance (*).

Figure 16 illustrates peak muscle activity for all 8 muscles across each of the 6 tasks. All muscles demonstrated a significant main effect for task with the exception of the FDS (P = 0.11). The 6.8 kg garbage removal task elicited the highest peak muscle activity in the cervical extensors (42.93 ± 5.54% MVC), upper trapezius (84.48 ± 9.71% MVC), anterior deltoid (57.99 ± 9.13% MVC), biceps brachii (55.86 ± 5.97% MVC), and EDC (76.63 ± 12.45% MVC) while the vacuuming task elicited the highest peak muscle activity in the posterior deltoid (57.52 ± 3.83% MVC) and the lateral deltoid (58.63 ± 6.82% MVC). Static and dynamic mopping were associated with the lowest peak muscle activity for all muscles.

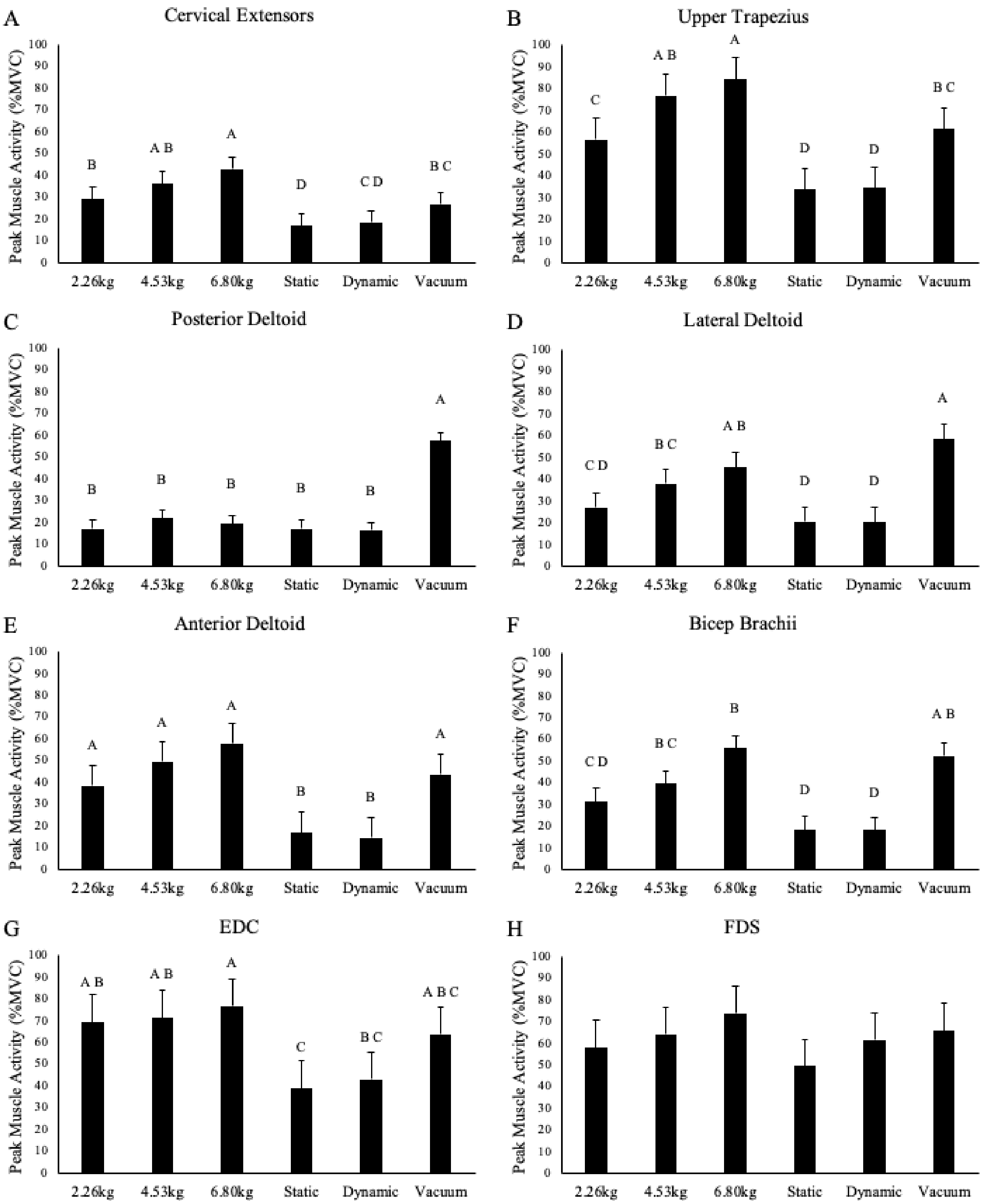

Figure 16. Group averages (n=10) of peak muscle activity (displayed as a % of maximum) during all 6 cleaning tasks. Error bars represent the standard error. Letters indicate membership in different statistical groups, ranked from highest (A) to lowest (D).

4.2 Kinematics

For all joints, there were no significant task by time point interactions for mean joint angle (Neck flexion: p = 0.71, Trunk flexion: p = 0.15, Lateral trunk flexion: p = 0.57, Shoulder flexion: p = 0.84, Shoulder Abduction: p = 0.25, Elbow flexion: p = 0.12, Wrist ulnar/radial deviation: p = 0.52, Wrist flexion: p = 0.86) or ROM (Neck flexion: p = 0.06, Trunk flexion: p = 0.11, Lateral trunk flexion: p = 0.59, Shoulder flexion: p = 0.39, Shoulder Abduction: p = 0.09, Elbow flexion: p = 0.91, Wrist ulnar/radial deviation: p = 0.83, Wrist flexion: p = 0.62). For the main effect of time point there were no significant differences in mean joint angles and ROM for all joints examined. For the main effect of task, all joints demonstrated significant differences for both mean joint angle and ROM with the exception of wrist ulnar/radial deviation ROM (p = 0.21). Table 2 displays the mean joint angle and ROM for each task.

4.2.1 Neck Flexion

For the main effect of task on mean neck flexion the Greenhouse-Geisser estimate of the departure from sphericity was $\varepsilon = 0.28$. This main effect was significant, $F_{(1.4,\ 11.2)} = 10.6$, p = 0.005. Pairwise comparisons revealed that during static mopping (41 ± 3.4º) and dynamic mopping (39 ± 3.9º) custodians adopted significantly higher neck flexion angles, on average, compared to the garbage removal task (2.26kg: 24 ± 3.9º, 4.53kg: 23 ± 4.1º, 6.80kg: 22 ± 4.2º). Mean neck flexion for all 6 tasks exceeded 22º.

4.2.2 Trunk Flexion

For the main effect of task on mean neck flexion the Greenhouse-Geisser estimate of the departure from sphericity was $\varepsilon = 0.29$. This main effect was significant, $F_{(1.5,\ 11.6)} = 33.9$, p = 0.000. Pairwise comparisons revealed that garbage removal (2.26kg: 36 ± 3.2º, 4.53kg: 37 ± 3.4º, 6.80kg: 37 ± 2.9°) required significantly more trunk flexion, on average, than mopping (static: 16 ± 1.9°, dynamic: 16 ± 1.7°) and vacuuming (18 ± 1.6°).

4.2.3 Lateral Trunk Flexion

For the main effect of task on mean lateral trunk flexion the Greenhouse-Geisser estimate of the departure from sphericity was $\varepsilon = 0.24$. This main effect was significant, $F_{(1.37,\ 10.94)} = 45.46$, $p = 0.000$. Pairwise comparisons revealed that custodians adopted significantly more lateral trunk flexion, on average, to the right during vacuuming (6 ± 2.3°) than garbage removal and mopping. Custodians adopted lateral flexion to the left during the mopping tasks (static: 6 ± 2.3°, dynamic: 5 ± 3.4°) although not statistically different from the garbage removal tasks.

4.2.4 Shoulder Flexion

For the main effect of task on mean shoulder flexion the Greenhouse-Geisser estimate of the departure from sphericity was $\varepsilon = 0.27$. This main effect was significant, $F_{(1.19,\ 9.48)} = 8.45$, $p = 0.014$. Pairwise comparisons revealed that garbage removal (2.26kg: 3 ± 1.4°, 4.53kg: 32 ± 1.7°, 6.80kg: 33 ± 2°) required significantly more shoulder flexion, on average, than mopping and vacuuming. Mean shoulder flexion for mopping was found to be 10 ± 4°.

4.2.5 Shoulder Abduction

For the main effect of task on mean shoulder abduction the Greenhouse-Geisser estimate of the departure from sphericity was $\varepsilon = 0.48$. This main effect was significant, $F_{(2.4,\ 19.14)} = 11.4$, $p = 0.000$. Pairwise comparisons revealed that custodians adopted significantly more shoulder abduction, on average, during vacuuming (19 ± 1.8°) compared to mopping and garbage removal.

4.2.6 Elbow Flexion

Mean right elbow flexion was analyzed to compare static mopping and vacuuming. This main effect was significant, $F_{(1, 8)} = 230.22$, $p = 0.000$. Mean right elbow flexion was found to be 120º (± 2.3) for the mopping task and continuously above 93º which was significantly more compared to vacuuming (59 ± 3.6º). Mean flexion of the left elbow was calculated to be 46º during static mopping. For mopping, the upper positioned arm on the handle was the right arm while the left arm adopted the lower position.

4.2.7 Wrist Deviation

Mean right wrist ulnar/radial deviation was analyzed to compare static mopping and vacuuming. This main effect was significant, $F_{(1, 8)} = 44.09$, $p = 0.000$. During the vacuuming task the wrist, on average, was found to be in ulnar deviation (mean: 13 ± 1.9º, range: 11º$_{\text{radial}}$ - 32º$_{\text{ulnar}}$) and relatively neutral during mopping (mean: 2 ± 1.2º, range: 19º$_{\text{radial}}$ - 20º$_{\text{ulnar}}$).

4.2.8 Wrist Flexion

Mean right wrist flexion was analyzed to compare static mopping and vacuuming. This main effect was significant, $F_{(1, 8)} = 100.29$, $p = 0.000$. During the vacuuming task the wrist, on average, was found to be in flexion (mean: 12 ± 3.9º, range: 14º$_{\text{extension}}$ - 35º$_{\text{flexion}}$) and neutral during mopping (range: 30º$_{\text{extension}}$ - 30º$_{\text{flexion}}$).

Table 2. Summarized results for mean joint angles and ROM for all 6 tasks. Letters indicate membership in different statistical groups, ranked from highest (A) to lowest (D). An asterisks (*_) indicates significant differences between the static mopping and vacuuming trials ($P < 0.05$)._ (For lateral trunk flexion a subscript ‘L’ represents flexion to the left and a subscript ‘R’ represents flexion to the right. For shoulder and wrist flexion a subscript of ‘Ext’ signifies the angle in extension, and for shoulder abduction a subscript ‘Ad’ signifies the angle in adduction).

		Task					
		2.26kg	4.53kg	6.8kg	Static	Dynamic	Vacuum
Neck Flexion	Mean (°)	24 ^{B}	23 ^{B}	22 ^{B}	41 ^{A}	39 ^{A}	35 ^{AB}
	ROM (°)	(3 - 45) ^{A}	(6 - 47) ^{A}	(7 - 46) ^{A}	(30 – 48) ^{B}	(30 - 50) ^{B}	(31 – 47) ^{B}
Trunk Flexion	Mean (°)	36 ^{A}	37 ^{A}	38 ^{A}	16 ^{B}	18 ^{B}	18 ^{B}
	ROM (°)	(1 – 60) ^{B}	(4 – 61) ^{B}	(4 – 64) ^{A}	(4 – 22) ^{C}	(3 – 24) ^{C}	(9 – 28) ^{C}
Lateral Trunk Flexion	Mean (°)	1	1	1	6$_{L}$ ^{B}	5$_{L}$	3 ^{A}
	ROM (°)	(10$_{L}$ – 13$_{R}$) ^{A}	(10$_{L}$ – 13$_{R}$) ^{A}	(11$_{L}$ – 13$_{R}$) ^{A}	(11$_{L}$ – 1$_{L}$) ^{B}	(12$_{L}$ – 1$_{R}$) ^{B}	(7$_{L}$ – 16$_{R}$) ^{A}
Shoulder Flexion (R)	Mean (°)	31 ^{A}	33 ^{A}	32 ^{A}	10 ^{B}	9 ^{B}	3$_{Ext}$ ^{B}
	ROM (°)	(0 – 58) ^{AB}	(0 – 61) ^{AB}	(0 – 60) ^{AB}	(12$_{Ext}$ – 32) ^{B}	(11$_{Ext}$ – 27) ^{B}	(44$_{Ext}$ – 40) ^{A}
Shoulder Abduction (R)	Mean (°)	10 ^{C}	11 ^{BC}	10 ^{C}	18 ^{AB}	17 ^{ABC}	19 ^{A}
	ROM (°)	(4 – 26) ^{AB}	(4 – 27) ^{AB}	(4 – 27) ^{AB}	(6$_{Ad}$ – 31) ^{B}	(5$_{Ad}$ – 29) ^{B}	(2$_{Ad}$ – 41) ^{A}
Elbow Flexion (R)	Mean (°)				120*		59
	ROM (°)				(93 – 137)*		(22 – 100)

Table 2. *continued.*

Elbow Flexion (L)	Mean (º)	46	-	-
	ROM (º)	(27 – 68)	-	-
Wrist Flexion	Mean (º)	1_{Ext}*	-	12
	ROM (º)	(29_{Ext} – 30)*	-	(14_{Ext} – 35)
Wrist U/R Deviation	Mean (º)	2_{R}*	-	13_{U}
	ROM (º)	(19_{R} – 20_{U})	-	(11_{R} – 32_{U})

5.0 Discussion

This work examined upper extremity muscle activity and kinematics during common custodial tasks to: 1) evaluate physical demands across a variety of tasks and 2) to investigate if there are differences in the measured variables from the beginning of a custodian's shift compared to the end of their shift. Our findings indicate that custodians did not change their technique (no significant changes in kinematics) while performing the tasks either at the beginning or end of the shift. In contrast, muscle activity changed significantly (from pre to post evaluations) for muscles around the shoulder complex and forearm. In the shoulder complex an increase in upper trapezius activity and a decrease in anterior deltoid and posterior deltoid activity was observed and in the forearm an increase in FDS activity and a decrease in EDC activity was observed pre-shift to post-shift. Tasks demands did not change from our pre to post shift evaluations, but muscle activity generally increased with no changes in technique (kinematics). The results of this study suggest that custodians altered muscular strategies in order to maintain kinematic performance of the tasks at the end of a work shift. This work highlights the potential vulnerability of the muscles around the shoulder and forearm to overuse injuries in the workplace and suggests that strategic task scheduling could benefit custodians.

5.1 Kinematics

In the present study, mean joint angles and joint ROM did not change significantly pre-shift to post-shift. It was hypothesized that these kinematic variables would change as a result of the time point being assessed; however, no such change was observed. Therefore, hypothesis 3 was not supported and we fail to reject the null hypothesis. In addition, hypothesis 4 was also not supported and we fail to reject the null hypothesis. Hypothesis 4 stated an increase in trunk flexion post-shift compared to pre-shift as fatigue of the upper extremity has been found to cause individual's center of mass and center of pressure to shift laterally to the non-dominant side, suggesting individuals may lean toward their non-reaching side when fatigued (Gregory et al., 2008). The lack of change in lateral trunk flexion therefore suggests that either the right upper extremity may not have been fatigued during the post-shift trials or that if it was fatigued, observable changes may not manifest as significant lateral trunk flexion to the non-dominant side. Based on the changes in muscle activity around the shoulder, the latter is more likely the case. Similarly, hypothesis 4 stated that there would be a decrease in shoulder flexion post-shift compared to pre-shift as previous studies have found a decrease following fatigue. However, in the present study no such decrease was observed (McDonald et al., 2019).

Mean trunk flexion during mopping and vacuuming in the present study was found to be 18º and for garbage removal it was found to be 37º. Trunk flexion greater than 20º is common during these tasks which has previously been found to contribute to over 25% of injuries to the back (Woods & Buckle, 2006, Village et al., 2009). Our 18º of trunk flexion for mopping and vacuuming is likely conservative as custodians did not have to manoeuvre obstacles such as furniture during the experiment as they would in an occupational setting. During floor mopping the mean elbow flexion of the right arm was 120º and continuously flexed more than 90º throughout the task while the mean elbow flexion of the left arm was 46º. Elbow flexion angles were consistent with those found by Søgaard and colleagues (2001) however in the present study there was 12º less shoulder flexion and 11º less shoulder abduction. The decrease in shoulder flexion and abduction is likely due to the more suitable handle height in the present study (mean height: 172.6 cm, handle height: 150 cm) compared to Søgaard and colleagues (2001) where the handle height was around eye level (mean height: 159 cm, handle height: 150 cm). This is relevant as muscle activity has been found to be significantly lower when the handle height is around shoulder level or chin level as compared to eye level (Wallius et al., 2016). Wrist ROM was found to range from 29º extension to 30º flexion during mopping and 14º extension to 35º flexion during vacuuming. Liu and colleagues (2003) indicated that workers are at a greater risk of developing carpal tunnel syndrome when the wrist angles of flexion/extension exceed 20º, therefore, our results suggest custodians could be at risk of developing MSDs of the wrist. Further analysis considering wrist velocity and repetition during these tasks may be helpful in determining an exposure-response relationship (Nordander et al., 2013).

5.2 Muscle Activity

In the present study, muscles of the forearm and shoulder demonstrated significant changes in mean and peak muscle activity from pre-shift to post-shift. Considering the absence of a change in joint kinematics and the change in muscle activity over time, it appears that custodians altered muscle activation strategies in order to maintain performance (Dingwell et al., 2008). Changes in muscle activation strategies have been shown to permit adaptations to movement errors as a result of fatigue during repetitive tasks in order to maintain desirable performance output (Mudie et al., 2016). Fatigue related changes in muscle activity during submaximal isometric contractions typically manifests as an increase in EMG amplitude and a decrease in frequency (Kamen & Gabriel, 2010). The present study only analyzed EMG amplitude.

The vacuuming task and the 6.80kg garbage removal tasks were associated with the highest normalized mean muscle activity for all muscles. Mean muscle activity was the highest during the garbage removal task for the cervical extensor (13.5% MVC), upper trapezius (15.7% MVC), anterior deltoid (11.9% MVC), biceps brachii (11.5% MVC), EDC (15.3% MVC), and FDS (15.8% MVC). For the vacuuming task, the highest mean muscle activity was found in the posterior deltoid (8.6% MVC) and middle deltoid (10.7% MVC). Alternatively, the static and dynamic mopping tasks elicited the lowest mean muscle activity relative to maximum, ranging from 4.1% MVC (anterior deltoid) to 13.0% MVC (FDS). This study used a mop without water and may underestimate the muscle activity required for wet mopping as wet mopping has been shown to significantly increase muscle activity (Hopsu et al., 2000). Upper trapezius activity in the present study was found to range from 7.8% MVC (pre-shift, static mopping) to 10.1 % MVC (post-shift, static mopping) as performed with a mop without water, however, Hopsu and colleagues (2000) found upper trapezius activity to be 15-20% MVC during wet mopping.

The American Conference of Governmental Dental Hygienists (ACGIH) has proposed threshold limit values (TLV) recommended for workplace tasks that require the use of the upper limbs. These limits are based on the maximal acceptable loads required to do a task safely for a given duty cycle. A duty cycle is expressed as the proportion of task duration spent in effort. The TLV suggests acceptable loads below 39.5% of maximum for a 10% duty cycle. However, at an 80% duty cycle the TLV suggests 9.8% of maximum for acceptable loads. Cleaning tasks have been found to have a duty cycle ranging from 60-80% resulting in TLVs from 9.8% - 13.9% (Cabeças, 2007). At these high duty cycles Abdel-Malek and colleagues (2020) suggest that the maximum acceptable effort equation (used by ACGIH to formulate TLV) may provide more realistic threshold limit values. This would result in more conservative threshold limit values (5.2%-11.5%). Although the TLV is representative of maximum force output, there is a lack of data on force requirements for custodial tasks, making it difficult to obtain an effort level in the field. Additionally, the relationship between external force output and EMG is complex. However, if we use EMG as a surrogate for effort/intensity to help conceptualize our findings, we can start to gain some insight into the physical demands of custodians during these tasks. Future work should instrument custodial tools with force transducers to provide more insight into TLVs for the profession. Considering the muscles of the forearm, the FDS demonstrated higher muscle activity post-shift (mean: 17.1% MVC, peak: 81.5% MVC) compared to pre-shift (mean: 8.7% MVC, peak: 42.5% MVC) while the EDC demonstrated lower muscle activity post-shift (mean: 10.62% MVC, peak: 53.6% MVC) compared to pre-shift (mean: 15% MVC, peak: 67.38% MVC). Muscle activity of the FDS post-shift and the EDC pre-shift exceed the threshold limit values, which could result in localized muscle fatigue and place custodians at risk of developing MSDs. Initially, the increase in FDS amplitude indicates potential signs of fatigue however the concurrent decrease in EDC amplitude proposes an alternative or supplementary explanation. The wrist extensors tend to exhibit higher levels of muscle activity than the wrist flexors relative to their maximal activation, as seen in the pre-shift session, leaving them more susceptible to fatigue and overuse injuries (Forman et al., 2020). If we consider that EMG amplitude corresponds with the amount of force generated by the muscle and that fatigue is associated with a decrease in maximal force generating capacity, then the decrease in EDC amplitude would suggest it is not generating as much force post-shift compared to pre-shift potentially as a result of fatigue.

The absence of an increase in the EMG amplitude of a muscle during a task following fatigue has been observed in previous studies. Tse and colleagues (2016) performed a fatiguing protocol on the anterior deltoid prior to a drilling task, yet despite significant signs of fatigue (measured as an increase in EMG amplitude and increase in frequency) they observed no increase in EMG amplitude during post-fatigue work cycles. The researchers stated that this may suggest that these muscles were less active and potentially protected by other muscles to allow for recovery. This may provide some insight into the results of the present study regarding the observed changed in the FDS and EDC.

The FDS and EDC form an antagonist/agonist muscle pairing. The FDS primarily functions to flex the four medial metacarpophalangeal joints but can also act as a secondary flexor of the wrist, conversely the EDC primarily functions to extend the four medial metacarpophalangeal joints but can also act as a secondary extensor of the wrist. Therefore, they are important for the execution of gripping tasks and may provide assistance in tasks requiring wrist flexion/extension. Forman and colleagues (2019) examined the influence of simultaneous handgrip and wrist force on FDS and EDC activity. They observed that with lower grip forces and simultaneous higher palmar forces, muscle activity decreased for the EDC and increase for the FDS. Additionally, during a dual-task condition (no grip force and high palmar force), relative muscle activity was approximately 3 times higher in the FDS (~25% MVC) than the EDC (~8% MVC). Therefore, the results of the present study may be explained by a decrease in grip strength and increase in wrist flexion exertion.

To summarize, the significant increase in FDS activity and decrease in EDC activity post-shift compared to pre-shift may suggest the custodians experience forearm fatigue over the duration of a workday. This would not be surprising as custodians have been reported to spend on average 80% of their time grasping something with their right hand and over 60% of their time either pushing/pulling or lifting something (Koehoorn et al., 2011). The decrease in EDC activity suggests it is generating less force (potentially to allow for recovery) which would translate into a decrease in grip force. A decrease in grip force would likely cause an increase in wrist flexion exertion in order to maintain hand forces required to operate the tools. This decrease in grip force and increase in wrist flexion exertion would then further explain the change in forearm muscle activity from pre-shift to post-shift.

The muscles around the shoulder show similar changes with respect to time point as seen by higher activity in the upper trapezius post-shift (mean: 12.6% MVC, peak: 63.6% MVC) compared to pre-shift (mean: 10.3% MVC, peak: 52.5% MVC) and lower activity in the anterior deltoid and posterior deltoid post-shift (AD: mean = 6.1% MVC, peak = 29.8% MVC; PD: mean = 4.5% MVC, peak = 22.0% MVC) compared to pre-shift (AD: mean = 9.2% MVC, peak = 44.0% MVC; PD: mean = 5.5% MVC, peak = 29.8% MVC). These changes in muscle activity around the shoulder suggest the custodians altered muscle activation strategies to maintain task performance throughout the workday. Considering the duty cycle, the upper trapezius was close to the TLV while the anterior deltoid was just below the TLV at the pre-shift timing. Despite the decrease in deltoid activity, there was no significant changes shoulder flexion and extension. Tse and colleagues (2016) found that pushing/pulling tasks significantly alter scapular movement, therefore, had the present study employed a more complex model of the shoulder by including the scapula then any potential changes could have helped explain the observed change in muscle activity. Additionally, they also found that following fatigue of the anterior deltoid there was no increase in EMG amplitude during task performance as one might expect, suggesting that it was a protective strategy to allow for recovery. This may help explain the reasons for the observed change in the present study assuming the deltoid was experiencing fatigue. However, Tse and colleagues (2016) also observed muscle fatigue in the posterior deltoid following the fatigue protocol of the anterior deltoid, yet the posterior deltoid displayed the expected increase in EMG amplitude during post fatigue trials and this would contradict the results of the present study. Although, since their fatigue protocol targeted the anterior deltoid, it is possible that the posterior deltoid did not fatigue to the same extent that would manifest adaptations that necessitate recovery. Considering the effects of dual-task performance on muscle activity in the upper extremity, concurrent sub-maximal shoulder exertion and hand gripping have been shown to increase forearm muscle activity and decrease deltoid muscle activity (Au & Keir, 2007). This is consistent with the results of the present study and may also help explain the observed changes. Cleaning tasks have been found to require high levels of upper trapezius activity (Bell & Steele, 2012; Bak et al., 2018). Furthermore, an increase in upper trapezius activity over time has been observed during repetitive upper extremity tasks which is consistent with the results of this study (Gillette & Stephenson, 2017).

The results from this study provide evidence that multiple upper extremity muscles exhibit changes in activity over the duration of the workday, specifically during the three tasks examined. This insight may help guide the development of future studies regarding the cause of the observed changes. Additionally, our results highlight the effect of an increased task load on muscle activity demonstrating the importance of lightweight tool designs and safe lifting techniques. Therefore, Brock University should supply custodial staff with lightweight tool designs, especially vacuum cleaners. Although completely transitioning all vacuums is likely unreasonable, it would be beneficial to identify the areas at Brock where vacuuming is responsible for the largest portion of the workday and provide the custodians within that area the lighter models. Additionally, custodians should be provided autonomy, if not already. Autonomy could reduce levels of fatigue as it would provide cleaners with the opportunity to optimize their work-to-rest ratio by taking breaks when desired and providing freedom to separate heavy workload tasks with lighter workload tasks. Finally, custodians should be provided a membership to the fitness facilities, if not already. Training programs should be available to workers that focus on the provision of general health and safe workplace practices. Hultman and colleagues (1984) showed that a preventative educational back care program improved cleaners' working posture and improvements were maintained up to 3 months after the training. Physical conditioning training can increase an individuals' physical capacity therefore reducing the relative workload during a shift (Kumar & Kumar, 2008). Cleaners have been shown to experience less physical discomfort as a result of physical conditioning (Kumar & Kumar, 2008).

5.3 Limitations

This study is not without its limitations. Results from the study are evidence that custodians utilize different muscular strategies over the duration of their work shift. The electrode placement was not marked to ensure they were placed in the exact same position for pre-shift and post-shift sessions. Although electrode placement followed guidelines outlined by Peretto (1994) a change in placement could change the muscle fibers that are being recorded and thus change the characteristics of the signal since the surface electromyogram is biased towards the muscle fibers that are closer to the electrode. Additionally, MVC normalization has been found to suffer from poor reliability as it is affected by inertial effects at the onset of the contraction, subject fatigue, subject posture, synergistic contributions, subject motivation, pain, MSDs, and neurological conditions (Sousa & Tavares, 2012). However, steps were taken to try and mitigate these factors by means of screening forms, verbal encouragement, and controlling posture. Furthermore, the EMG from an isometric MVC may not represent the maximum activation capacity of the muscle either at lengths other than those at which the MVC was performed, or under non-isometric conditions. This may explain some of the high peak muscle activations found in our study. To evaluate sex differences, a future study should include a larger sample pool and equal sample sizes allocated to each biological sex. Significant sex differences have been found in previous work investigating household vacuuming (Bak et al., 2018). The height of our sample (172.6 cm) was also greater than typically reported in the literature (mean of 6 studies = 161.3 cm). The cleaning population is stated to be predominantly females however the mean height of our sample is closer to that of males (in Canada, males: 174.6 cm, females: 162.1 cm) (Stats Canada, 2008). However, our mean sample height may be accurate for the Brock University custodial population. The results of our study may also underestimate the observed post-shift changes for a few reasons. The participants performed the post-shift trials after the first 6 hours of their shift and not the full 8 hours, therefore the study only provides information regarding 75% of their work shift. Moreover, the tasks did not perfectly simulate the work environment as the lab space was free of obstacles (chairs, tables, etc.), the trial times were performed for a shorter duration, and only a wet mop without water was used. These factors have been found to increase repetition, load, and unfavourable working postures (Hopsu et al., 2000; Kumar et al., 2005b). Our study calculated peak muscle activity as the highest amplitude of the EMG signal for a given trial. Despite short trial times, an APDF analysis may have provided a more representative peak (90th percentile) value for our data (Jonsson, 1982). An APDF analysis would have also determined static muscle loads in which muscles were active for the majority of the task. Finally, based on EMG amplitude we can not specify whether the changes in muscle activity pre-shift compared to post-shift were a result of muscle fatigue or a change in stratgey to transfer the muscular load. This could have been resolved had we performed reference contractions during each session to analyze the frequency content of the EMG signal or the use of a force transducer to assess potential force decrements.

5.4 Future Directions

Current literature is lacking evidence on the time related changes in muscle activity and kinematics experienced by custodial work. These results demonstrate a change in muscle activity; however, future research should investigate this further. The development of technology, especially wearable EMG electrodes and markerless motion capture would allow for the examination of custodial tasks in work environment rather than a lab setting. This would provide an accurate representation of the work demands and allow for the onset of kinematic and muscular changes to be identified in the time domain.

5.5 Conclusions

This was the first study to examine muscle activity and body segment kinematics of the upper extremity during typical custodial tasks performed at the beginning (pre-shift) versus the end (post-shift) of a typical shift. Contrary to our kinematic hypotheses, there were no differences in upper extremity kinematics between the two testing sessions. Conversely, muscle activity was found to significantly change between the two testing sessions in muscles around the shoulder and the forearm. This provides evidence that custodians may experience muscular fatigue throughout the day, and as a result, alter muscular strategies to maintain task performance. This could place custodians at risk of developing upper extremity MSDs.

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Appendices

Appendix A – Consent Form

Informed Consent

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Project Title: Cleaning Custodians of Injury: Assessing the Risk of Developing Upper Extremity Injuries While Performing Cleaning Tasks

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INVITATION
You are invited to participate in a research study that involves male and female adults (free of injury to the upper extremity) currently working as a custodial employee at Brock University. Brock Occupational Health & Safety Specialists as well as the Manager, Health Management & Wellness and the Custodial Services Supervisor have all provided support and approval for this work.

In Canada, occupations including janitors, caretakers, and building superintendents are the fourth most prevalent occupational group among men in the labour force, while cleaners are the 10th most prevalent occupational group among women (Statistics Canada, 2008). Cleaners provide an essential service to industries, businesses and general communities. Cleaning tasks, typically labor-intensive, are characterized by static muscle loads (mainly involving bending and twisting of the back) and repetitive movements of the arms and hands delivering a high output of force. Tasks such as lifting, mopping, and vacuuming often involve awkward postures and high muscular activities. These types of prolonged and/or repetitive muscle activities cause muscle fatigue and may lead to musculoskeletal disorders (MSD).
A survey of CUPE custodians indicates that 55.4 percent of custodians in British Colombia are not able to maintain schools to meet their own expectations for a clean, safe and healthy school environment. The issues identified were the increase in workload with less time to complete their work, as well as more than half of respondents reporting they experienced stress-related injuries and illness (CUPE). This increased workload and physical demand of the job increases the risk of developing MSD's.

Previous research has assessed various tasks such as vacuuming, mopping, and lifting garbage. Muscle activity and kinematics have been measured using electromyography, force transducers, and link segment models. Research has found that cleaners are at a high risk of developing musculoskeletal disorders (Chang, 2012). Assessing custodians at different times can help us understand the change in kinematics and muscle activity. This will help us evaluate if custodians experience a greater risk of developing MSD's throughout the duration of their shift. An in-depth analysis of these tasks to determine muscle activity and the change in kinematics throughout a shift will be valuable in creating an intervention to reduce MSD's in the custodial population.

The purpose of this study is to assess custodial cleaning tasks and determine the risk of developing musculoskeletal disorders in the upper extremities. The change in kinematics over the duration of a shift will also be assessed to quantify the postural changes and associated risk factors.

WHAT'S INVOLVED

As a participant, you will be asked to perform three common cleaning tasks during two laboratory visits, one at the beginning of a shift and one at the end of a shift. Each task will be repeated three times and you will complete 3 sets of 1-minute repetitions each time.

Experiment Protocol

Upon arrival to the lab, the investigators will explain and demonstrate all the tasks to you. We will also familiarize you with the equipment being used and verbally explain and review the consent form.

You will be asked to complete 3 custodial tasks. The tasks will be simulated such that they are very similar to the tasks typically completed at Brock University by custodial staff. Brock custodial services have provided us with the materials (props) for the study, thus, the same equipment used around campus will be used in the simulated laboratory study. The tasks will include:
Mopping

Vacuuming
Garbage removal

You will complete 3 sets of 3 (1 minute) repetitions for each task. This will be performed at two different times (2 separate visits to the laboratory):
Before the start of your shift
At the end of your shift

2 minutes of rest will be given between each set and 5 minutes of rest will be given between tasks. You will execute each task as you normally would.

Task 1 (Mopping):

You will complete the mopping task with a standard mop on a simulated surface. You will mop in the side to side and front to back directions and complete the task as you normally would.

Task 2 (Vacuuming):

You will complete the vacuuming task on a carpeted surface with a standard Brock issued vacuum. You will complete the task as you normally would in an open space and simulated office environment.

Task 3 (Garbage Removal):

You will simulate garbage removal for 3 different loads. A low, medium and heavy load will be simulated at approximately 2.5, 5 and 10 lbs. These loads are likely lower than those typically performed by the Brock custodial staff.

Instrumentation

Once familiarized with all of the tasks, you will be instrumented for our biomechanical measures.

3D Kinematics (movements and posture)

Three-dimensional movements of the upper extremity will be tracked using a 10-camera motion capture system (Vicon, Oxford, UK). Small, light reflecting markers will be placed over various areas of your upper extremity, including the upper arms, forearms and hands using double sided tape. This system tracks the 3D location of small reflective markers and does not produce a typical video recording. Markers will be secured with 2sided tape.

Electromyography (EMG) (Muscle demands)

Muscle activity will be recorded using surface electromyography (SEMG). We will stick small electrodes over muscles of interest. Prior to electrode placement, standard preparations, including shaving the surface and cleansing the skin with alcohol will be performed. We require to shave the shoulder and upper arm locations prior to electrode placement to improve the quality of our recording sites. A single-use, disposable razor will be used and if bleeding or razor burn occurs, this will become the priority, rather than continuing the protocol. EMG will be recorded from 8 muscles on the dominate upper extremity. Selected muscles will include:

Shoulder muscles: Anterior deltoid, middle deltoid, posterior deltoid
Neck muscles: upper trapezius, cervical extensors,
Arm muscles: biceps, flexor carpi radialis, extensor digitorum communis, flexor digitorum superficialis.

Following preparation, you will perform a series of maximal voluntary contractions to normalize the EMG signals. You will perform short 3 second isometric (no movement) maximal exertions of shoulder flexion, abduction, adduction, and external and internal rotation contractions to normalize the EMG signals. To obtain shoulder maximal contractions, you will be manually resisted by the experimenter while standing. Shoulder maximal contractions will require you to flex the arm to parallel with the floor (90 degrees) and manually resist shoulder flexion, adduction and abduction. Internal and external rotation will be manually resisted with your arm to your side (neutral position) and your elbow bent to 90 degrees. A maximal shoulder shrug will be completed in sitting by maximally shrugging the shoulders while holding the bottom of a seat, while sitting.

Due to the measurement equipment, we require that you avoid wearing bulking clothing. Often tank tops or tight clothing is acceptable. Preferably, standard athletic wear is appropriate. If there is reflective material on your clothing, we may have to cover it with non-reflective tape.

Video Cameras

Video cameras (2) will capture the cleaning tasks.

Eligibility

Males and females are eligible to participate. We are seeking individuals who have not had upper extremity pain or injury in the past 12 months. If you have any history of chronic pain or neurological impairment to the upper extremity, we will discuss eligibility with you. Any neurological disorders or chronic injuries reported warrant exclusion from participation in this study.

Timeline

Including instrumentation and experimental setup, it is expected that you will be in the biomechanics laboratory (TH 141) for approximately 1.5 hours for each visit.

POTENTIAL BENEFITS AND RISKS

Aside from exposure to the research environment, there are no known or anticipated direct benefits to you for your involvement in this project. The primary benefit to participants in this study will be that it will assessing the profession in which you work. This is of importance given that the results of this project may have implications on future changes to this profession. At the end of your session you will be debriefed, at which point the investigators will answer any questions you might have about the experimental protocol.

There may be minimal risk associated with this study. For instance, the use of electromyography may require tape to secure the electrodes to the skin. However, in the unlikely event there is irritation caused by surface electrodes, this will fade in 1-2 days. We require to shave the shoulder and upper arm locations prior to electrode placement to improve the quality of our recording sites. A single-use, disposable razor will be used and if bleeding or razor burn occurs, this will become the priority, rather than continuing the protocol. As a requirement for electromyography investigations, maximal voluntary exertions are required. You may experience some mild muscle soreness as a result of these maximal contractions. However, these maximal activities can be considered similar to activities of daily living often experienced at home.

We would like to ensure that your participation (or not) in this research study is completely voluntary. It will in no way affect your status at Brock, or with the Brock Custodial Manager. Brock Custodial is supportive of this study and will be made aware of who is participating. However, this is simply to allow for any changes required to scheduling and will in no way influence your employment status.

CONFIDENTIALITY

Your identity will be kept confidential and only made available to the researchers. You will be identified only by a subject identification code during the data collection phase of this study. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and will be stored in a personal folder on the computer that can only be accessed by the user logged into the computer. This data will only be available to the researcher’s listed above in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces.

Should you request that your images or video not be released they will be withheld from public release with no consequence to you. Data will be kept indefinitely. Sometimes analysis techniques and ideas change over time and we would prefer to have access to the data should a new analysis be performed. In addition, sometimes publication of results can take years to complete and we prefer to hold on to data in case there are ever questions about the quality or integrity of our data. After 1 year, all master lists containing personal identifiers will be destroyed.

Access to this data will be restricted to Dr. Holmes, the principal student investigator, and the co-investigator involved in this work.

Data will be made available to the employer or supervisor, since this information can inform managers about how to schedule works for a safer shift. However, managers will not be given access to individual participant data. They will only see group averages from the summary information from all participants. No identifying markers will be available to the employer.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. If you are a Brock employee, withdrawing from the study will in no way affect your standing at Brock. If you wish to withdraw during the study, simply tell the investigator that you no longer wish to participate. Participation, non-participation or withdrawal from the study will not affect one's standing at Brock University.

COMPENSATION FOR PARTICIPATION

You will be receiving normal pay while participating during a work shift. You will also receive a $10 Tim Horton's gift card for participating in this study. If you should need to withdraw and can no longer complete the session, you will still receive the $10 compensation.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Feedback about the details of this study and your participation will be available to you by contacting Dr. Holmes at the address at the top of the form or completing the attached feedback letter after your participation has been completed or after you withdraw from the study if you wish to. Results should be made available approximately 6 months after your completion of the study. The results will be group data about the main findings of the study. If you wish to know more about individual data, we can arrange to meet.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact Dr. Holmes using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (File #18-302). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

CONSENT FORM

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time. Please review the consent to photos and/or videos on the next page.

Name: ____

Signature: ____ Date: __________________________

CONSENT TO KEEP DATA

I agree to allow the data collected to be used again should a new analysis be performed in the future.

Name: ____

Signature: ____Date: __________________________

Appendix B – Recruitment Letter

Dear Brock Custodial Staff,

The “Holmes Lab”, Brock’s Ergonomics Research Laboratory is conducting a study on the physical demands of custodial workers. We are excited to be partnering with Brock Health and Safety and Brock Custodial to evaluate the physical demands of common custodial tasks. At Brock, the Ergonomics lab is dedicated to evaluating job demands, in an attempt to make workplaces safer. It is no surprise that Custodial work is physically demanding and as a result, workplace injuries are common.

We are looking to recruit participants for a research study. The study will involve us using motion capture technology (the same technology used in animated movies and gaming) to evaluate posture and movements during common custodial tasks. All data collection is non-invasive.

If you are interested in a better understanding of how physically demanding your job is and if you are interested in helping make the professions safer, we welcome you to participate! The Brock Custodial Manager has been made aware of this project and is fully supportive. Your time commitment for the study would be approximately 2-3 hours divided up over 2 visits to our laboratory (TH 141). You will be reimbursed for your time.

If you are interested in hearing more about this work. Please contact Zach Pipher, a graduate student working on the project. He will provide more details about the study with you.

Zach Pipher
Email: zp12bb@brocku.ca Phone:905-964-3486