Quantification of Upper Extremity Physical Exposures of Materials Handling Tasks in Seated and Standing Configurations

by

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my reviewers.

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Abstract

Prolonged periods in sitting or standing may negatively influence worker health. Integration of sit-stand workstations has attempted to mitigate these deleterious effects, and has generated positive results in terms of postural discomfort, injury risk and worker fatigue. Identification of how identical tasks are affected by sitting and standing is necessary to take advantage of loading differences between these configurations. The purpose of this research was to determine if differences in workplace configurations between seated and standing postures created changes in posture or muscular activity levels during manual materials handling tasks. Twenty male and twenty female participants performed four manual materials handling tasks: a 40N static push, a 40N static pull, a weighted bottle transfer set at 15% of the participant's maximal arm elevation force, and a light assembly task in sitting and standing. Upper extremity electromyography was collected at 8 sites, and changes in local joint moments and body discomfort were calculated. Interactions between task and sit/stand configuration resulted in increases of up to 500% in some joint moments, 94% in EMG activity and 880% in some local body discomfort regions when tasks were completed in sitting. A main effect of sitting appeared primarily in joint moments and muscle activity, and generally resulted in increased loading in sitting. Important exceptions existed, which included resultant wrist joint loading 8.2 times larger in standing, and foot/shank discomfort increasing by up to 609%. Task differentially affected all EMG outputs, as well as most local joint moments and body discomfort regions. Future recommendations regarding upper extremity exposures during manual materials handling tasks should consider placing workers in standing postures instead of seated ones to minimize musculoskeletal loading to the upper extremity. In addition, the effects of task and sit/stand configuration should be considered in order to leverage differences between these positions, with tasks in standing generally resulting in decreased musculoskeletal disorder risks.

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For my parents…

Your love, sacrifices and teachings

formed the foundations of my success.

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I. Introduction

Musculoskeletal injuries in the workplace delimit corporate productivity and individual worker performance and health. Provincially occurring injuries are primarily outlined through statistics collected by the Workplace Safety Insurance Board (WSIB) of Ontario. In their 2011 report, the WSIB identified that claims involving the low back and shoulder represented a “high impact” claim group, and had significant impacts on both workers and employers. These claims represented approximately 34% of all allowed lost time claims and 45% of all lost time benefits (WSIB, 2011). In addition, over 22% of all claims are due to bodily reactions, which include overexertion, repetitive motion, and static postures (WSIB, 2011). Effective mitigation of these deleterious effects remains a critical problem in ergonomics.

1.1 Prolonged postures and the use of sit/stand workstations

Determination of whether specific jobs should be completed in seated or standing positions is still unknown, and evidence exists to suggest that prolonged periods of time in either of these postures may negatively influence worker health. Occupational sit-stand workstation integration attempts to mitigate these deleterious effects. These workstations intend to reduce time in awkward postures, which has been associated with increased worker pain and discomfort (Bernard, 1997). This work-pain relationship has further been associated with fatigue (Wiker et al., 1989), and can exacerbate risk of future musculoskeletal injury.

Previous research regarding sit-stand workstations has lacked quantification of upper extremity exposures and muscular demands in manual materials handling scenarios. Research in this area has focused primarily on self-reported low back pain development (Nerhood & Thompson, 1994; Roelofs & Straker, 2002). Improved quantification of the physical demands associated with identical tasks in sitting and standing postures is necessary to take advantage of rotating between these positions. Evaluation of loading characteristics will allow improved insight into whole body exposures during the same tasks performed in seated and standing working postures.

1.2 Purpose

The purpose of this research was to:

- Examine the effects of four different manual materials handling tasks on posture and muscular activity of the upper extremity and torso. These tasks were:
    - A static, isometric one-handed 40 N forward push
    - A static, isometric one-handed 40 N backward pull
    - A dynamic weighted transfer task
    - A dynamic light assembly task
- Determine if differences in workplace configuration between seated and standing postures created local body changes. This includes changes in activity levels of upper extremity musculature, joint moments at the wrists, elbows, shoulders and low back, and localized body discomfort.

1.3 Hypotheses

This investigation focused on quantifying upper extremity joint loading and muscular activity during manual materials handling tasks in sitting and standing workstation configurations. The hypotheses of this investigation were:

1. *An interaction effect between manual materials handling task and workspace configuration exists for the upper extremity.*

Upper extremity posture outcomes between seated and standing configurations are as markedly different as they are for low back kinematics (Callaghan & McGill, 2001). The work tasks chosen in this research were selected not only for their ability to replicate common materials handling tasks, but are different from one another in terms of upper extremity loading characteristics. It is plausible to assume that an interaction effect between task and configuration may also be present for some tasks. If this is true, then it could be beneficial to complete certain tasks in one sit/stand configuration over the other for that work task.

2. *A joint trade-off between the wrist, shoulder and low back exists between seated and standing configurations.*

Rotations between sitting and standing workplace configurations have been suggested to counteract the negative consequences of exclusivity related to both postures, but exposure values for a common set of exertions is lacking. Performance of the same tasks during sitting and standing that includes potential upper extremity accommodation for the large changes in spinal postures between these two configurations has had little or no evaluation. Previous research indicates that alternating between sitting and standing may lead to higher discomfort for the hand, wrist and forearm (Ebara et al, 2008); thus, it is possible that differences exist in joint loading between seated and standing postures. Joint moments at the wrist, elbow and shoulder were calculated and represented as a percentage of maximal moment production, and capacity calculations to create a trade-off index for each joint were developed with the following formula:

$$TOI = \frac{NM_{standing}}{NM_{sitting}} x100$$

Where TOI= trade-off index for each joint, $NM_{standing}$ = resultant joint moment of the X, Y and Z moments at the 0.9 APDF level for that joint in standing, $NM_{sitting}$ = resultant joint moment of the X, Y and Z moments at the 0.9 APDF level for that joint in sitting. This equation was used for each joint to determine its trade-off index in each of the four MMH tasks examined in this study. The 0.9 level was used to look at peak changes between sitting and standing work configurations.

By evaluating changes in musculoskeletal demands and joint moments, these findings will allow researchers and ergonomists to assess potential joint trade-offs in identical manual materials handling tasks performed in seated and standing configurations. These joint trade-offs can be used to identify scenarios that would place the worker at increased risk of future musculoskeletal disorders and enable practical, evidence-based workplace interventions. These interventions may help to prevent some shoulder injuries, and in turn decrease associated workplace lost time costs. The investigation will also provide insight into the fundamental mechanics at the shoulder while performing manual materials handling tasks.

3. *Individual muscular electromyographic activity is influenced by workstation configuration.*

Studies that account for differences in upper extremity demands between sitting and standing are limited. However, arm elevation angle is known to influence trapezius and deltoid activation levels (Inman et al., 1944; Johnson et al., 1994). Sitting and standing are distinctly different from one another, with seated postures averaging approximately 55% greater lumbar flexion as a percentage of the participant's maximum compared to standing (Callaghan & McGill, 2001). This may result in changes in upper extremity posture. It is likely that axial humeral rotation and elevation may differ in these two postures, altering moment arms and muscular lines of action inserting into the scapula and humerus (Ackland et al., 2008; Ackland & Pandy, 2009). Changes in individual muscular capacities would likely alter activity characteristics and muscular activity patterns, which has implications for injury risk or prevention.

II. Review of relevant literature

Seated and standing workspace configurations are both common in work. However, prolonged periods of time in these sedentary positions result in the development of pain, discomfort and musculoskeletal disorders. Thus, rotations between seated and standing configurations has been suggested as a potential mechanism to mitigate these injury risks, but few studies have evaluated the effects of these rotations on muscle and joint loading of the upper extremity. Robust documentation of these upper extremity exposure parameters while completing manual materials handling tasks is critical for identifying how specific musculoskeletal demands and potential injury risk differ between sitting and standing.

2.1 Risks Associated with Sedentary Work

Sedentary work has been linked to musculoskeletal discomfort. Sixty percent of office workers complain of physical discomfort (An et al., 2001). Often, the work itself may be the cause of the discomfort, particularly in prolonged sitting postures. Juul-Kristensen & Jensen (2005) examined self-reported ergonomic factors and factors related to work technique as potential modifiers for musculoskeletal symptoms in office workers. They reported that 38.4% of respondents associated their physical discomfort with prolonged sitting (Juul-Kristensen & Jensen, 2005). This discomfort may be precipitated by various factors, including maintaining a static work posture or general lack of body movement (Manchikanti, 2000; Korhonen et al, 2003). This can include prolonged standing or prolonged seated postures, both of which have been reported to increase low back pain in workers (Brown, 1975).

Sedentary behaviour may also increase risk of various physiological diseases. In an examination of the influence of prolonged screen viewing time on several health outcomes in

Australian adults, Dunstan and colleagues (2010) reported increased hazard ratios of cancer mortality (1.09), CVD mortality (1.18), and all-cause mortality (1.11) for each 1-hour increment in screen viewing time per day. Increased levels of sedentary behaviour are also linked to increased risk of metabolic syndromes, including increased cardio-metabolic and inflammatory markers (Gardiner et al, 2011). This includes triglycerides, markers of insulin resistance, and C-reactive protein, a known inflammatory marker associated with coronary heart disease and vascular mortality (Kaptoge et al, 2010). Sedentary periods can also create increased risk of non-Hodgkin Lymphoid Neoplasms in women, with those who sat for at least 6 hours per day at a 28% higher risk compared to women who sat fewer than three hours per day (Teras et al, 2012). Many of these authors suggested that reduction of prolonged activities, especially prolonged sitting, may be beneficial to reducing these physiological risks.

2.2 Prolonged Sitting in the Workplace

Prolonged sedentary periods in seated configurations have been associated with negative health effects for workers. Seated postures generate workplace limitations, which include decreased workspace volume, sensitivities to minor changes in work task spatial requirements, undesirable lumbar and cervical spine deformations, and a potential loading transfer to the upper limbs (Chaffin, 2006).

Prolonged sitting is also known to increase localized and whole body discomfort. Video display unit operators who remained in prolonged sitting postures for as little as two hours self-reported that their discomfort doubled from 0.92 to 1.95 units on a visual analog scale, and in-chair movements were minimal. Further, Gregory et al (2005) reported increases in perceived low back discomfort by workers using both office chairs and stability balls. Through the use of a

100-mm visual analog scale, localized and whole-body discomfort was reported in two one-hour sitting trials. Both the stability ball and office chair had increases in low back discomfort for both the office chair and stability ball after an hour ($p=0.0010$). However, the stability ball resulted in significantly higher whole-body discomfort than the office chair, with pain scores of 17.5mm and 9.1mm, respectively ($p<0.0001$). This increase in whole-body discomfort may be partially explained by McGill et al (2006), who examined the seat pressure and contact area when using exercise balls compared to stable seat surfaces. They found that while the stability ball had the lowest peak contact pressure of all seating scenarios, its contact area was significantly higher than any other seating type ($p<0.01$). The authors postulated that the exercise ball spreads out the contact area into tissues not usually loaded during sitting – namely, the gluteals and hamstring muscles (McGill et al, 2006). This increase in soft-tissue compression compared to sitting in an office chair may have led to circulation blockage acting as a mechanism of pain, soreness, and numbness (de Looze et al, 2003).

Prolonged sitting can also generate postures that increase spinal injury risk, both to the vertebrae and the intervertebral discs. De Carvalho & Callaghan (2012) examined the influence of lumbar supports during driving on spinal and pelvic postures at the level of the lumbar vertebrae. Some seating configurations resulted in lumbar flexion values that approached 60-97% of the maximal flexion range of motion. This increase in flexion may increase intradiscal pressure or create stress loading scenarios that create different demands compared to upright standing (De Carvalho & Callaghan, 2012). Sato and colleagues (1999) examined intradiscal pressures and spinal load in various body postures, and found a correlation between the spinal load and the angle of the motion segment in the standing position, but not in the sitting position. When comparing across the body positions, they found that upright sitting created spinal loads that were approximately 25% greater than standing (Sato et al, 1999). In addition, seated postures created increased pressure in the intervertebral disc, with a 90 kPa increase compared to upright standing. This agrees with previous research indicating increased disc pressure in seated postures (Andersson et al., 1977; Wilder et al., 1985). This increased flexion may also affect spinal loading patterns at the vertebral level, resulting in differential risks between postures. In 2007, Alexander and colleagues reported that flexed and upright sitting created significantly higher endplate focal stresses than standing, prone extension or supine lying. Sitting postures were postulated to increase the risk of posterior derangement of the lumbar spine and contribute to localized tissue damage (Alexander et al, 2007), and could eventually lead to symmetric disc degeneration and herniation (Videman et al, 1990). These postures also place increased passive strain on the posterior elements of the spine, leading to additional damage (Adams & Dolan, 1996; McGill & Brown, 1992; Solomonow et al, 2003; Twomney & Taylor, 1982). Callaghan et al (2010) examined pelvis rotation and lumbar flexion in a prolonged driving task, and found that individuals tended to “sink in” the automobile seat over time, resulting in a 5° increase in pelvic rotation and lumbar flexion throughout the driving protocol. However, it was unclear to what extent these changes were due to deformation of the seat cushions, or to viscoelastic creep of body tissues (Callaghan et al, 2010). Males typically exhibit greater pelvic rotation and lumbar flexion when compared to their female counterparts when moving from upright standing to seated configurations (Bridger et al, 1992; Dunk & Callaghan, 2005). Additional research should focus on if the material properties of the seat are the driving force for these biomechanical changes in posture or if sitting itself is the root of this increased injury risk.

Given the potential of progressively severe spinal injuries resulting from prolonged pelvic rotation and lumbar flexion associated with sitting, the risk of chronic low back injury intensifies, and can relate to multiple physiological and biomechanical side effects. Prolonged sitting alone, and/or in combination with whole body vibration and awkward postures, is a named risk factor for various medical conditions, including low back pain (Lis et al, 2007; Pope et al, 2002). Pelvic rotation and lumbar flexion may also increase muscular activity surrounding the spinal complex (Andersson & Ortengren, 1974; Wilke et al., 1999). Recent work by Schinkel-Ivy et al (2013) indicated that individuals who are symptomatic to pain development (PD) in prolonged sitting show different co-contraction patterns in the internal oblique, external oblique and erector spinae than their non-pain developing (NPD) counterparts. Specifically, PDs exhibited higher levels of co-contraction than NPDs, and this level of co-contraction increased over time. The authors postulated that co-contraction and pain development may interact in a vicious cycle – high levels of co-contraction may predispose individuals to pain development and in an attempt to alleviate pain and reduce tissue stresses, co-contraction increases, which accounts for the continual increases in pain observed in PD participants. Over time, cumulative effects from this cycle could result in chronic low back pain or damage to spinal structures.

Despite several known occupational benefits, prolonged sitting may also substantially affect the upper extremity. Seated postures have classically been associated with several primary benefits: reduced overall energy expenditure, reduced stresses on the lower body, reduced circulation burden to the lower extremity, and enhanced fine motor or precision control (Chaffin, 2006). Bot (2007) reported that prolonged sitting reduced the risk of sick leave related to the neck or upper extremity in a subgroup of patients in the three successive months after baseline. However, seated work also has drawbacks, including decreased workspace volume, sensitivity to minor changes in work task spatial requirements, undesirable lumbar and cervical spine deformations, and a potential transfer of physical demands to the upper limbs. Increased forward reach distances result in increased activity for musculature surrounding the shoulder complex at the same submaximal push and pull exertion level, with muscle activity levels increasing from 10 to as high as 25 %MVC when work positions moved from 60 to 100cm forward (McDonald et al., 2012). Increased forward flexion results in decreased shoulder force production during pulling exertions, for instance, in one study, maximal pulls at 45° were 1.23 times stronger than pulls at 90° of shoulder flexion (Imhrhan & Ramakrishnan, 1991). This mirrors findings by Garg & Beller (1990), who reported a 16% decrease in maximal pulling force between 40 and 70° of shoulder flexion. However, most of this work has examined maximal loading, and little data exists for submaximal loading scenarios and their effects on the upper extremity. Additional research is required to quantify potential loading changes in these seated work positions.

2.3 Prolonged Standing in the Workplace

Prolonged standing is also associated with negative influences on worker health. Prolonged occupational standing has been classically defined as spending over fifty percent of the time during a full work shift in the standing position (Tomei et al, 1999). The gravitational force of the mass of the upper body may create viscoelastic deformation or fluid loss in the intervertebral disc (Dieen et al., 1994). Standing can also exacerbate reported pain, spinal loading, and other health complications in the worker.

Prolonged standing reportedly contributes to an increase in self-reported pain. Macfarlane et al (1997) completed a population-based longitudinal study to determine physical factors related to employment that predicts a new episode of low back pain, reporting that standing for greater than two hours was associated with an increased risk of low back pain in workers, with an odds ratio of 2.1 for men, and 3.5 for women. A more recent study by Andersen et al (2007) aimed to examine the effect of work-related factors and individual and health-related factors on the onset of more severe musculoskeletal pain in 4 regions – the neck/shoulders, the upper extremity, the low back, and the lower extremity. In the final multivariate model, standing for greater than 30 minutes per hour was strongly associated with low back pain and any regional pain, with hazard ratios of 1.7-2.1. In 2008, Roelen et al completed a cross-sectional study of 983 male employees working in the manufacturing industry found that prolonged standing was related to pain in the legs, thorax, and low back (Roelen et al, 2008). Other musculoskeletal pain and injuries can be exacerbated through prolonged standing. Miranda et al (2002) found that 10% of workers develop knee pain within one year. Among the risk factors identified as contributing to knee pain was working in a standing position; often with the trunk flexed forward (Miranda et al, 2002). They also found that this pain persisted for 66% of workers who had this injury at the beginning of the observation period. Finally, in workers with no prior back pain history, clinical levels of back pain developed in 40 to 70% of individuals when exposed to acute bouts of prolonged standing (Nelson-Wong & Callaghan, 2010; Marshall et al, 2011; Gallagher, Nelson-Wong & Callaghan, 2011).

Prolonged standing may also increase spinal loading in the worker. Adams & Hutton (1985) completed a series of experiments on cadaveric lumbar spines to show how posture can affect spine mechanics and intervertebral disc health. While in a standing posture, increased load is placed on the apophyseal joints of the lumbar spine. This results in these joints resisting the majority of the shear force acting on the spine (Hutton et al., 1977) and over 15% of the compressive force (Adams & Hutton, 1980). In spines with degenerated discs, this load increased to 70% of the compressive force, and can result in gross osteoarthritic changes (Adams & Hutton, 1980). Spinal compression can undergo changes during prolonged standing. Leivseth &

Drerup (1997) measured spinal shrinkage in the thoracic and lumbar spine in subjects working in a sitting and a standing posture for 6.5 hours in a simulated work environment. They found that prolonged standing led to a 4.16 mm shrinkage in the lumbar spine, compared to 1.73 mm in the sitting cohort. The authors believe that the greater shrinkage in the lumbar spine during standing work is likely due to differences in lumbar lordosis and the effect of bending and torsion while handling work materials compared to the seated postures. This increased loading has a strong association with low back pain (Andersen et al, 2007; Roelen et al., 2008; Tissot et al., 2009).

Prolonged standing may also increase the risk for certain comorbidities. Primary among these is chronic venous insufficiency, which has an increased prevalence in workers whose occupations require prolonged standing (McCulloch, 2002). Sufficient pressure (at least 10-15 mmHg) must be maintained in order to ensure efficient blood flow return (Tomei et al, 1999). As a worker maintains a standing position, the valves and venous-muscle pump need to work harder to fight against the pull of gravity. If the amount of pressure is insufficient to propel blood upward against gravity, blood may pool in the lower extremities. (McCulloch, 2002). Workers who suffer from chronic venous disorders spend a significantly greater portion of their workday in prolonged standing compared to those without venous disorders (Tomei et al, 1999; Krijnen et al, 1997). The findings of Tomei's work suggest that the amount of time standing had a much stronger association with venous disorders ($p<0.00001$) than the type of occupation the worker performed, as occupation type had no significant correlation with venous pathology incidence ($p=0.1573$) (Tomei et al., 1999). Krinjen et al (1997) examined volume changes of the lower extremity and chronic venous insufficiency in male workers whose jobs required prolonged standing, and found that workers with chronic venous insufficiency had significant increases in lower extremity volume, with increases over 50 mL. Over time, increases in leg volume can cause a loss of integrity in the walls of the veins in the lower extremity, resulting in varicose veins and further health complications. Interplay between standing and arm positioning may also affect biomechanical and musculoskeletal loading. Unsupported arms in standing keyboarding tasks resulted in muscular activity levels near or above 20% MVC in the trapezius and elevator muscles of the arm (Onishi et al, 1982). These non-maximal protracted isometric contractions typical of fixed postures may lead to sensations of discomfort and pain in the short term, but may eventually lead to the onset of disease due to alterations of the soft tissues (Grieco, 1986). As such, prolonged standing should be avoided in workplace situations as much as possible to avoid these biomechanical and physiological risks on the worker.

2.4 Seated/Standing Rotations and Ergonomic Interventions

Increases in repetitive movements in the workplace may limit or stereotype body movement, increasing risks of prolonged sedentary postures. Grieco (1986) examined an idea of "postural fixity" – remaining in the same posture for extended periods of time. The common occurrence of an individual remaining in a single position without gross postural movements for an extended period of time is a prevalent risk factor for disorders of the lumbo-sacral spine, decreases in blood circulation surrounding musculature of the spine, and discomfort and pain in the upper extremity if left unsupported (Greico, 1986). As research into the negative effects surrounding the use of prolonged sitting or standing continues to increase, researchers continue to search for alternatives to these postures.

In an effort to counteract the deleterious effects of prolonged sitting or standing, rotations between these whole body postures have been suggested. Callaghan & McGill (2001) examined lumbar spine kinematics, spinal joint loads and trunk muscle activation patterns during prolonged sitting, and compared these values to standing outputs. They found that standing produced distinctly different spinal postures compared to sitting across all eight participants. Seated postures averaged approximately 55% greater lumbar flexion as a percentage of the participant's maximum compared to standing configurations, while standing configurations resulted in low back compressive loads that were 37% less than sitting loads (Callaghan & McGill, 2001). Additional research agrees with these findings that sitting and standing create differences in lumbar spine and pelvic postures to warrant changes between these postures (Alexander et al., 2007; Dunk et al., 2009).

Rotations between these two positions may also decrease postural discomfort, injury risk and worker fatigue. Workers with sit-stand workstations self-reported 62% less body discomfort and >50% fewer injuries and illnesses (Nerhood & Thompson, 1994). Roelofs & Straker (2002) examined discomfort and posture preferences of 30 full-time bank tellers who worked at a standing height workstation in three conditions: sitting in a high chair, standing, and alternating between the two postures. They found increased discomfort in the upper extremities in the just sitting condition and increased discomfort in the lower extremities in the just standing condition. They also found that 70% of their participants preferred the alternating posture condition (Roelofs & Straker, 2002). Employees at sit-stand adjustable workstations also report feeling more energetic and less tired by the end of the workday compared to prolonged sitting or standing, with reported energy levels increasing by 70% and fatigue decreasing by 60% by the end of the workday (Paul, 1995b).

However, switching between sitting and standing postures may also have negative consequences. Ideal wrist postures in standing postures are quite different than ideal wrist postures in seated position (Hedge et al., 2005). Indeed, keyboard use on a flat surface for typing can result in non-neutral wrist postures (Hedge et al., 1999). Previously, Keir & Wells (2002) indicated that elevated keyboard positions such as those involved in numerical entry or bank teller positions typically entail increased wrist extension. These postures may drastically increase the required extensor moment, as an extended (though common) wrist posture of 30° required upwards of 30% of the available wrist extensor moment (Keir & Wells, 2002). Ebara et al (2008) examined workers' musculoskeletal discomfort, alertness and performance while completing a typing task using sit-stand workstations. Results indicated that wrist discomfort scores increased by 27% over standard seated configurations when workers alternated between seated and standing positions. In addition, they found that sit-stand workstations did not generate beneficial effects compared to seated or high-chair conditions in terms of worker-reported musculoskeletal discomfort (Ebara et al, 2008). However, this contradicts arguments made by Hedge & Ray (2004) that the varied work postures of sit-stand workstations decreased upper extremity discomfort.

Examination of changes in demands between these two workspace configurations remains relatively scarce. Chau et al (2010) completed a systematic review on the effectiveness of workplace interventions for reducing sitting. The authors noted that this research area is in its infancy, and it is difficult to establish conclusions without enough quantitative evidence. Currently, most research has focused on low back or specific joint changes between sitting and standing tasks. Several studies have assessed sit:stand ratios across a number of dependent variables, and have found that sit-stand configurations generally decrease self-reported feelings of pain or discomfort. Paul and colleagues completed several studies using sit-stand workstations (1995a; 1995b; 1995c) that examined worker's perceived fatigue, spinal shrinkage and foot swelling. They found that alternating between these two configurations resulted in approximately 60% less perceived fatigue by the worker, 4.18 mm less spinal shrinkage (a 62% decrease), and less foot swelling (12.3mL compared to 21mL) in the workers. Hasegawa et al (2001) used a ratio of sitting-to-standing postures of 50%, and found that participants decreased their errors in a keyboard typing task by 20-40% when moving between postures compared to stationary positions. More recently, Husemann et al (2009) simulated data entry office work with a sit-stand ratio of 2:1 and compared their performance to a control group who was seated. They found that worker discomfort complaints in the sit-stand group decreased by 20-60%, while performance and errors were not different between groups. However, none of these studies focused on biomechanical exposures as outcome measures or reported values for isolated seated or standing work. As such, interpretability of these findings in relation to whole-body exposures to similar tasks in the workplace in seated or standing postures is difficult.

2.5 Upper Extremity Demands in the Workplace

Upper extremity demands are varied in the workplace, and are differentially affected through spatial and task influences. Localization of the task relative to the worker may increase loading or alleviate stresses. These stresses may result in increased discomfort or musculoskeletal disorder risk. Similarly, the types of manual materials handling tasks completed have differential effects on upper extremity.

2.5.1 Spatial Considerations

Shoulder and upper back tissues are affected by how the arms are positioned and supported in space. In general, work heights higher than the elbow result in humeral abduction, which can create increased stress on the musculature of the arms and neck. Hagberg (1981) examined changes in musculoskeletal activity in three workstation heights, and found that increased workstation heights resulted in increased middle trapezius and middle deltoid activity. Other research has reported up to four times higher incidence of cumulative trauma disorders related to high exposure to non-neutral postures and other ergonomics stressors (Punnett et al., 2004). Addtionally, Kee & Karwowski (2001) used perceived comfort ratings from males in prolonged sitting or standing positions, and used joint postures to develop regression equations. A min-max normalization procedure was applied to each subject's ratings:

$$Normalized\ confort\ score_{ijk} = \frac{raw\ data_{ijk} - min\ comfort_k}{max\ comfort_k - min\ comfort_k} \times 100$$

Where i = i^{th} level of posture; j = j^{th} joint posture; k = k^{th} subject;

raw $data_{ijk}$ = comfort at the i^{th} level of the j^{th} joint posture in the k^{th} subject;

max $comfort_k$ = maximum comfort in the k^{th} subject among all his ratings;

min $comfort_k$ = minimum comfort in the k^{th} subject among all his ratings;

normalized comfort $score_{ijk}$ = normalized comfort score at the i^{th} level of the j^{th} joint posture in the k^{th} subject.

These normalized comfort scores were examined at each level of joint postures across all subjects for sitting and standing configurations. From these equations, the authors represented the relationships between different levels of joint deviation or joint posture and corresponding normalized comfort scores, with increasing shoulder discomfort as the arm deviated further from the torso.

Work locations relative to the worker impact muscular activity and can influence future musculoskeletal risk. Postural asymmetry, changes in vertical and horizontal locations, and increases in velocity alter upper extremity capabilities (Garg & Beller, 1990; Imrhan & Ramakrishnan, 1992; Kumar 1995). In an effort to create a 3-D spatial muscle activity map for the right upper extremity during horizontal pushing and pulling tasks, McDonald et al (2012) had participants perform submaximal pushing and pulling exertions in 70 locations in 3-D space.

Spatial position affected total muscle activity of shoulder musculature in all three directions (moving locations anteriorly/posteriorly, left/right, and superior/inferior) in both pushing ($p<0.001$) and pulling ($p<0.002$) exertions. Within these three directions, anterior-posterior hand location was the most influential, followed by left-right location, then superior-inferior location. Movements in each direction differentially affected muscular outputs. As work heights increased, muscular activity increased significantly, with the highest muscular outputs at the highest work heights examined. This supported research by Antony & Keir (2010), who found that raising the arm from 30° to 90° doubled the mean static shoulder EMG. However, determination of loading on the upper extremity when moving from sitting to standing workstation remains unknown, and additional research is required in this area.

2.5.2 Manual Materials Handling and the Upper Extremity

Manual materials handling tasks are common in industry, and the type of task required of the worker may affect their future injury risk to the upper extremity. Between 50 and 75% of all manual materials handling tasks consist of pushing or pulling an object (Baril-Gingras & Lortie, 1990), and overexertion injuries account for over 30% of injuries in the Transportation, Warehousing and Utilities Sector (NIOSH, 2010). Ensuring effective quantification of these loads on the upper extremity is critical. However, most previous research has examined how maximal outputs change in pushing and pulling exertions (Garg & Beller, 1990; Imrhan & Ramakrishnan, 1991). The amount of repetition may also affect the upper extremity. Repetitive motions are often seen in light assembly tasks. High levels of repetitive work combined with lifting at or above the shoulder level increase the risk of arm pain in workers, with an odds ratio of 1.9 (Andersen et al, 2007). Other research supports the notion that repetitive motions are a risk factor for upper extremity pain (Macfarlane et al., 2000; Ryall et al., 2006). Static exertions also pose risks to the worker. Static strength has been defined as "the capacity to produce torque or force by a maximal voluntary isometric contraction", and has been used as a measure of worker capacity to determine if an individual is capable of completing a certain job (Chaffin, 1975). However, predictions for worker capacity for light manual materials handling tasks are not well correlated (Wiker et al, 1990). Static loading performed for long periods of time or repeated frequently can lead to chronic shoulder pain (Herberts et al, 1984) or a decrease in skilled motor performance through increased pain and discomfort in the hands and arms (Grandjean & Hünting, 1977). Rotations between tasks may also affect musculoskeletal disorder risk to the upper extremity. Job rotation aims to reduce high levels of loading over a work day through alternation between tasks, with the tasks within the rotation chosen to recruit different muscle groups in an attempt to prevent fatigue (Jonsson, 1988; Raina & Dickerson, 2009). However, the cycle time between these rotations may affect the upper extremity. When examining cycle times of 15, 30, 60 and 120s, performing work in the longest cycles induced a shorter average endurance time in the upper extremity, while the shortest cycle resulted in the longest average endurance time (Meszaros, 2013).

Interest in sit to stand workstations has increased to provide seated workers with the options of performing tasks in seated, standing or other configurations. However, little information exists to guide what tasks are best performed in seated versus standing and how these configurations interact with physical demands, especially for the upper extremity. Horizontal pushing and pulling are common industrial tasks (Chaffin & Andres, 1983; Hoozemans et al., 1998; Todd, 2005; MacKinnon & Vaughan, 2005), while the movement of lightweight objects on a work surface is important for many light assembly tasks. Investigation of these tasks during changes in workspace configuration will help delineate how muscular activity and postural outcomes change between these sitting and standing configurations. This project will aim to quantify upper extremity joint loading and muscular activity in sitting and standing workstation configurations for four common manual materials handling tasks. Novel exploration of regional joint trade-offs while performing the same task in seated and standing configurations will enable better workstation design decisions, potentially yielding substantial benefits to science and industry.

III. Methods

Collection and interpretation of data for this study involved participant recruitment, completion of various MMH tasks while using various biomechanical instruments, followed by subsequent processing and analysis of this data. University-aged, right hand dominant individuals acted as participants, and this work implemented the use of surface electromyography, motion capture and hand force data. Data collection involved two 30-minute sessions involving manual materials handling tasks on two separate days in two workstation configurations (sitting and standing). Post-collection processing and analysis quantified differences between seated and standing postures on muscular demands and joint loading on of the upper extremity.

3.1 Participants

Twenty right-handed male (22.5 ± 2.23 years, 1.79 ± 0.07 m, 79.5 ± 9.06 kg) and twenty right-handed females (22.3 ± 1.94 years, 1.64 ± 0.07 m, 61.2 ± 8.78 kg) recruited from a convenience sample participated. The participant pool for stature ranged from a 13th percentile female to a 99th percentile male. Participants were not height or weight matched between sexes. Both sexes were recruited to allow increased application of the findings to a working population. Participants were recruited with posters and verbally and exclusion criteria included self-reported upper limb or low back pain in the past 12 months, self-identification as developing low back pain from prolonged seated exposures (for example, a long drive), holding a job requiring prolonged standing exposures (>10 hours/week), or allergies to rubbing alcohol and skin adhesives.

A pre-collection briefing was completed with each participant at the start of each session. The purposes, methods, risks and benefits of this study were explained, after which they signed a form of consent prior to participation if they chose to continue (Appendix A2). Participants received financial compensation for their participation at a rate of $40, which was given upon completion of both test sessions. Each participant also received a feedback letter after participation outlining study details and researcher contact information (Appendix A4). This study was reviewed and received clearance through the institutional Office of Research Ethics.

3.2 Instrumentation

3.2.1 Surface Electromyography

EMG was collected from four muscles of the upper limb bilaterally, totalling 8 surface sites. These sites were the middle deltoid, supraspinatus, infraspinatus, and upper trapezius. A single ground electrode was placed over the participant's right clavicle. Bipolar Ag-AgCl dual surface electrodes with fixed 20 mm inter-electrode spacing (Noraxon, Arizona, USA) were placed over each muscle belly in accordance with recommended placements (Table 1). Prior to electrode placement, the overlaying skin was shaved and cleansed with an alcohol solution to minimize skin impedance. EMG signals were collected using the Noraxon Telemyo 2400T G2 telemetered EMG system (Noraxon, Arizona, USA) using a 16-bit A/D card with a maximum range of ±10V (VICON, Oxford, UK). This system included band pass filtering (10-500Hz) and differential amplification (common-mode rejection ratio >100 dB at 60Hz, input impedance 100MΩ) of the signals. The sampling rate was set to 1500 Hz.

Table 1: Surface Electrode Placement Instructions

Muscle	Surface Electrode Placement
Middle Deltoid	2-4 cm below the lateral rim of the acromion[a]
Supraspinatus	Approximately 2-3 cm superior to the scapular spine at its midpoint[a]
Infraspinatus	Approximately 4cm below the scapular spine at its midpoint, over the infrascapular fossa[a]
Upper Trapezius	Approximately 2cm lateral to the midpoint[b] between the C7 spinous process and the posterolateral border of the acromion

[a]Brookham (2010), [b]McLean et al., (2003)

3.2.2 Motion Capture

Three-dimensional motion was tracked using eight VICON MX20 optoelectronic infrared cameras. These cameras tracked the position of passive reflective markers secured to the skin over anatomical landmarks (Tables 2 & 3). In seated positions, 5 rigid clusters (totalling 17 markers) and 21 individual markers on the torso and upper extremities were tracked. In standing positions, an additional 6 clusters (totalling 30 markers) and additional 18 individual markers were tracked on the lower body. Captured kinematic data was recorded with the VICON Nexus 1.7.1 software (VICON Motion Systems, Oxford, UK), and was sampled at 50 Hz. Once all markers were placed in their appropriate positions, calibration trials were completed. These trials involved the participant standing in the anatomical position (standing with feet shoulder width apart, arms out to the sides with palm facing forward, head up and facing forward), and five seconds of data was collected. These trials were inspected before collection to ensure that all markers were visible. These trials were used to fit the marker templates constructed in VICON to each individual participant, allowing accurate marker reconstruction if a marker was occluded during subsequent trials.

Table 2: Anatomical locations and acronyms of individual reflective markers

Marker Label	**Description**
Marker Label	Description
EAR*	Anterior to the external auditory canal of the ear
SS	Suprasternal notch
C7	7th cervical vertebra spinous process
T8	8th thoracic vertebra spinous process
L5	5th lumbar vertebra spinous process
PSIS*	Posterior superior iliac spine
ACR*	Acromion
ME*	Medial humeral epicondyle
LE*	Lateral humeral epicondyle
RS*	Radial styloid
US*	Ulnar styloid
MCP2*	2nd metacarpal-phalangeal joint
MCP5*	5th metacarpal-phalangeal joint
ASIS*†	Anterior superior iliac spine
GT*†	Greater trochanter of the femur
MC*†	Medial femoral condyle
LC*†	Lateral femoral condyle
MM*†	Medial malleolus
LM*†	Lateral malleolus
HEEL*†	Posterior aspect of the calcaneus
TOE*†	Distal end of the first metatarsal
MT5*†	Distal end of the fifth metatarsal

*indicates bilateral placement †used in standing configurations only

Table 3: Marker Cluster labels and descriptions

Marker Label	Description
CHEST1 CHEST2 CHEST3 CHEST4 CHEST5	Chest Cluster (between C7 and SS markers)
UA1* UA2* UA3*	Upper Arm Triad (halfway between ACR and LE markers)
FA1* FA2* FA3*	Forearm Triad (halfway between LE and US markers)
THIGH1*† THIGH2*† THIGH3*† THIGH4*† THIGH5*†	Thigh Cluster (halfway between GT and LC markers)
SHANK1*† SHANK2*† SHANK3*† SHANK4*† SHANK5*†	Shank Cluster (halfway between LC and LM markers)
FOOT1*† FOOT2*† FOOT3*† FOOT4*† FOOT5*†	Foot Cluster (dorsal surface of the foot)

*indicates bilateral placement †used in standing configurations only

3.2.3 Hand Force Transducer

During the push and pull manual materials handling tasks, force outputs were measured using an AMTI 6 degree-of-freedom force transducer (MC3A, AMTI MA, USA). This force transducer was rigidly fixed between a D-shaped cylindrical handle and a steel attachment to a MOTOMAN HP-50 robotic arm (Motoman Robotics Division, Yaskawa America, USA), allowing movement of the transducer in relation to the participant (Figure 1). Force was sampled at 1500 Hz using VICON Nexus 1.7.1 software.

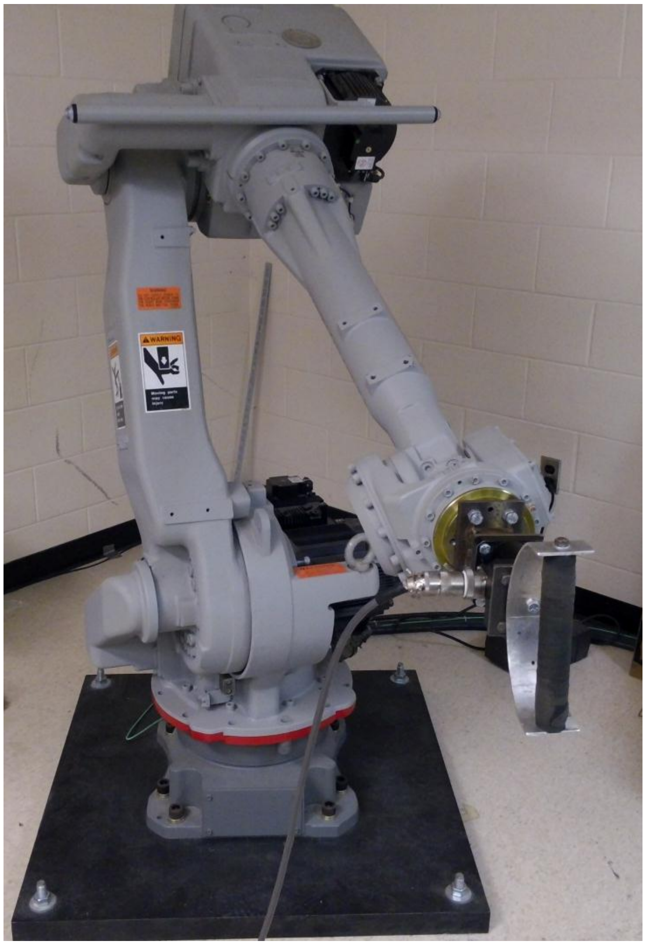

Figure 1: A force transducer was connected between a rigid D-Link handle and a MOTOMAP HP-50 robotic arm, allowing movement of the force transducer relative to the participant.

3.2.4 Self-Reported Body Discomfort

Ratings of perceived discomfort were recorded before the start of the experimental protocol and after completion of each experimental task section, totalling five ratings collections. Ratings of perceived discomfort were rated on a visual-analog scale 100mm long (Appendix A5). Participants rated the upper limbs, torso and lower back discomfort after each completed task, with 0 mm representing ‘no discomfort’ and 100 mm representing ‘extreme discomfort’. A total of 18 body sections across these body parts were monitored.

3.3 Photographs and Video Recording

Photographs and video recordings were taken during the study if consent was provided by the participant. These photographs and video recording were focused on the upper limb and torso. These were obtained primarily for teaching and communication purposes such as when presenting the study results in a scientific presentation or publication. Any facial features or other distinguishing features that were visible in photos or recordings used for these above mentioned purposes was blackened out to maintain participant confidentiality.

3.4 Testing Protocol

The protocol for each participant for each experimental session involved the application of surface electromyography equipment, collection of maximal voluntary exertions, followed by a 5 minute rest period, application of the reflective markers for motion capture, then collection of the experimental trials. (Figure 2). Upon completion of all experimental trials, all equipment was removed from the participant as they were debriefed by the researcher. They were then given the option to receive feedback on the results of the study (Appendix A4) and receive remuneration for their participation.

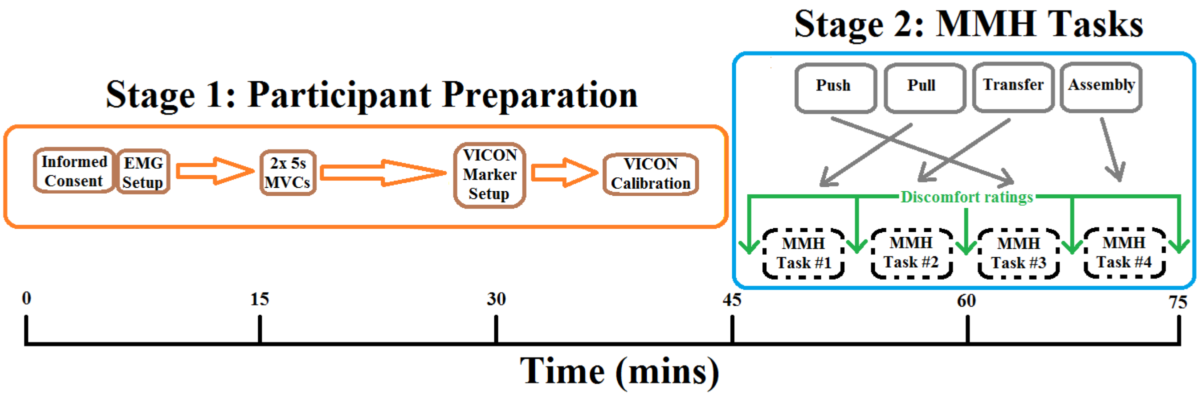

Figure 2: Each session consisted of two stages: participant preparation involving consent, EMG and marker placements was completed first, followed by a randomized order of the four MMH tasks.

3.4.1 Maximal voluntary contractions

Participants completed twelve different maximum voluntary isometric exertion tests under manual resistance. Each test was designed to elicit maximal activation from each muscle, and was derived from the literature (Criswell, 2011). Maximal voluntary exertions were performed twice for each muscle group to improve reliability of the results (Fischer et al, 2010) with a minimum of two minutes rest between maximal exertions (Chaffin, 1975). The highest maximal voluntary electrical activity from these trials was used as the reference to normalize subsequent electromyographic data for that muscle (Winter, 1991). Postures for eliciting maximal activity from each muscle are located in Table 4.

Table 4: Reference contractions used to elicit muscle activity of recorded muscles

Label	Muscle	Reference Contraction
ADEL	Anterior Deltoid	Seated, resisted 90° humeral abduction[a]
SUPR	Supraspinatus	Side-lying, resisted 5° shoulder abduction[a]
INFR	Infraspinatus	Side-lying, 90° elbow flexion, resisted external rotation[a]
UTRP	Upper Trapezius	Prone, resisted 90° humeral abduction, thumb pointing at floor[a]

[a] Cram & Kasman, 1998

3.4.2 Manual materials handling tasks

Four manual materials handling tasks were investigated in this study, and were examined in both the seated and standing configurations. These tasks were isometric push and pull exertions, a light load transfer task, and a light assembly task. The order of the four tasks in each session was randomized between participants. As there were two collection sessions, all four tasks completed in sitting were collected during one session, while all standing trials were completed in the other session. The order of sessions was randomized between participants. The protocol to complete all manual materials handling tasks was approximately 30 minutes in length. For each MMH task in sitting and standing, the participant and task were placed into optimal positions based on current ergonomic guidelines, then participants were given the option to adjust their body posture relative to the work task if they desired. This postural flexibility was completed in an effort to replicate work task scenarios, allowing some freedom for the participant to move into a position they found most comfortable.

Static isometric pushes and pulls constituted two of the four manual material handling test scenarios. Each participant performed five 7-second 40N static unilateral pushes and pulls with the left and right hands, resulting in twenty trials across these two scenarios. 40N was chosen to represent an occupationally relevant force level and one that would not produce fatigue during the experiment. Participants used a power grip on the cylindrical handle, which was then manipulated relative to the participant for various work scenarios. In each scenario, the cylindrical handle was placed so that the desired force will be exerted perpendicular to the handle, allowing maximal force exertion without a friction limitation at the grip (Seo, 2010).The handle was positioned so that the handle rested in the participant’s palm when their elbow was flexed 90° and their forearm was facing forward. The handle was located directly in line with the acromion on the same side as the unilateral hand completing the exertion (Figure 3). This height was chosen to conform to NIOSH recommended guidelines for light assembly (NIOSH, 1997). Each participant had access to live feedback of their force outputs with a custom program using LabView software (National Instruments, Texas, USA). Off-axis forces were not limited in order to create a more realistic workplace experience. Participants were instructed to maintain body position and to not lean in any direction during the collection trials. Participants received approximately 1 minute of rest between exertions. Each test scenario (10x40N pushes, 10x40N pulls) took approximately ten minutes to complete.

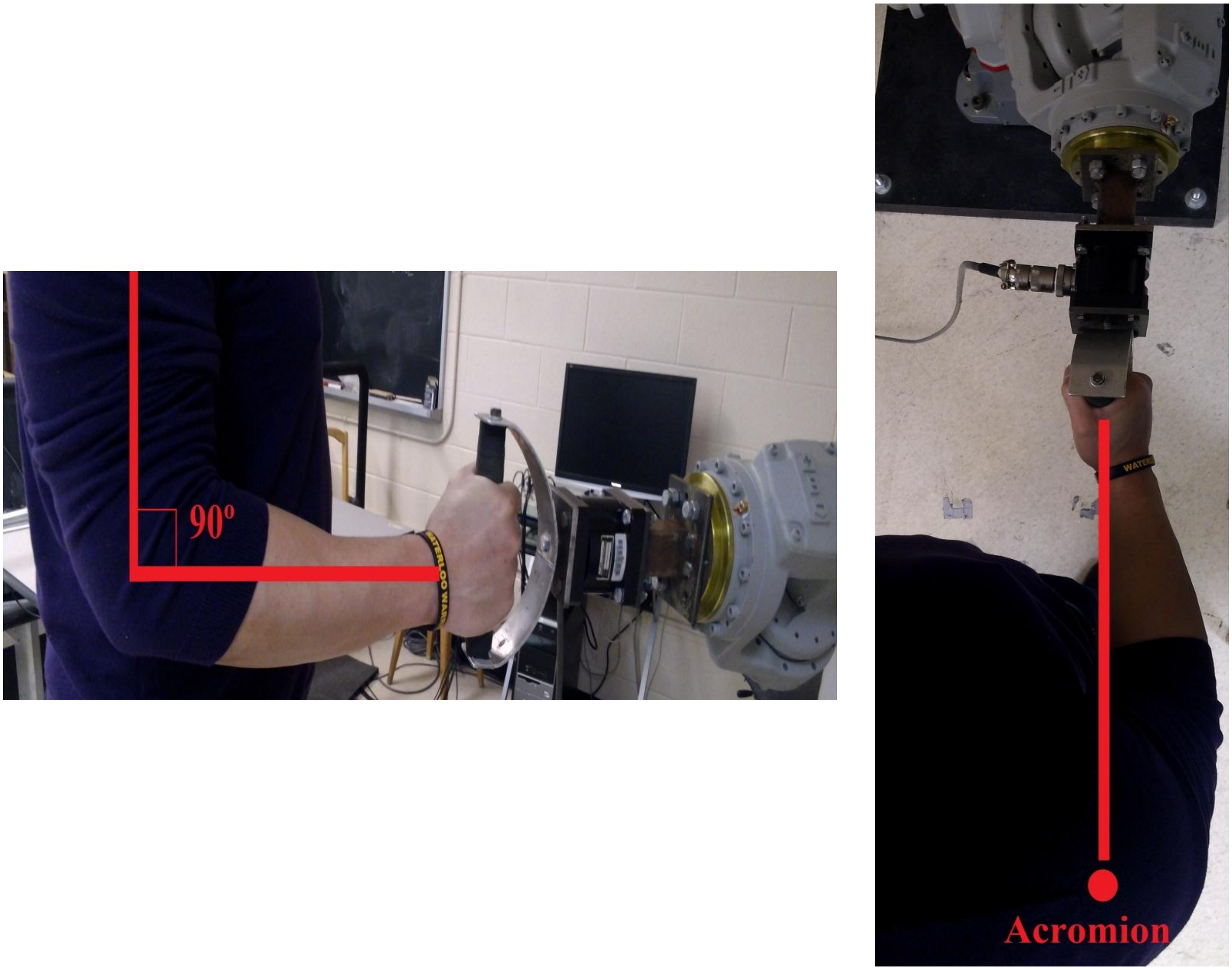

Figure 3: Participants used a one-handed power grip when holding onto the handle during push and pull tasks, with their elbow at 90°. The handle location was placed in line with the acromion on the same side of the body.

The light load transfer task consisted of moving a weighted bottle on a table from an origin point to a point marked on the table and returning it to its origin point. Before starting this test scenario, participants completed three maximal arm elevations as their force output was measured using a hand dynamometer placed above the wrist. Participants sat on a backless chair with their arm in 90° of forward flexion with their thumb facing the ceiling. The researcher held a hand dynamometer at the wrist for the participant to push upwards into. Each trial lasted five seconds, and participants were instructed to push upwards maximally into the hand dynamometer. Each arm was tested separately, and three trials were completed for each arm. A minimum of two minutes rest was provided to the participant between each exertion. The maximal force outputs from these three trials were averaged to produce a single arm elevation force value. Participants transferred bottles filled with lead shot whose weight was equal to 15% of this maximum value. Tabletop heights were normalized to the participant's stature, with table placement set at just below elbow height. This height was chosen as it has been recommended for work heights in light assembly (NIOSH, 1997). In seated trials, the participant was seated and a backless chair was adjusted so that the participant's knee and hip angles were at 90°.

Movements during this transfer task involved the participant moving the bottle from a common origin point, out to one of the five destination points then back to the origin. Five paths marked A through E were clearly marked on a table to designate movement destinations for the transfer task (Figure 4). Each destination point was 50 cm from the origin point, placed at 45 degrees from one another along azimuths from left to right. At each location, the worker placed the bottle down onto a small trigger that closed a 9V circuit, indicating proper placement at the destination location. This voltage was collected using VICON Nexus 1.7.1 software, and was collected at 1500 Hz. This allowed the worker to have a brief moment of rest between loading periods, and the triggers allowed determination of when hand loads were present for the worker in post-collection kinematic analysis. This trigger system was produced with the help of the Kinesiology Electronics Shop attached to the biomechanics wing in the building. These movements were completed at a cadence of 20 transfers per minute, and were controlled through the use of a metronome. This cadence allowed the participant to transfer the bottle to the destination in one second, move it back to the origin in one second, and have a one second rest period. This task scenario was broken down into four subsections:

- Right hand, moving clockwise from destination A to destination E
- Left hand, moving clockwise from destination A to destination E
- Right hand, moving counter-clockwise from destination E to destination A
- Left hand, moving counter-clockwise from destination E to destination A

Each of these subsections was completed for 2.5 minutes, and was randomized within this test block. This test scenario took approximately 10 minutes to complete.

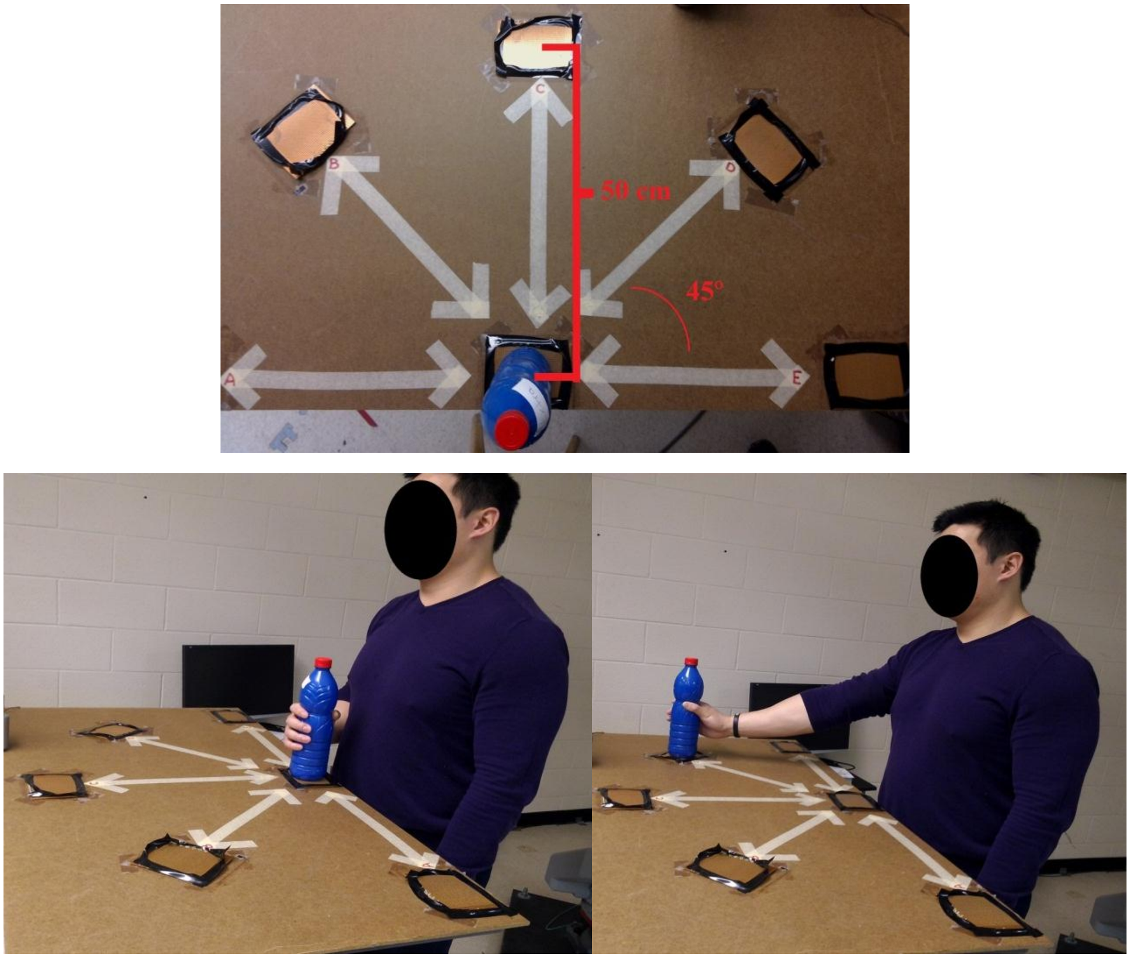

Figure 4: Participants moved a weighted bottle from a central target out to one of five target locations before returning to the origin. This was completed at a rate of 50 transfers/minute, for a total of 10 minutes.

The fourth test scenario was a light assembly task. This involved placing steel washers over holes in a pegboard and inserting a small wooden dowel into this hole in the pegboard (Figure 5). A tabletop was placed directly in front of the participant, and was again normalized to their stature by placing the table just below elbow height. In seated trials, the participant was seated and a backless chair adjusted so that the participant's knee and hip angles were 90°. The participant had the pegboard placed on the table in front of them with the washers and dowels placed in small containers on either side of the pegboard. Participants were required to insert one peg in the pegboard every three seconds, or 20 pegs per minute. Four identical trials were collected, each 2.5 minutes long, resulting in the participants inserting 50 pegs per trial. Cadence was maintained through the use of a metronome. This test scenario took approximately 10 minutes to complete.

Figure 5: Participants inserted pegs into a wooden pegboard at a cadence of 50 pegs/ minute for a total of ten minutes.

3.5 Data Analysis

Surface electromyography, joint motion and body segment discomfort was processed for analysis. Electromyography data was filtered and normalized to its respective maximal voluntary exertion and presented as a percentage (%MVE). Link segments were defined from filtered marker data and segmental coordinate systems were created to examine local joint loading. All kinematic and electromyographic data was processed with MATLAB software version 2013 (Mathworks Inc, MA, USA) and statistical analysis was performed with JMP® 10 statistical software (SAS Institute Inc., NC, USA).

3.5.1 Electromyographic Signal Analysis

EMG signals were analyzed with respect to amplitude. All signals from test exertions were linear enveloped and normalized to their respective muscle specific maximal voluntary exertions. DC bias was removed by taking the average of the signal and subtracting it from each point. A high pass 4th order Butterworth filter with a cut-off frequency of 30Hz was applied to all signals in order to remove any heart rate contamination (Drake & Callaghan, 2006). The signals were then linear enveloped via full-wave rectification followed by low pass filtering (Winter, 2009). A dual pass, 4th order low pass Butterworth filter with a cut-off frequency of 4Hz was used in linear enveloping to represent the low frequency trend of the signals produced by the upper extremity and trunk musculature. A dual pass filter was used instead of single pass, as mitigation of electromechanical delay to match to kinematic outputs was not required for this research. Signals were normalized to the maximal activation for each muscle obtained across the two MVE trials.

EMG signal analysis was examined by task. For each task, an amplitude probability distribution function (APDF) was generated. The muscular output of the muscle in %MVC was recorded at each time point during the task and ordered based on its magnitude to determine the distribution of activity levels This method was developed by Hagberg & Jonsson (1975) to examine myoelectric signals for ergonomics research. Generally, the amplitudes of three percentiles from these APDFs are examined: the 10th percentile (APDF=0.1) is used as an indicator of 'rest', the 50th percentile (APDF=0.5) as a predictor of 'work load', and the 90th percentile (APDF=0.9) represents 'heavy contractions' (Robertson, 2010). The 0.1, 0.5 and 0.9 levels will be used in this research to represent the 'rest', 'work load' and 'heavy contraction' levels used previously in the literature. In addition, the 0.3 and 0.7 APDF probabilities will be extracted in an effort to provide additional insight beyond these three values. (Figure 6).

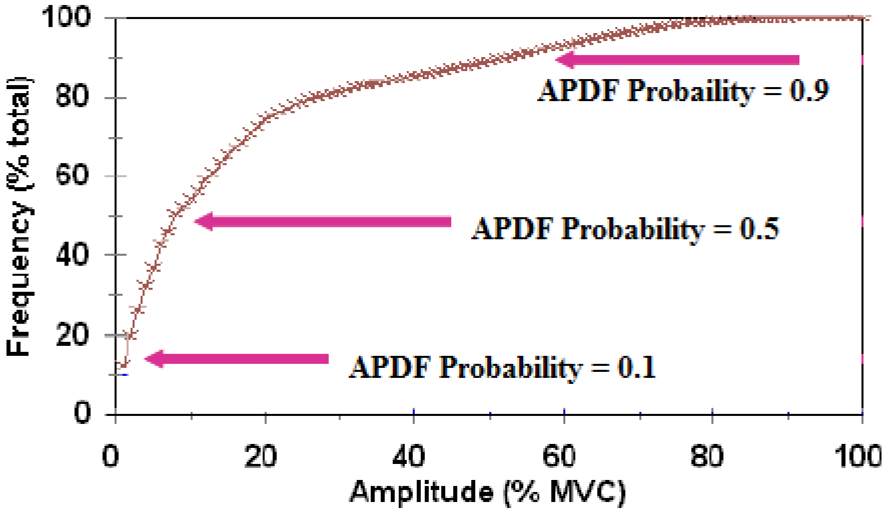

Figure 6. A sample APDF for an EMG output. As probability increases, the %MVC amplitude increases (adapted from Robertson, 2010)

3.5.2 Kinematic Analysis

Kinematic analysis consisted of data filtering, marker reconstruction and local joint coordinate system construction, followed by conversion of marker data to joint center data and calculation of external joint moments. All raw kinematic data was low pass filtered with a cut-off frequency of 6 Hz (Winter, 2009) and segment length and orthogonal coordinate systems were constructed using ISB definitions provided by Wu et al (2005). Static calibration trials were performed prior to the MMH tasks using a standardized position to determine the position of markers and allow for reconstruction in every subsequent recorded frame. Once local joint coordinate systems were constructed, this marker data was converted into locations of joint center (LOC) data. This LOC data were exported to a 3-D static resultant moment analysis program similar to previous external dynamic shoulder moment models (Dickerson et al., 2006; Dickerson et al., 2007). Participant weight, stature and measured hand force (measured from the force transducer in the static tasks, and the weights of the materials in the dynamic tasks) were used as inputs into a top down inverse quasi-static model to determine time series moment data for each trial and each task. Forces identified as pushes or pulls were applied parallel to the plane of the palm in the model, and transfer forces were applied downward (Figure 7).

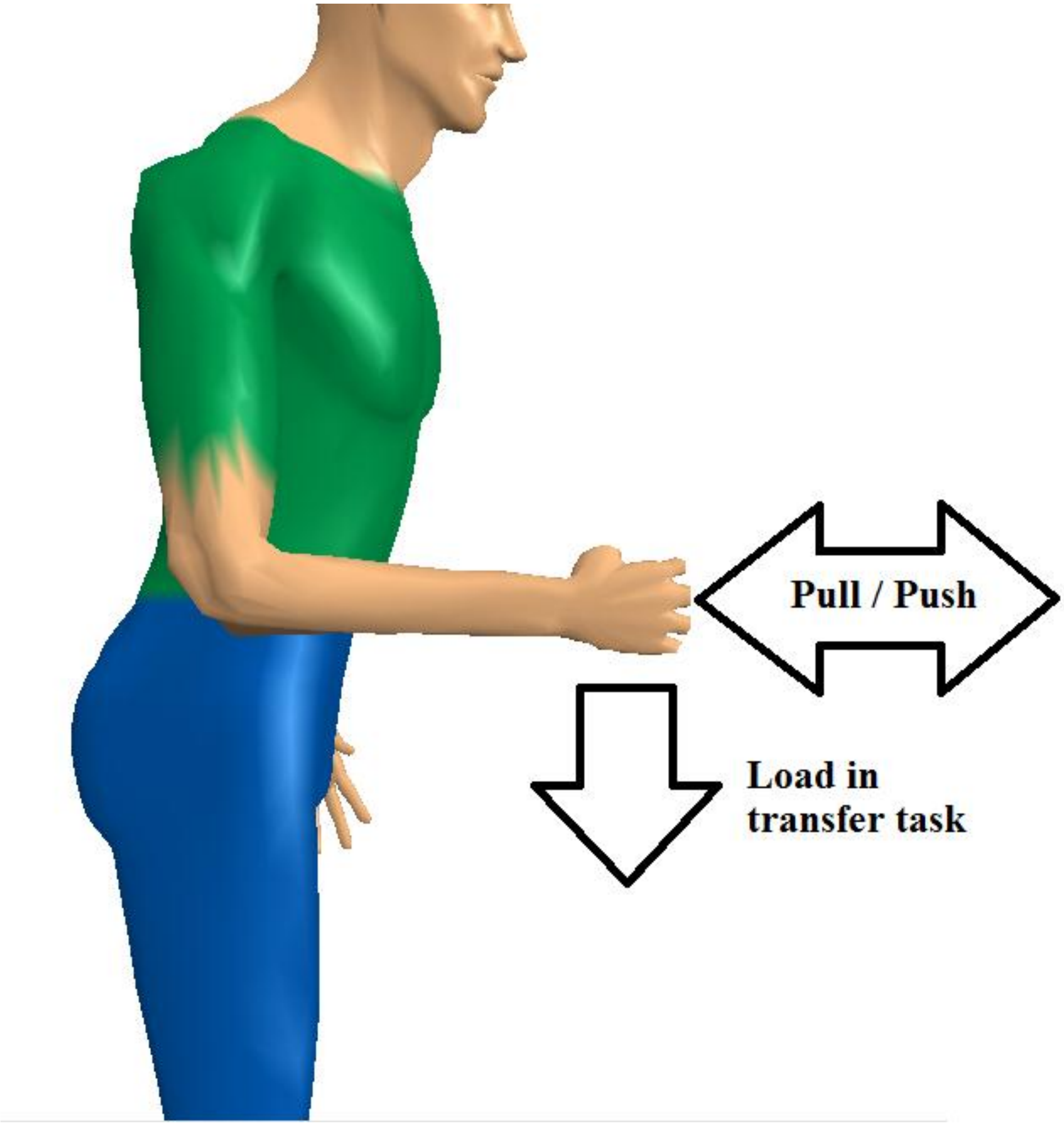

Figure 7. Application of external hand forces was dependent on the MMH task. Push and pull tasks were directed in the same sagittal plane as the palm of the hand, while the bottle load in the transfer task was projected downwards.

This model consists of seven segments: the trunk (with head), and bilateral upper arms, forearms and hands. Segment masses were calculated as percentages of body weight (Webb Associates, 1978) and joint centres of the low back (L5/S1), glenohumeral, elbow and wrist joints were estimated using published guidelines (Dempster, 1955). These locations were used to derive segmental locations of centers of mass (COM) (Dickerson et al., 2007). Calculation of the external joint forces (shown for the hand segment) is described by Equations 1-3:

$$\sum F_x = F_{H,x} + W_{H,x} + R_{Wr,x} = 0 \qquad (1)$$

$$\sum F_y = F_{H,y} + W_{H,y} + R_{Wr,y} = 0 \qquad (2)$$

$$\sum F_z = F_{H,z} + W_{H,z} + R_{Wr,z} = 0 \qquad (3)$$

Where F = force at the hand, W = weight of the hand, R = reaction force at the wrist (Wr). Similar calculations were performed on the other body segments. The 3-dimensional moment calculation for the hand is Equation 4. The sums of the moments were assumed to equal zero (static equilibrium):

$$\sum M = d_{WH} \times F_H + d_{CM_H} \times W_H + M_{Wr} = 0 \qquad (4)$$

Where M = the moment, d = distance, WH = weight of the hand, F = force, CM_H = center of mass of the hand, Wr = moment of the wrist. Similar calculations were completed at the elbow, shoulder and low back.

After completion of these calculations at each frame for the wrist, elbow, shoulder and low back joints, APDFs of the X, Y and Z components of each joint moment were calculated. A joint trade-off index was used to examine potential inter-joint loading differences (Equation 5). This equation was applied at each joint to determine if joint loading increases or decreases across configurations.

$$TOI = \frac{NM_{\ standing}}{NM_{isitting}} \qquad (5)$$

Where TOI= trade-off index for each joint, NM_{standing} = resultant joint moment of the X, Y and Z moments at the 0.9 APDF level for that joint in standing, NM_{sitting} = resultant joint moment of the X, Y and Z moments at the 0.9 APDF level for that joint in sitting. The 0.9 level was used to look at peak changes between sitting and standing work configurations.

This equation was used for each joint to determine its trade-off index in each of the four MMH tasks examined in this study. For each TOI, a value greater than 1.00 would indicate that the resultant moment is greater in standing than in sitting, while a value below 1.00 would indicate a greater resultant moment in sitting.

3.5.3 Body Discomfort Analysis

Discomfort ratings for each of the 19 body locations were measured on the 100mm visual-analogue scale to the closest mm. Scores from the baseline rating of perceived discomfort (RPD) taken at the start of testing were used to adjust each subsequent RPD. The baseline for each participant was removed from each task during the protocol. This allowed the RPD scores to be compared as a difference from baseline.

3.5.4 Statistical Analysis

All statistical analyses were completed with JMP 10.0 software (SAS Institute, North Carolina, USA). Statistical significance was considered at $\alpha = 0.05$. Tukey HSD post-hoc analysis was conducted if statistically significant differences are found. Each manual materials handling task was analysed for both workspace configurations. Ratings of perceived exertions analysis consisted of each separate body section measured in the discomfort measurements. A mixed model analysis of variance (ANOVA) with two factors (manual materials handling task, workspace configuration) and one interaction (task * configuration) was applied with one between subject factor of sex. Joint moment analysis used 0.1, 0.3, 0.5, 0.7, and 0.9 values determined through the APDFs. This outcome variable was tested to examine joint moment changes between sitting and standing configurations for identical manual materials handling tasks. EMG analysis used the 0.1, 0.3, 0.5, 0.7 and 0.9 values determined through the APDFs, allowing examination of muscular activity changes between configurations and tasks. Dependent factors included all 8 muscles, differences in joint loading, and body discomfort ratings at each of the 18 body locations.

IV. Results

Significant effects of work configuration and task existed for all dependent variables examined. The results are discussed by dependent variable below for ease of understanding.

4.1 Electromyography

Differences in muscular activity were evident in all muscles.. Significant interaction effects between body configuration and task appeared for UTRP and SUPR bilaterally, with p values ranging from 0.0374 to 0.0004 (Table 5). Post hoc Tukey HSD testing revealed that completing individual tasks in sitting resulted in higher activity levels than its standing counterpart (Figure 8). Moving from sitting to standing resulted in increases of up to 3 %MVC in push tasks, 7.6 %MVC in transfer tasks, and 4.7 %MVC in assembly tasks. Pull tasks experienced little change between sitting and standing, with muscle activity levels changing by less than 1 %MVC between the two configurations. This interaction was significant for these muscles at all APDF levels analyzed, was absent for the other muscles (Table 6, Appendix B).

A main effect of sit/stand configuration was present for the left SUPR, as well as UTRP bilaterally (p = 0.0031-0.0477; Table 5). This effect was significant for all APDF levels in the left UTRP, but was only significant for the 0.1 level in the right UTRP and the 0.7 and 0.9 levels in the left SUPR. This main effect doubled left UTRP activity at peak levels from 4 to 8 %MVC when working in sitting compared to standing, and left SUPR activity at peak levels increased by 25% from 6 to 8 %MVC at the 0.9 APDF level.

Main effects of task existed for all muscles at all APDF levels (p<0.0001, Table 5). At low APDF levels (0.1), the Push task had the highest activity levels for most muscles except for UTRP bilaterally, when the Assembly task was highest (p<0.0001). At this level, activity levels

Table 5: Statistical significance of EMG results across all APDF values for all muscles examined. Config = sit/stand configuration, MDEL = middle deltoid, UTRP = upper trapezius, SUPR = supraspinatus, INFR = infraspinatus. Shading denotes significant differences in EMG outputs.

Left Side						Right Side				
Muscle	APDF Level	Config	Task	Config * Task		Muscle	APDF Level	Config	Task	Config * Task
MDEL	0.1	0.4641	<0.0001	0.6562		MDEL	0.1	0.3687	<0.0001	0.8959
	0.3	0.4165	<0.0001	0.7694			0.3	0.3672	<0.0001	0.9387
	0.5	0.4079	<0.0001	0.8099			0.5	0.3687	<0.0001	0.9733
	0.7	0.4129	<0.0001	0.8525			0.7	0.3644	<0.0001	0.9657
	0.9	0.4175	<0.0001	0.8401			0.9	0.3696	<0.0001	0.8692
UTRP	0.1	0.0061	<0.0001	0.0127		UTRP	0.1	0.0349	<0.0001	0.0374
	0.3	0.0054	<0.0001	0.0093			0.3	0.0635	<0.0001	0.0176
	0.5	0.0048	<0.0001	0.004			0.5	0.0794	<0.0001	0.0128
	0.7	0.0039	<0.0001	0.0015			0.7	0.0871	<0.0001	0.0104
	0.9	0.0031	<0.0001	0.0008			0.9	0.0958	<0.0001	0.009
SUPR	0.1	0.071	<0.0001	0.0199		SUPR	0.1	0.1145	<0.0001	0.0006
	0.3	0.0714	<0.0001	0.017			0.3	0.115	<0.0001	0.0014
	0.5	0.0588	<0.0001	0.0067			0.5	0.1851	<0.0001	0.0028
	0.7	0.046	<0.0001	0.0019			0.7	0.1871	<0.0001	0.0052
	0.9	0.0477	<0.0001	0.0023			0.9	0.1755	<0.0001	0.0102
INFR	0.1	0.4247	<0.0001	0.8429		INFR	0.1	0.4514	<0.0001	0.8749
	0.3	0.4763	<0.0001	0.7619			0.3	0.4222	<0.0001	0.8765
	0.5	0.3981	<0.0001	0.8569			0.5	0.4775	<0.0001	0.8674
	0.7	0.3657	<0.0001	0.8468			0.7	0.4541	<0.0001	0.8618
	0.9	0.4569	<0.0001	0.859			0.9	0.334	<0.0001	0.7198

were highest in the infraspinatus bilaterally during push tasks at 7 %MVC. At moderate APDF levels (0.5), the task causing highest muscle activity varied between the Push and Transfer tasks across muscles. At peak activity levels (APDF=0.9), the Transfer task resulted in the highest activity levels across all muscles examined, with activity levels ranging from 13-17 %MVC, and highest in infraspinatus bilaterally (Figure 9).

Table 6. EMG activity normalized to %MVC across tasks, conditions and APDF levels for the left upper trapezius and supraspinatus. Significant interaction effects were present at all APDF levels for this muscle, with completing a task in sitting resulting in higher activity levels than in standing.

L_UTRP	**APDF Level**				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	3.6	4.1	4.5	4.9	5.6
Sit + Pull	1.2	1.3	1.4	1.6	1.8
Sit + Transfer	2.3	4.3	7.1	11.0	17.2
Sit + Assembly	4.2	5.4	6.4	7.5	9.3
Stand + Push	1.8	2.1	2.3	2.6	3.0
Stand + Pull	1.0	1.1	1.2	1.3	1.5
Stand + Transfer	1.0	2.1	3.5	5.8	9.6
Stand + Assembly	2.1	2.8	3.3	3.9	4.8

L_SUPR	**APDF Level**				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	4.4	5.0	5.5	5.9	6.7
Sit + Pull	1.9	2.2	2.4	2.6	2.9
Sit + Transfer	3.1	5.2	7.9	11.5	17.0
Sit + Assembly	4.4	5.7	6.6	7.6	9.4
Stand + Push	3.6	4.1	4.5	4.9	5.6
Stand + Pull	2.2	2.5	2.7	3.0	3.4
Stand + Transfer	1.8	3.4	5.4	8.0	12.5
Stand + Assembly	2.8	3.7	4.4	5.1	6.4

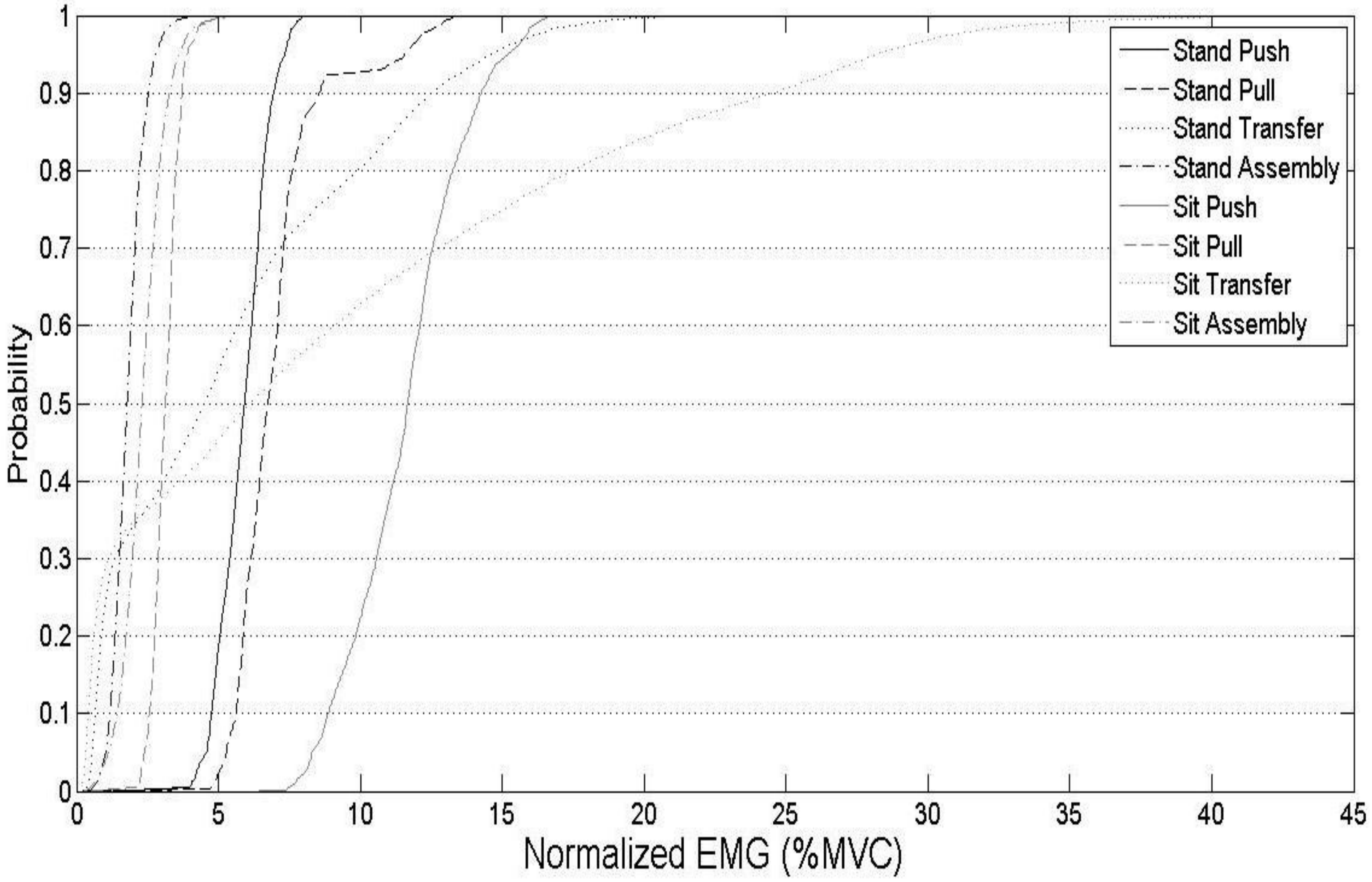

Figure 8. **APDF curves of right UTRP for one participant across work configurations & tasks. The four MMH tasks are represented in both sitting and standing, resulting in eight lines. Lines further to the right represent increased activation at a given probability, while increased verticality represents an increased probability of working at or below that activity level.**

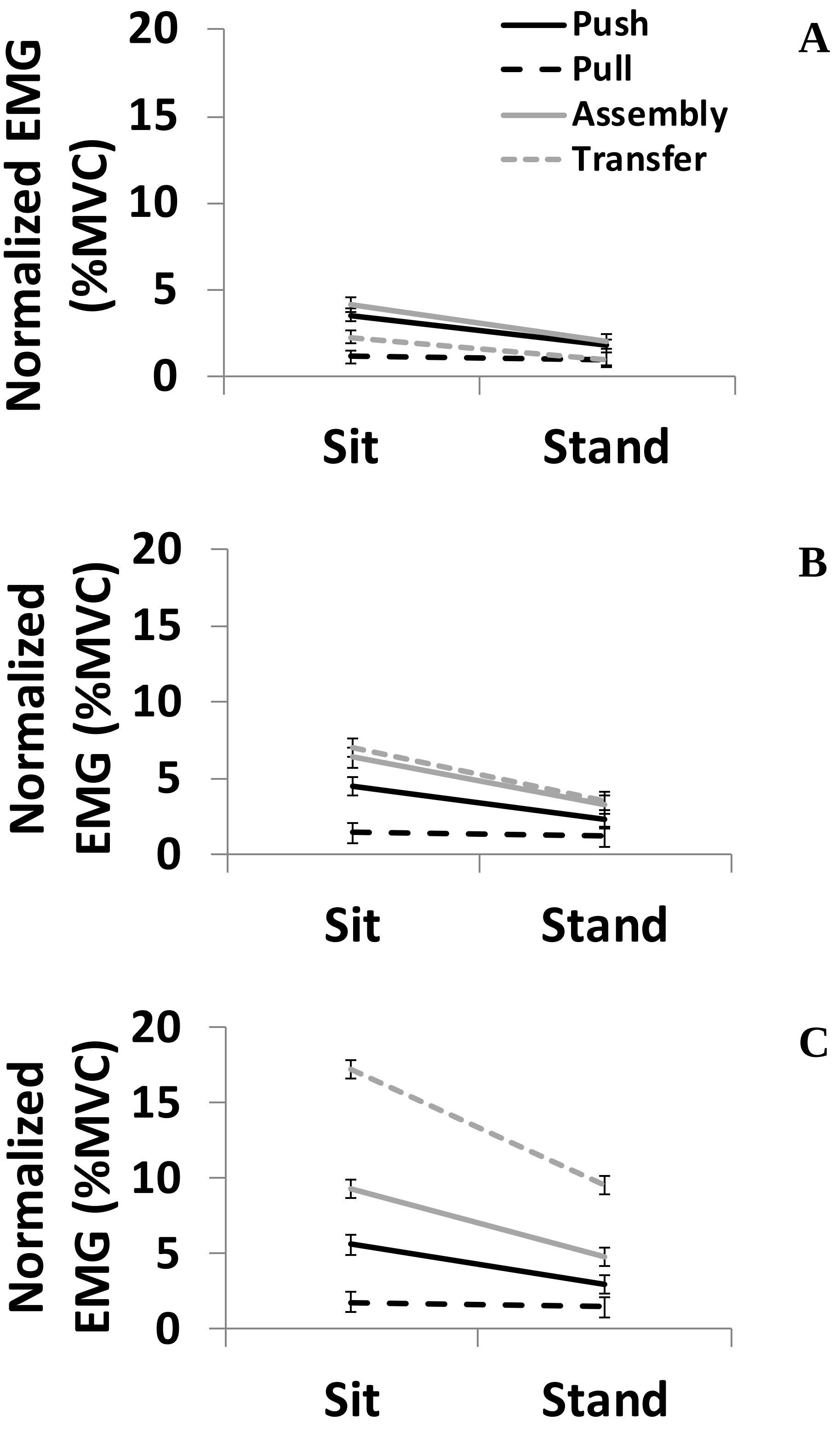

Figure 9. Normalized EMG activity of right upper trapezius across work configurations and tasks at APDF levels of 0.1 (A), 0.5 (B) and 0.9 (C).

4.2 Joint Moments

Differences in joint moments appeared for most directions at all joints examined. Interactions between work task and sit/stand configuration existed across joints and APDF levels. Interactions occurred primarily in the shoulders and L5S1 joints, with some interactions occurring in the elbow and wrist joints at select APDF levels. Post hoc testing revealed different trends in the shoulders and low back interactions. In the shoulders, dynamic tasks (transfer & assembly) resulted in moments that were up to 3.6 Nm larger in sitting, while static tasks (push & pull) resulted in moments that were up to 7 Nm larger in standing. Most tasks resulted in higher moments in sitting than in standing for the low back.

A main effect of sit/stand configuration was present, appearing primarily in the left arm and low back. In the left arm, standing doubled abduction/adduction moments in sitting from 1.5 to 3.1 Nm, but the opposite occurred in the forward flexion/extension moment, where they decreased by 50% from 6.6 to 4.1 Nm (Table 9). In the low back, sitting increased lateral bend moments from 8.4 to 18.9 Nm, and standing increased flexion/extension moments from 9.1 to 22.7 Nm (Table 10).

A main effect of work task appeared at all APDF levels examined except for the right wrist radial/ulnar deviation moment at APDF values of 0.3 and 0.5, the left wrist radial/ulnar deviation moment at 0.1, 0.3 and 0.5, the L5 flexion/extension moment at 0.3 and 0.5, and all right wrist pronation/supination moment levels (Tables 7-9, Appendix C). Post hoc testing revealed that different tasks were responsible for the largest moments at each joint, which were mostly consistent in terms of their hierarchy across APDF levels. Pull tasks created the highest joint moments at the wrist, while push tasks resulted in the highest joint moments at the shoulders. Both elbow joints and the L5/S1 joint experienced the greatest joint moments from the push or assembly tasks across APDF levels.

Table 7. Statistical results for left and right wrist joint moments. Shading represents significant effects for that joint moment at that APDF level.

	Left Side					Right Side			
	APDF Level	Config	Task	Config* Task		APDF Level	Config	Task	Config* Task
Radial/ Ulnar Deviation	0.1	0.23	0.0298	0.614	Radial/ Ulnar Deviation	0.1	0.1664	0.4544	0.1371
	0.3	0.3015	0.2025	0.6105		0.3	0.4177	0.3707	0.1459
	0.5	0.5945	0.1304	0.5644		0.5	0.3085	0.1114	0.096
	0.7	0.8936	0.0289	0.5226		0.7	0.0008	0.0001	0.0024
	0.9	0.6483	0.0004	0.3083		0.9	0.0001	0.0001	0.2953
Pronation/ Supination	0.1	0.2979	0.3155	0.5744	Pronation/ Supination	0.1	0.0854	0.0001	0.0001
	0.3	0.3203	0.5584	0.543		0.3	0.3583	0.0001	0.0001
	0.5	0.3014	0.7342	0.5517		0.5	0.83	0.0001	0.0001
	0.7	0.295	0.8065	0.5458		0.7	0.8925	0.0001	0.0001
	0.9	0.31	0.8158	0.529		0.9	0.4747	0.0001	0.0001
Flexion/ Extension	0.1	0.6368	0.0377	0.6444	Flexion/ Extension	0.1	0.0057	0.0001	0.1317
	0.3	0.7569	0.0014	0.7263		0.3	0.0009	0.0001	0.1576
	0.5	0.7449	0.0005	0.7263		0.5	0.0002	0.0001	0.2049
	0.7	0.3404	0.0001	0.7595		0.7	0.0002	0.0001	0.2003
	0.9	0.1892	0.0001	0.7756		0.9	0.0001	0.0001	0.2953

Table 8. Statistical results for left and right elbow joint moments. Shading represents significant effects for that joint moment at that APDF level.

	Left Side					Right Side			
	APDF Level	Config	Task	Config* Task		APDF Level	Config	Task	Config* Task
Varus/ Valgus	0.1	0.4398	0.0001	0.0612	Varus/ Valgus	0.1	0.2213	0.0001	0.0494
	0.3	0.6272	0.0001	0.1464		0.3	0.6302	0.0001	0.2288
	0.5	0.6278	0.0001	0.2308		0.5	0.4806	0.0001	0.1278
	0.7	0.707	0.0001	0.1472		0.7	0.4355	0.0001	0.056
	0.9	0.464	0.0001	0.1249		0.9	0.6231	0.0001	0.093
Internal/ External Axial Rotation	0.1	0.6904	0.0001	0.0028	Internal/ External Axial Rotation	0.1	0.5843	0.0001	0.0001
	0.3	0.1509	0.0001	0.0039		0.3	0.5899	0.0001	0.0001
	0.5	0.0684	0.0001	0.0163		0.5	0.4658	0.0001	0.0001
	0.7	0.0709	0.0001	0.0102		0.7	0.4101	0.0001	0.0001
	0.9	0.0738	0.0001	0.0117		0.9	0.4055	0.0001	0.0001
Flexion/ Extension	0.1	0.3459	0.0001	0.0701	Flexion/ Extension	0.1	0.0015	0.0001	0.1225
	0.3	0.286	0.0001	0.0629		0.3	0.0001	0.0001	0.0443
	0.5	0.2854	0.0001	0.0395		0.5	0.0007	0.0001	0.1059
	0.7	0.6729	0.0001	0.119		0.7	0.004	0.0001	0.0824
	0.9	0.6154	0.0001	0.1208		0.9	0.0062	0.0001	0.0947

Table 9. Statistical results for left and right shoulder joint moments. Shading represents significant effects for that joint moment at that APDF level.

	Right Side			
	APDF Level	Config	Task	Config* Task
Abduction/ Adduction	0.1	0.4813	0.0001	0.3466
	0.3	0.8281	0.0001	0.6284
	0.5	0.7612	0.0001	0.6125
	0.7	0.7227	0.0001	0.4972
	0.9	0.536	0.0001	0.4693
Internal/ External Rotation	0.1	0.0086	0.0001	0.0001
	0.3	0.0073	0.0001	0.0001
	0.5	0.009	0.0001	0.0001
	0.7	0.0145	0.0001	0.0001
	0.9	0.0809	0.0001	0.0001
Forward Flexion/ Extension	0.1	0.2026	0.0001	0.0001
	0.3	0.2869	0.0001	0.0003
	0.5	0.4701	0.0001	0.0006
	0.7	0.8003	0.0001	0.0001
	0.9	0.5576	0.0001	0.0001

	Left Side			
	APDF Level	Config	Task	Config* Task
Abduction/ Adduction	0.1	0.0007	0.0001	0.0001
	0.3	0.0005	0.0001	0.0001
	0.5	0.0003	0.0001	0.0001
	0.7	0.0004	0.0001	0.0001
	0.9	0.0013	0.0001	0.0001
Internal/ External Rotation	0.1	0.0241	0.0001	0.0001
	0.3	0.1139	0.0001	0.0001
	0.5	0.0853	0.0001	0.0001
	0.7	0.0752	0.0001	0.0001
	0.9	0.0276	0.0001	0.0001
Forward Flexion/ Extension	0.1	0.0023	0.0001	0.0003
	0.3	0.0004	0.0001	0.0028
	0.5	0.0001	0.0001	0.0123
	0.7	0.0001	0.0001	0.0185
	0.9	0.0001	0.0001	0.0194

Table 10. Statistical Results for L5/S1 joint moments. Shading represents significant effects for that joint moment at that APDF level.

	APDF Level	Config	Task	Config* Task
Lateral Bend	0.1	0.0002	0.0001	0.0271
	0.3	0.0001	0.0004	0.0066
	0.5	0.0001	0.0001	0.0046
	0.7	0.0001	0.0001	0.0158
	0.9	0.0001	0.0001	0.2336
Axial Twist	0.1	0.2451	0.0001	0.6648
	0.3	0.1752	0.0001	0.3294
	0.5	0.2082	0.0009	0.2169
	0.7	0.1798	0.0015	0.1778
	0.9	0.1514	0.0001	0.1421
Flexion/ Extension	0.1	0.0422	0.0249	0.0108
	0.3	0.0406	0.5707	0.056
	0.5	0.0422	0.0634	0.0779
	0.7	0.0562	0.0008	0.1457
	0.9	0.0953	0.0001	0.4172

4.3 Body Discomfort Analysis

Differences in local body discomfort existed for multiple body sections, and appeared most often in the back and foot/shank sections. Significant interaction effects between work configuration and task appeared bilaterally in the shoulders, mid back, and shank/foot sections, as well as in the right lower back (p=0.0002 to0.0244, Table 6). Post-hoc Tukey testing revealed that completing a task in standing decreased discomfort in the left shoulder (60%), right shoulder (21%), left mid back (88%), right mid back (76%), and right low back (58%). Exceptions existed in the left and right foot/shank segments, which had increases of up to 273% and 609%, respectively (Figure 10). In addition, the transfer and assembly tasks resulted in greater discomfort than the push or pull tasks in all significant interactions. A main effect of work configuration appeared for the shank/foot sections bilaterally, the left mid back, and the left thigh (p=0.0005 to 0.0182, Table 6). Post hoc testing showed that the left mid back had greater discomfort in sitting than in standing, while all other significant body sections had greater discomfort in standing than in sitting. Main effects of task were found bilaterally for the shoulders, upper arms mid back, low back and shank/foot sections, as well as the left forearm (p<0.0001 to 0.0064, Table 11). Post hoc Tukey testing indicated that the greatest discomfort appeared in the assembly or transfer tasks for each of these body regions.

Table 11. P values for local body discomfort across task and configuration for 19 body sections.

Body Region	Work Configuration	Task	Config* Task
Neck	0.8145	0.3174	0.4093
Left Shoulder	0.3045	<0.0001	0.0094
Right Shoulder	0.2925	<0.0001	0.0244
Left Mid Back	0.0182	0.0038	0.0032
Right Mid Back	0.0578	<0.0001	0.003
Left Lower Back	0.2532	0.0007	0.0796
Right Lower Back	0.2512	0.0007	0.014
Left Buttock	0.719	0.3926	0.5467
Right Buttock	0.5069	0.6496	0.3995
Left Thigh	0.0138	0.198	0.1634
Right Thigh	0.0988	0.576	0.168
Left Shank & Foot	0.0005	0.0009	0.0003
Right Shank & Foot	0.003	0.0017	0.0002
Left Upper Arm	0.4531	0.0034	0.068
Left Forearm	0.6467	0.0064	0.953
Left Hand	0.7927	0.074	0.9195
Right Upper Arm	0.191	0.0025	0.1659
Right Forearm	0.8108	0.0676	0.7322
Right Hand	0.0923	0.1027	0.8947

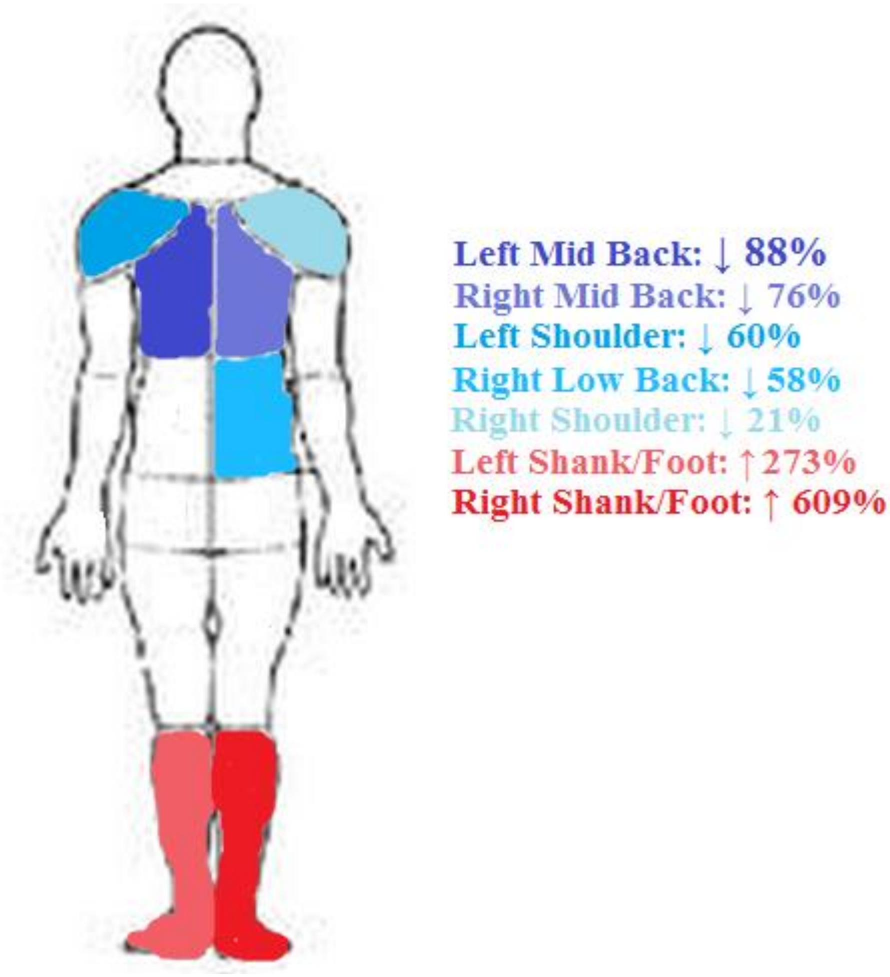

Figure 10. Interactions between task and configuration modified local body discomfort for the assembly task. Body regions coloured blue showed a decrease in discomfort when moving to standing, while red regions showed an increase. The respective magnitudes are colour coded. Regions coloured white showed no significant difference in body discomfort between sitting and standing.

4.4 Sit/Stand Trade-Off Index Results

Trade-offs between sitting and standing were seen at the wrist, elbow and shoulder for most manual materials handling tasks. Joints whose trade-off values were greater than 1.00 within a task represented significant increases in joint loading in standing compared to sitting. These differences appeared in both wrists in the push and pull tasks, as well as the left wrist in the transfer task and the right shoulder during push tasks (Table 12). The largest trade-off value was in the left wrist in the transfer task, with a ratio of 8.21. The torso experienced significant trade-off values below 1.00 in the push, pull and transfer tasks, indicating decreased moments in sitting compared to standing. No joint experienced a significant sit-stand trade-off in the assembly task.

Table 12. Joint trade-off indices across tasks. Significant trade-offs between sitting and standing are represented by *.

	Push (%)	**Pull (%)**	**Transfer (%)**	**Assembly (%)**
Left Wrist	1.19*	1.26*	8.21*	1.05
Left Elbow	1.11	1.13	1.30	0.94
Left Shoulder	1.11	1.23	1.74	0.98
Right Wrist	1.22*	1.34*	1.11	1.08
Right Elbow	0.95	1.07	1.03	1.06
Right Shoulder	1.05*	1.05	0.82	0.84
L5/S1	0.71*	0.73*	0.94*	0.95

4.5 Sex Differences

Sex effects appeared in EMG and joint moment outputs, but did not appear in localized body discomfort. Females experienced increased EMG activity in all muscles at all APDF levels, with p values ranging from <0.0001 to 0.0205. EMG outputs from females ranged between 32-126% greater for the same muscle across tasks and configurations. Sex effects also appeared in right elbow flexion, right shoulder internal/external rotation and forward flexion, left elbow varus/valgus and axial rotation, left shoulder abduction/adduction, internal/external rotation and forward flexion moments, as well as torso lateral bend and axial twist moments. In each of these circumstances, males had larger joint moment magnitudes, but the direction of these moments remained unchanged ($p<0.0001$ to 0.0483).

V. Discussion

The aim of this research was to determine local body changes in EMG outputs, local joint moments and localized body discomfort during four manual materials handling tasks in two workspace configurations. The results indicate that interaction effects between task and sit/stand configuration existed for all dependent variables tested, as well as a main effects of sit/stand configuration. Main effects of work task were present, but this appearance is unsurprising, as the hand load differences and demands within a task would likely produce differential outputs..

Each of the three hypotheses was responded to directly by experimental data. To reiterate, the hypotheses were:

1. *An interaction effect between manual materials handling task and workspace configuration exists for the upper extremity.*

Task/configuration interactions appeared in all three dependent variable types tested, and had differential results on each outcome measure. This interaction occurred 20 of 40 APDF levels in EMG outputs, 49 of 105 APDF levels for local joint moments, and 7 of 19 body discomfort regions. Completing a task in sitting usually resulted in greater EMG levels and joint moments, but exceptions existed in some circumstances. This hypothesis was conditionally accepted, as it appeared in 50% of EMG levels, 46% of joint moment levels, and 36% of discomfort regions examined.

2. *A joint trade-off between the wrist, shoulder and low back exists between seated and standing configurations.*

Significant trade-offs were found at each of these joints appearing at all wrist, shoulder and back joints, except for the left shoulder. Within these indices, the wrists experienced greater loading in standing, while the low back experienced decreased loading in standing. Significant trade-offs in the shoulders were only seen in the right shoulder during the push task. This hypothesis was conditionally accepted, as 6 of the 7 joints showed this trade-off..

3. *Individual muscular electromyographic activity is influenced by workstation configuration.*

   Muscular activity levels were influenced by workstation configuration, appearing in 8 of 40 APDF levels. The left supraspinatus and upper trapezius were affected bilaterally by sit/stand configuration, but did not appear at all APDF levels. This hypothesis was conditionally accepted, as this effect appeared in 20% of the EMG levels examined.

A task/configuration interaction appeared in all dependent variables, and main effects of sit/stand configuration primarily affected joint moment and EMG outputs. Work task effects were also present across these dependent variables. These have been broken down into subsections below, along additional sections covering the sit/stand trade-off index and sex and handedness effects.

5.1 Effects of Task/Configuration Interactions

Task/configuration interactions appeared in all three dependent variable types tested, and had differential results on each outcome measure. This interaction appeared in 4 of 8 muscle activity outputs, as well as 14 of 21 joint moment calculations and 7 of 19 localized body discomfort regions.

Interaction effects on EMG activity appeared in the left UTRP and SUPR bilaterally, with tasks in sitting usually resulting in greater muscle activity levels. Although differences occurred within tasks, completion of tasks in sitting was not universally more demanding than completion in sitting (Figure 9). The interaction between task and configuration resulted in increases in the push, transfer and assembly tasks of 3, 7.6 and 4.7 %MVC, respectively. Similar interactions between task and interaction on muscle activity have been investigated previously in supermarket cashiers. Lehman et al (2001) examined interactions between working position (sitting versus standing) and scanner types on muscle activity, upper limb and spinal posture, and subjective preference of cashiers. They reported interactions between task and work configuration were prevalent in the muscle activity of shoulder and trapezius muscles, with standing configurations producing smaller activity levels than seated configurations (Lehman et al, 2001). Similar redesigns for cashier checkouts by Draicchio et al (2012) found that moving cashiers from seated to standing positions resulted in decreased mean and peak EMG activity for most muscles examined. The current study confirms these results, in that interactions between task and configuration resulted in decreases in muscular activity for some muscles of the upper extremity when participants moved from seated to standing work configurations, but this interaction was not seen in the MDEL or INFR bilaterally. While the push, transfer and assembly tasks showed increased muscle activity in sitting, the pull task had activity changes less than 1 %MVC between sitting and standing.

Sit/stand configuration combined with task to alter local joint moments, and these interactions produced different results depending on whether the task was static or dynamic. In the dynamic transfer and assembly tasks, sitting resulted in larger local joint moments in the upper extremity than in standing. The static push and pull tasks experienced the opposite result, with smaller joint moments in sitting compared to standing. Moving between configurations only altered the magnitude of the joint moment; it did not alter its direction. While all handle locations were placed in the same sagittal plane as the acromion on the active side, it is possible that the additional postural flexibility while standing resulted in individuals moving their wrist, elbow or shoulder positions slightly further away from the line of action or the exerted force during these standing push tasks, resulting in higher net moments (Hoozemans et al, 1998). These movements may have altered the joint positions of the upper extremity into positions that created differential moment arm lengths, despite identical hand load positions relative to the participant. It is likely that participants placed increased focus on maintaining an optimal arm position and maintaining elbow position closer to the torso in sitting, but the increased postural flexibility in standing may have led to less focus on this elbow placement, resulting in larger joint moments. Joint moments in the torso were primarily affected in lateral bending, with the flexion/extension moment only affected at the 0.1 APDF level. Increased lateral bend was seen in sitting tasks across all significant APDF levels, with these sitting tasks resulting in universally more lateral bend. The largest changes appeared in the transfer and assembly tasks, as these moments increased from 28.3Nm to 39.8Nm, and 2.9Nm to 17.3Nm when moving to sitting, respectively. This represents a 40% increase in the seated transfer compared to standing, and almost a 500% increase in the assembly task. This may have been caused by the increased freedom of motion participants had during standing tasks. While standing, participants could expand their base of support by widening their foot placement, allowing greater shifts in body weight. This decrease in postural fixity would allow for increased movement, and may act as a preventative measure for musculoskeletal disorders and worker discomfort (Greico, 1986). These shifts may have facilitated different movement strategies and resulted in decreased lateral bend in the back. Changes in low back flexion/extension only appeared at the 0.1 APDF level, with each task resulting in a change between flexion and extension moments depending on sit/stand configuration. Each task in standing had an extension moment, while all tasks in sitting had a flexion moment. Additionally, increases in moment magnitude were seen in the transfer and assembly tasks, with flexion moment magnitudes in sitting representing 175% and 273% of the extension moments seen in standing, respectively. These changes in low back moments were likely affected by spinal posture changes between sitting and standing. Seated and standing positions are known to produce different spinal postures, which affect spinal loading and potential low back moments (Callaghan & McGill, 2001; Dunk et al, 2009). These differences in spinal posture were likely responsible for the changes in loading at the low back. Low back moments may have also been affected by arm position. Previous research by Dreischarf et al (2010) examined the effects of different arm positions on spinal loading through the use of telemetered vertebral body replacements (VBRs). They found that a seated position in certain arm positions led to lumbar spinal loads in these VBRs that ranged from 107% to 228% of the values for standing (Dreischarf et al, 2010). These spinal postures in sitting place the spine in flexion moments, which place increased loads on the spine and soft tissues (Andersson et al, 1974; Andersson, 1980). Low back moments found in this thesis appeared to have been strongly affected by arm position, and may have had similar responses to differing arm positions as those found by Dreischarf et al.

Combinations of work task and sit/stand location also affected localized body discomfort, with most body regions experiencing increased discomfort in sitting. These interactions appeared in the shoulder, mid back and foot/shank sections bilaterally, as well as the right low back region. However, these seated postures were not universally worse than standing positions. Conversely, all standing work tasks had higher discomfort levels than any seated task for the foot/shank body regions. This can be attributed to the rest provided to the lower limbs during seated tasks. Standing is a known factor for increasing local discomfort in the lower limb (Roelen et al, 2008), and the results found in this study confirm this.

5.2 Effects of Sitting and Standing

Main effects of sit/stand configuration appeared in EMG, joint moment and localized body discomfort results. Main effects of sit/stand occurred most commonly in joint moments, then in muscular activity outputs.

Local joint moments experienced changes between sitting and standing. Sitting resulted in increased right shoulder internal rotation and left shoulder extension, while standing resulted in increased left wrist extension, left elbow flexion, and left shoulder abduction. Low back moments were also affected by task configuration, with increased lateral bend and forward flexion in sitting. The reductions in shoulder moments seen when moving from sitting to standing are similar to previous work completed by Draicchio et al (2012). Their investigation of a redesign of a casher checkout from sitting to standing resulted in decreases in shoulder ranges of motion used to complete identical tasks when cashiers moved from seated to standing positions (Draicchio et al, 2012). However, the increases in joint moments found in current study in the left arm when moving from sitting to standing do not coincide with previous research, as the left arm did not experience these decreases. It is likely that handedness was a factor with the moments seen in the left arm. While the right arm experienced decreases in joint moments when moving to standing as found previously in the literature, increases were seen in the left arm, primarily in wrist extension, elbow flexion and shoulder extension. As all participants were right-handed, it is possible that a lack of familiarity with using their left arm for precision tasks resulted in different work strategies, resulting in differential moment outputs. Low back moments also experienced changes. Sitting work configurations resulted in increased forward flexion moments. This increased forward flexion supports previous research that identified increased forward flexion in sitting (Callaghan & McGill, 2001; Alexander et al., 2007; Dunk et al., 2009).

Muscular activity outputs were differentially affected by sit/stand configuration. The left upper trapezius differed across all APDF levels, and at some APDF levels for the right upper trapezius and left supraspinatus were different. For these muscles, tasks in sitting generally resulted in higher activity. This main effect doubled left UTRP activity at peak levels from 4 to 8 %MVC when working in sitting compared to standing, and left SUPR activity at peak levels increased by 25% from 6 to 8 %MVC at the 0.9 APDF level. This increase in activity could be related to decreased force generation capability in sitting. Chow & Dickerson (2009) examined influences of gross body position (sitting and sitting) on maximal volitional force generation. Their results showed that maximal isometric force was greater in standing than sitting for all exertions tested. As the hand forces required for task completion remained unchanged across sit/stand configurations, the force levels in sitting represent a greater percentage of an individual's maximal force values, resulting in higher activity levels. Similar increased activity levels in sitting have been examined in supermarket cashiers during MMH tasks. Previous research by Psihogios & Jones (2001) examined muscular activity during 4 hour work cashier shifts in either sitting or standing workstations. They found increases in muscular activity in the neck and shoulders in seated checkouts. Similar reports of standing workstations resulting in decreased activity levels exist (Lannerstern et al, 1990; Sandsjö et al, 1996; Lehman et al, 2001). Despite working heights set within ergonomic guidelines, activity levels in the upper trapezius resulted in static loading levels that prevent relaxation of the muscle, which may lead to fatigue and worker discomfort (Sandsjö et al, 1996).

Local body discomfort was affected by work configurations. The left thigh, left mid back and bilateral shank/foot segments were affected by sit/stand configuration. The left thigh and shank/foot segments experienced greater discomfort in standing, while the right mid back had greater discomfort in sitting. The increased load placed on the legs to maintain body posture in standing is the likely cause for increases in discomfort in these areas. Psihogios & Jones (2001) also found increased lower limb discomfort in cashiers when they moved from seated to standing positions. The authors believed that this increased discomfort was due to the increased load on the lower limbs compared to standing. The workers may have felt increased discomfort in standing due to the cashiers being accustomed to completing their task in sitting and lacking experience in standing work postures, and that this discomfort level may decrease as they acclimatized to the workstation (Psihogios & Jones, 2001). Conversely, the left mid back experienced increased discomfort in sitting. This discomfort may have been due to the backless chair, which may have caused increased muscle activation to maintain upper body posture when a backed chair would provide more support for the upper body.

5.3 Trade-Off Indices

Trade-off effects appeared between tasks, and appeared primarily in the wrists and low back. Within these indices, the wrists experienced greater loading in standing, while the low back experienced decreased loading in standing. This increased loading in the wrists in standing may be a result of non-neutral wrist postures in standing. Hedge et al (2005) examined wrist posture and body movements during keyboarding tasks in sitting and standing. They determined that standing postures had greater wrist extension for typing tasks, and that standing postures had greater levels of wrist discomfort for identical work tasks (Hedge et al, 2005). As the orientation of the work tasks did not change relative to the table, it is possible that wrist angles altered between sitting and standing, resulting in changes in joint moments. This resulted in a trade-off between sitting and standing for wrist joint moments, with standing postures producing loads that were up to 8.2 times larger in standing (Figure 11). However, the magnitude of this trade-off appears to be primarily driven by the small magnitude of the absolute joint moments. Resultant moments of the left wrist in standing and sitting during the transfer task at the 0.9 APDF level were 5.13 Nm and 0.96 Nm respectively, indicating a difference of 4.17 Nm between these positions. Because the resultant moments were relatively small, even minute differences between the resultant moments would result in large changes in the trade-off index. In terms of joint risk, the wrist joint has a mean population strength of 8.2 Nm in flexion/extension, and 11.0 Nm in ulnar/radial deviation (Stobbe, 1982). While it is unlikely that these maximal values would occur at identical time points, taking a resultant moment from this research assumes that this is the case. However, this difference in resultant moments could represent over 30% of the mean population wrist strength, and warrants consideration in industrial design. Trade-offs appeared in both wrists during the push and pull tasks, while only appearing in the left wrist in the transfer task and neither wrist in the assembly task.

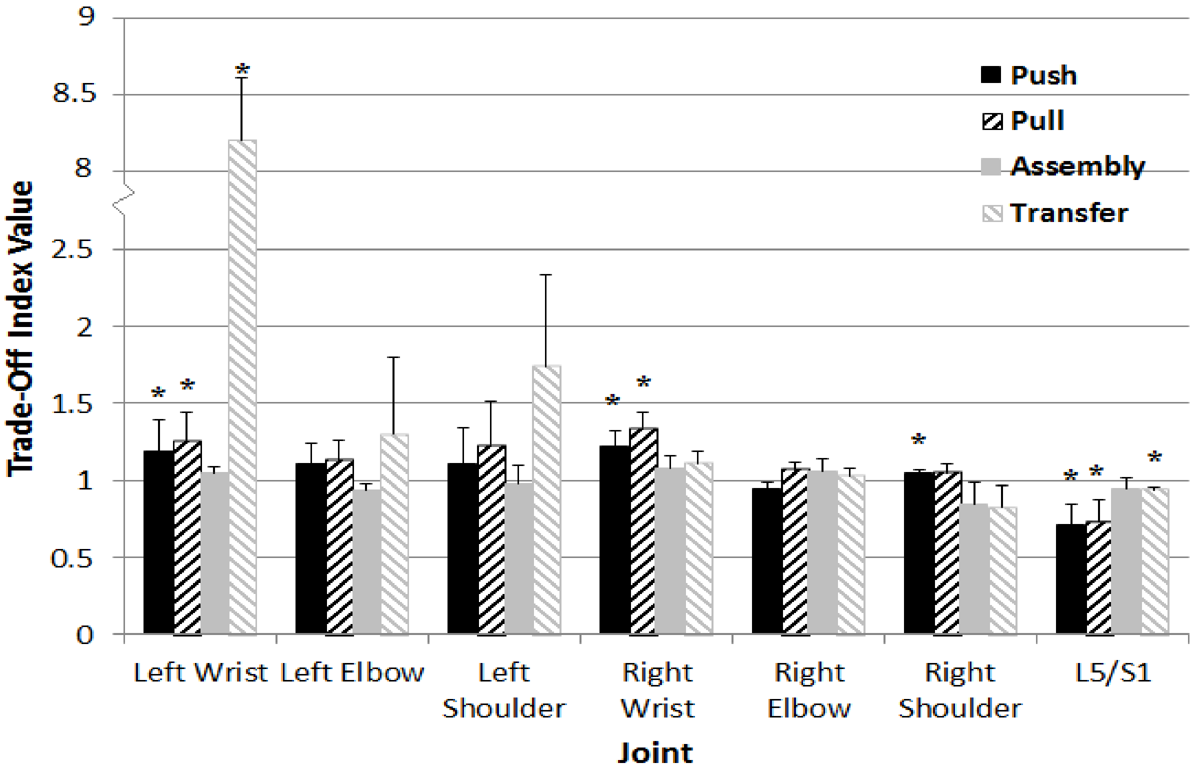

Figure 11. Trade-off indices for each joint across MMH tasks. A value greater than 1 indicates larger resultant moments in standing than in sitting. Significant trade-offs are labelled by *, and error bars indicate standard deviations.

Trade-offs at the low back also existed for most work tasks. These changes appeared in the push, pull and transfer tasks. In each of these tasks, completing the task in sitting resulted in greater resultant moments, with the trade-off indices indicating standing moments at 71 to 94% of the resultant moment in sitting. These trade-offs are primarily due to postural changes between sitting and standing. The increased flexion seen in sitting resulted in larger joint moments, and agreed with previous reports (Callaghan & McGill, 2001; Alexander et al., 2007; Dunk et al., 2009). These seated postures resulted in larger resultant moments as was reflected in the results of the trade-off index.

5.5 Effects of Work Task

A main effect of task resulted in the greatest changes in EMG activity, localized body discomfort, and local joint moments. At low APDF levels, the push task resulted in the highest EMG activity or joint moments, while the transfer task was responsible for these increased outputs at higher APDF levels. These changes, when combined with changes in localized body discomfort, stress the importance of task consideration on risk of future musculoskeletal loading.

The push task was responsible for the highest muscle activity across muscles at low APDF levels, as well as being responsible for some of the highest joint loading. This may be due to increased activation and differences in whole-body strategies compared to other tasks. Chow (2010) examined maximal pushes and pulls in standing, and reported higher activation patterns in upper extremity musculature during push exertions than in pulling ones. This research mimics the results of the current study. Jongkol (2006) also reported higher activity in the middle deltoid and trapezius during push exertions than in pulling exertions. Their work found that muscles of the upper extremity dominated pushing exertions, while the back extensor musculature had a much larger role in pulling exertions. While examining shoulder muscle demands in horizontal pushing and pulling, McDonald et al (2012) found greater activity levels of the supraspinatus and infraspinatus during pushing exertions than in pulling ones. Pulling exertions were largely dominated by latissimus dorsi in this research (McDonald et al, 2012). It is likely that a similar technique was used by participants in the current study, as pulling tasks resulted in the lowest activation across all upper extremity muscles tested (Figure 9). Pull and push tasks were also responsible for the highest joint moments across all tasks examined in this study. The moments at the elbows and shoulders were generally at least twice as large during pull and push tasks than the transfer or assembly tasks. The cause of these increased moments was due primarily to the direct hand loads. The push and pull loads were set at 40N, while the Transfer task load weighed ~10-20N, and the applied hand load in the assembly task was nominal. This increase in hand load resulted in increased joint moments, despite optimal work positions. As such, workers should consider that increases in applied loads may drastically impact local joint loading, despite their placement in minimized risk locations.

As APDF levels increased, the transfer task became responsible for the highest EMG activity levels and body discomfort for most muscles and body regions. This work task elicited the highest EMG outputs for all muscles at the 0.7 and 0.9 APDF levels, as well as being responsible for the greatest amount of discomfort for the majority of body zones with significant discomfort outputs. While this loading task had hand loads that tended to be smaller than the static push or pull tasks (~10-20N compared to 40N), the muscular outputs for this task were two to three times greater at high APDF levels (Figure 12, Appendix B). Sigholm et al (1984) examined influences of hand tool weight and arm position on shoulder muscle load, and found that lightweight loads (1-2kg) resulted in large increases in muscular activity over unloaded scenarios. Similar increases in muscular activity while holding hand loads (Wiker et al, 1989, Wiker et al, 1990) coincide with the increased activity levels while holding a load measured in the current study. Another potential cause for this marked increase in muscular activity may be due to increased shoulder flexion. Research by Antony & Keir (2010) found that shoulder muscle activity doubled when shoulder flexion went from 30 to 90° of shoulder flexion (Antony & Keir, 2010). It is likely that the transfer task was responsible for increased shoulder flexion compared to other tasks completed this study. Push and pull tasks were set at NIOSH optimal work heights placed just below the elbow, and the tabletop tasks of assembly and

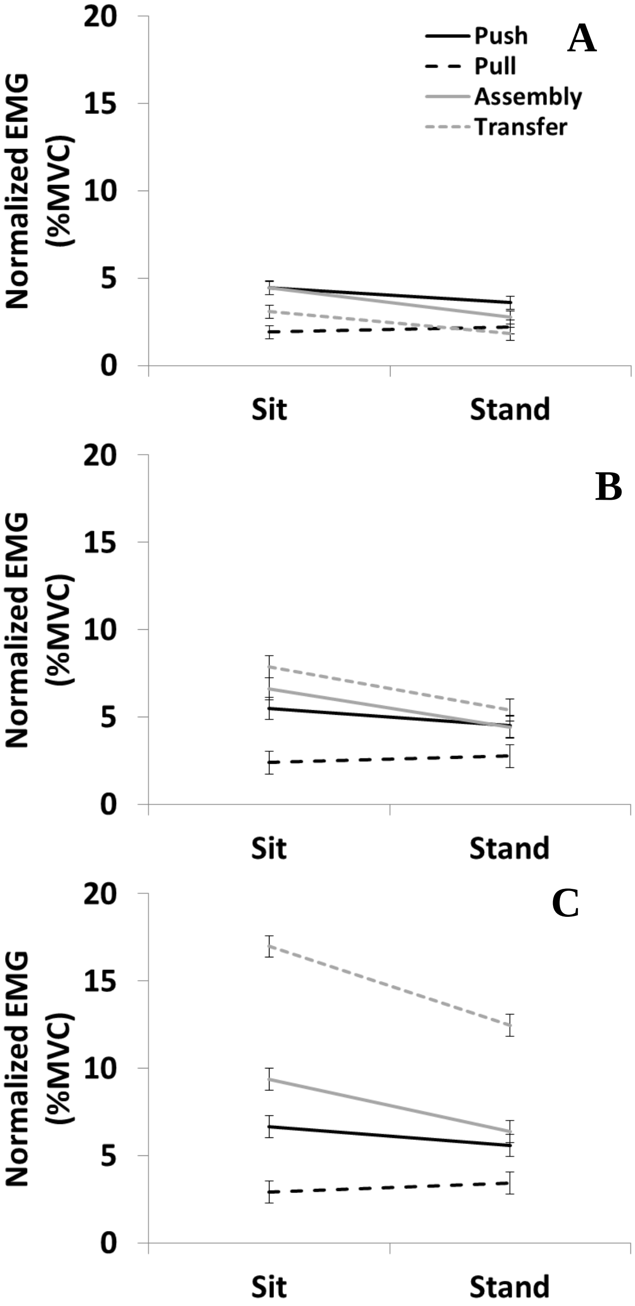

Figure 12. Normalized EMG activity of left supraspinatus across work configurations and tasks at APDF levels of 0.1 (A), 0.5 (B) and 0.9 (C).

transfer had the table placed at a similar height. However, as participants reached to each of the destination points in the transfer task increased shoulder flexion was generally required to lift the object off the table and reach out to a further distance. This increase in shoulder flexion may lead to increased intramuscular pressure in the musculature of the rotator cuff. Jarvholm et al (1998,

1991) showed that increases in shoulder intramuscular pressure increased as a function of elevation angle up to a peak at 90°. Prolonged high levels of intramuscular pressure are a known factor for restricting intramuscular blood flow, slowing recovery from local muscle fatigue and increasing feelings of fatigue in the worker (Start & Holmes, 1963; Mortimer et al, 1970; Palmerud et al, 2000). The increased muscular activity seen in the transfer task also increases fatigue risk and future musculoskeletal discomfort to the shoulder complex. Muscular activity at the 0.9 APDF level resulted in activity levels that ranged between 13-17 %MVC (Appendix B). This level of activity was close to the bottle weight, which was normalized to 15% of each participant's maximal elevation force with an extended arm. Previous research by Jorgensen (1988) stated that intermittent contractions at 15 %MVC or greater can cause fatigue within 3 hours. While these hand loads represented 15% of their maximal force output, the actual bottle weight ranged between 0.71-2.25 kg, depending on the participant. Hand loads that exceed 2.25 kg appear commonly in industrial settings. These increased hand loads may cause fatigue to occur even faster than this 3 hour period in the field.

While the assembly task was not responsible for the largest peak joint moments or muscle activity, this task still placed notable muscular activity loads on the upper extremity. Activity levels in the upper trapezius and infraspinatus during assembly tasks resulted in muscle activity levels that were approximately 50% larger than pushing or pulling tasks at the same APDF level (Figures 9, 11) This dynamic motion resulted in EMG levels near 10 %MVC at the 0.9 APDF level, despite marginal hand loads (Appendix B). This increased level of muscular activity is likely due to the precision needed to complete this task. Laursen et al (1998) examined the effects of precision on EMG outputs in shoulder musculature during hand movement tasks. Their results found that increases in precision demands resulted in increased muscle activity despite no other changes in required speed or hand loads. The authors argued that increases in upper extremity muscle activity could be due to increased stiffness demands of the shoulder and arm to control movement during precise hand tasks (Laursen et al, 1998). Additional research investigating precision during repetitive lifting found shoulder joint moments increased by up to 43% when precision requirements were increased (Joseph et al, 2014). Similar precision-related increases in muscle activity were found in infraspinatus, extensor carpi radialis and non-dominant trapezius muscles by Milerad & Ericson (1994). Work task designers should consider the effects of precision on future fatigue risk and musculoskeletal disorders, even when hand loads are minimal.

The work tasks and task durations examined in this study had differential effects on localized body discomfort. The transfer and assembly tasks were responsible for the greatest increases in discomfort from baseline for all affected body regions. While these two tasks had lower hand loads compared to the push and pull tasks, the increased discomfort experienced during these tasks were likely due to the repetitive movements found in these tasks. Thomsen et al (2007) examined hand forces and wrist positions in repetitive monotonous work, and found that high repetition was a strong ergonomic risk factor for future pain and musculoskeletal disorders. Repetitive movements at one joint may also be capable of transferring static loads to other nearby joints in the body. While the hands perform repetitive work tasks (such as the assembly and transfer tasks in this study), the musculature of the shoulder was required to maintain elevated arm postures throughout the movement, resulting in increased discomfort (Kronberg et al, 1990). This sustained loading of the shoulder joint resulted in increased discomfort across the shoulders and mid back bilaterally. Time may have also been a factor in the increased discomfort scores during these tasks. The total time spent completing the transfer and assembly tasks was 10 minutes each, broken into four equal sections. Conversely, participants spent only 70 seconds in each push and pull task (10 trials * 7 seconds each). It is plausible that some of the differences between discomfort ratings may have related to the differences in time spent in the static and dynamic tasks, and that short task times resulted in lower discomfort ratings than what would have been attained in longer trials. While the transfer and assembly tasks resulted in the highest discomfort levels, differences between the push and pull tasks were also evident. While not statistically different from each other, push tasks consistently resulted in normalized discomfort ratings that were 1-4% greater than pull tasks. This increase in discomfort is likely due to differing strategies for force production between pushing and pulling, where push forces are generated primarily through the shoulder and upper extremity, while pulling tasks are generated more through shoulder and torso activation. Hoozemans et al (2002) examined exposures of pushing and pulling in industrial tasks and their relation to discomfort complaints from workers. They found that while shoulder discomfort was affected by both pushing and pulling tasks, increased discomfort levels were found in pushing tasks (Hoozemans et al, 2002).

The changes found by differing work tasks were driven primarily by the design of the study. While responsible for changes across EMG, joint moments and discomfort levels, the tasks chosen in this research were selected not only for their ability to replicate common manual materials handling tasks, but also because of their differences from one another. Push and pull tasks are known to differentially affect the upper extremity (McDonald et al, 2012, Chow, 2010), and differences in hand loads between the assembly task led to unsurprising differences between them. In addition, changes between static and dynamic tasks changed joint moments, EMG and discomfort levels, but the tasks chosen for this research were already known to differentially affect upper extremity responses, so these changes are unsurprising.

5.5 Sex & Hand Effects

Significant dependent muscle activity and joint moment outputs appeared between males and females. EMG effects were present across all 8 muscles tested and occurred for joint moments primarily on the left shoulder and left elbow. While females completed identical tasks with an increase in normalized muscle activity, males had larger joint moments relative to females. It is likely that both of these effects were caused by differences in force generation capabilities and anthropometry between males and females. During the static push and pull tasks, this set force level of 40N likely represented a larger percentage of their maximal force outputs. Upper body muscle mass is ~75% greater in males than females (Lassek & Gaulin, 2009), resulting in greater force production in males than females. While the hand loads in the transfer task were normalized to each participant's maximal elevation force production, this hand load was likely larger in females relative to the total mass of their upper body, representing an increased load in terms of moment contributions, which led to increased muscle activity. In terms of joint moments, males experienced similar moment directions as females, but had larger magnitudes. This increase in magnitude is likely to do the larger stature and segment masses in males (Gordon et al, 1989). Participant statures ranged from a 13th percentile female to a 99th percentile male, and participants were not height or weight matched across sexes. In addition, the scaled hand loads during the transfer task used by males were usually heavier, resulting in increased moments. These larger masses and segment moment arms resulted in increased moments around local joints, despite identical work tasks.

Differences between the left and right joint moments were likely due to handedness. While the tasks completed had identical hand loading requirements, main effects of task appeared for all joint moments in the left arm at some levels, while not all right arm joint moments had significant differences between tasks. It is likely that since all participants were right-hand dominant, a lack of skill in minimizing off-axis forces in their non-dominant arm resulted in postures and techniques that were less efficient in minimizing joint moments. Previous research has shown a difference between dominant and non-dominant limbs, with an increase in consistency and velocity during precision tasks when using the dominant arm compared to the non-dominant arm (Peters, 1976; Todor et al, 1982). This decreased precision and consistency in the non-dominant arm likely led to postures that increased joint moments compared to the dominant arm.

5.6 Limitations

There were some limitations of this study. Only muscles of the upper extremity and rotator cuff were examined in this thesis. Additional insight into muscular activity of the low back and torso would provide additional information regarding how work configuration affects the upper body as a whole. In addition, only four work tasks were used in an effort to replicate work task scenarios. However, horizontal pushing and pulling are common industrial tasks (Chaffin & Andres, 1983; Hoozemans et al., 1998; Todd, 2005; MacKinnon & Vaughan, 2005), and constitute 50-75% of all manual materials handling tasks (Baril-Gingras & Lortie, 1990), making them appropriate surrogates for the majority of workplace tasks. Finally, the use of 0.5 and 0.9 APDF levels can only act as surrogates for mean and peak EMG and joint moments which are usually used, making comparisons to previous research in the literature more difficult. The 0.5 APDF level represents the median instead the mean, and the 0.9 APDF level may not be indicative of peak joint moments or EMG activity. However, the use of APDFs for ergonomic analysis has been established previously (Hagberg & Jonsson, 1975), and using the 0.1, 0.5 and 0.9 APDF levels conforms to previous literature (Robertson, 2010). These APDF results are unlikely to be biased by a one-time peak in activity, especially in dynamic tasks. Previous research by Jonsson (1988) focused on the merits of using APDFs for dynamic tasks and showed that APDFs provide increased information about prolonged dynamic tasks compared to mean or peak values, allowing interpretation across the entire loading spectrum of the task. Using this technique on both EMG outputs and joint moments allowed consistency of interpretation between these two dependent variables, as well as comparison of dissimilar task durations between the shorter static and the longer dynamic MMH trials. In an effort to provide additional insight beyond the regular use of the 0.1, 0.5, and 0.9 APDF levels, the use of the 0.3 and 0.7 levels was used in this study. However, these levels failed to improve insight, and were often not significantly different from the two surrounding APDF levels. Future research should focus on using the precedent levels set by Robertson, as the additional levels did not provide additional clarity into loading characteristics.

5.7 Suggestions for Future Investigations

The current study demonstrated important effects of work task and sit/stand configuration on specific exposures of the upper limb. Future research should include participants with greater experience in manual materials handling tasks to determine if differences between novice and experienced workers exist. Experienced workers completing manual materials handling tasks have increased kinetic and kinematic variability within a repetitive task compared to novices, and are more likely to adapt their methodologies to a task (Lee & Nussbaum, 2012). These differential changes are likely to affect EMG, joint loading and discomfort outputs. Additional research could include other shoulder, forearm and torso muscles to provide greater insight into the observed findings. By examining additional musculature surrounding the shoulder complex and torso, more definitive conclusions and a deeper understanding of loading patterns in these manual materials handling tasks may be established. Further, as all work heights and reach distances were set in optimal or near-optimal work positions, examination of these tasks at other work heights or reach distances help determine if joint loading patterns or discomfort ratings could be predicted from interpolations, which could be a useful tool in terms of ergonomics applications. The current study provides evidence of task and work station effects on muscular activity, joint loading and reported discomfort, but also identifies the need for continued research into manual materials handling tasks and workplace design.

5.8 Relevance to Ergonomics and Work Design

This study demonstrated that specific factors and their interactions influenced EMG, moment, and discomfort exposures in manual materials handling. Work task, sit/stand configuration, sex and handedness are all important factors that should be considered in designing work tasks or modifying existing jobs. Quantification of these exposures is necessary to take advantage of rotations between sitting and standing and to implement effective ergonomic interventions. For example, upper trapezius activation during sitting was up to 80% greater than completing the identical task during standing. This gross change in activity for nearly identical tasks has strong fatigue implications, and may be associated with future musculoskeletal disorder development. Further, the influences of sex or anthropometry emphasize the importance of considering worker capabilities for various tasks. While the transfer task completed in this study was normalized to each participant’s maximal elevation force, females experienced increased muscle activity for an identical task.

The experimental controls placed on various aspects of this research, while necessary for empirical testing, may make direct application to workplace settings difficult. The work heights and reach distances were chosen using current ergonomic standards and act as benchmarks for industrial design. In addition, the use of participants spanning heights and body masses of the male and female North American population allows for greater generalization of the outcomes found in this work. With this in mind, these results may assist in expanding knowledge of muscle activity and joint loading based on task and posture conditions, to the extent of the factors examined, and allow for better prediction of the consequences of workplace conditions. The end goal is to provide practicing ergonomists and work task designers with the means to improve workplace assessment and enable evidence-based recommendations on preventative measures to reduce the incidence of injuries and discomfort surrounding the upper extremity, resulting in decreased worker absences and associated health care costs.

VI. Conclusions

The purpose of this study was to quantitatively evaluate the influences of work task and sit/stand configuration on upper extremity muscle activity, local joint moments, and body discomfort exposure estimates with a focus on the upper extremity. Four work tasks were completed in seated and standing positions that were normalized using current ergonomic standards. From this work, completing tasks in standing resulted in lower muscle activity levels, smaller joint moments, and lower body discomfort compared to standing, though some exceptions existed. Significant joint trade-off indices occurred primarily at the wrists and low back, with joint moments at the wrist much greater in standing, and moments at the low back greater in sitting. These results improve the knowledge surrounding upper extremity loading patterns for manual materials handling tasks in sitting and standing. The results of this study have important ergonomics implications for practicing work task designers and ergonomists, who can use these results to evaluate, design or modify workstations, equipment or manual materials handling tasks to focus on mitigating elevated loading scenarios or musculoskeletal complaints of the upper extremity.

References

Ackland, D.C., Richardson, P.P., Pandy, M.G. (2009). Moment arms of the muscles spanning the anatomical shoulder. *Journal of Anatomy,* 213:383-390.

Ackland, D.C. & Pandy, M.G. (2009). Lines of action and stabilizing potential of the shoulder musculature. *Journal of Anatomy,* 215:184-197.

Adams, M.A. & Dolan, P. (1996). Time-dependent changes in the lumbar spine's resistance to bending. *Clinical Biomechanics*, 4:194-200.

Adams, M.A. & Hutton, W.C. (1980). The effect of posture on the role of the apophysial joints in resisting intervertebral compressive forces. *British Journal of Bone and Joint Surgery*, 62:358-362.

Adams, M.A. & Hutton, W.C. (1985). The effect of posture on the lumbar spine. *Journal of Bone and Joint Surgery*, 67(4):625-629.

Alexander, L.A., Hancock, E., Agouris, I., Smith, F.W., MacSween, A. (2007). The response of the nucleous pulposus of the lumbar intervertebral discs to functionally loaded positions. *Spine*, 32(14):1508-1512.

An, K.-N., Adams, M., Baldwin, M., Bongers, P., Brisby, H., Burdorf, A., et al., (2001). *Musculoskeletal disorders and the workplace: Low back and upper extremities*. Washinton, DC: National Academy Press.

Andersen, J.H., Haahr, J.P., Frost, P. (2007). Risk factors for more severe regional musculoskeletal symptoms: a two-year prospective study of a general working population. *Arthritis and Rheumatism,* 56(4):1355-1364.

Andersson, G. & Ortengren, R. (1974). Myoelectric back muscle activity during sitting. *Scandinavian Journal of Rehabilitation Medicine,* 6(3):73-90.

Andersson, G., Ortengren, R., Nachemson, A., (1977). Intradiskal pressure, intra-abdominal pressure and myoelectric back muscle activity related to posture and loading. *Clinical Orthopaedics and Related Research*, 129:156-164.

Andersson, G. (1980). The load on the lumber spine in sitting postures. In: D.J. Osborne & J.A. Levis (eds.) *Human Factors in Transport Research*. New York: Academic Press, 231-239.

Antony, N.T. & Keir, P.J. (2010). Effects of posture, movement and hand location on shoulder muscle activity. *Journal of Electromyography and Kinesiology*, 20:191-198.

Baril-Gingras, G. & Lortie, M. (1995). The handling of objects other than boxes: univariate analysis of handling techniques in a large transport company. *Ergonomics*, 38(5):905-925.

Bernard, B.P. (1997). Musculoskeletal disorders and workplace factors, 2nd ed. DHS (NIOSH) Publication No 97-141, Cincinatti: Department of Health and Human Services.

Bridger, R.S., Orkin, D., Henneberg, M. (1992). A quantitative investigation of lumbar and pelvis postures in standing and sitting: Interrelationships with body position and hip muscle length. *International Journal of Industrial Ergonomics*, 9:235-244.

Brookham, R.L., Wong, J.M., Dickerson, C.R. (2010). Upper limb posture and submaximal hand tasks influence shoulder muscle activity. *International Journal of Industrial Ergonomics*, 40(3):337-344.

Brown, J.R. (1975). Factors contributing to the development of low back pain in industrial workers. *American Industrial Hygiene Association Journal*, 36:26-31.

Callaghan, J.P. & McGill, S.M. (2001). Low back joint loading and kinematics during standing and unsupported sitting. *Ergonomics*, 44(3):280-294.

Callaghan, J.P., Coke, S.K., Beach, T.A.C. (2010). Gender- and time-varying postural and discomfort responses during prolonged driving. *Occupational Ergonomics*, 9:41-53.

Chaffin, D.B. (1975). Ergonomics guide for the assessment of human static strength. *American Industrial Hygiene Association Journal*, 36(7), 505-511.

Chaffin, D.B., Andersson, G.B.J., Martin, B.J. (2006) Occupational Biomechanics, 4th Ed. John Wiley and Sons, Inc., New Jersey.

Chaffin, D.B. & Andres, R.O. (1983). Volitional postures during maximal push/pull exertions in the sagittal plane. *Human Factors,* 25(5):541-550.

Chau, J.Y., van der Ploeg, H.P., van Uffelen, J.G.Z., Wong, J., Riphagen, I., Healy, G.N., Gilson, N.D., Dunstan, D.W., Bauman, A.E., Owen, N., Brown, W.J. (2010). Are workplace interventions to reduce sitting effective? A systematic review. *Preventative Medicine*, 51:352-356.

Cholewicki, J. & McGill, S.M. (1996). Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. *Clinical Biomechanics,* 11(1):1-15.

Chow, A.Y. & Dickerson, C.R. (2009). Shoulder strength of females while sitting and standing as a function of hand location and force direction. *Applied Ergonomics*, 40(3):303-308.

Chow, A.Y. (2010). Investigation of hand forces, shoulder and trunk muscle activation patterns and EMG/force ratios in push and pull exertions. *University of Waterloo Master's thesis.* https://uwspace.uwaterloo.ca/bitstream/handle/10012/5551/Chow_Amy.pdf?sequence=1

Cram, J.R. & Kasman, G.S. (1998). *Introduction to Surface Electromyography*. Alexandria: Aspen Publications.

De Carvalho, D.E. & Callaghan, J.P. (2012). Influence of automobile seat lumbar support prominence on spine and pelvic postures: A radiological investigation. *Applied Ergonomics*, 43:876-882.

De Looze, M.P., Kujit-Evers, L.F.M., Van Dieen, J. (2003). Sitting comfort and discomfort and the relationship with objective measures. *Ergonomics,* 46: 985-997.

Dempster, W.T. (1955). Space requirements of the Seated Operator, WADC-TR-55-159, Aerospace Medical Research Laboratories; Dayton, Ohio.

Dickerson, C.R., Martin, B.J., Chaffin, D.B. (2006). The relationship between shoulder torques and the perception of muscular effort in loaded reaches. *Ergonomics*, 49(11):1036-1051.

Dickerson, C.R., Chaffin, D.B., Hughes, R.E. (2007). Predictors of perceived effort in the shoulder during load transfer tasks. *Ergonomics*, 50(7):1004-1016.

Dieen, J.H., Creemers, M., Draisma, I., Toussaint, H.M. (1994). Repetitive lifting and spinal shrinkage: effects of age and lifting technique. *Clinical Biomechanics*, 9:61:63.

Draicchio, F., Trebbi, M., Mari, S., Forzano, F., Serrao, M., Sicklinger, A., Silvetti, a., Iavicoli, S., Ranavolo, A. (2012). Biomechanical evaluation of supermatker cashiers before and after a redesign of the checkout counter. *Ergonomics*, 55(6):650-669.

Drake, J.D.M & Callaghan, J.P. (2006). Elimination of electrocardiogram contamination from electromyogram signals: an evaluation of currently used removal techniques. *Journal of Electromyography and Kinesiology*, 16:175-187.

Dreischarf, M., Bergmann, G., Wilke, H.J., Rohlmann, A. (2010). Different arm positions and the shape of the thoracic spine can explain contradictory results in the literature about spinal loads for sitting and standing. *Spine*, 35(22):2015-2021.

Dunk, N.M & Callaghan, J.P. (2005). Gender-based differences in postural responses to seated exposures. *Clinical Biomechanics*, 20:1101-1110.

Dunk, N.M., Kedgley, A.E., Jenkyn, T.R., Callaghan, J.P. (2009). Evidence of a pelvis-driven flexion pattern: are the joints of the lower lumber spine fully flexed in seated postures? *Clinical Biomechanics*, 24:164-168.

Dunstan, D.W., Barr, E.L.M., Healy, G.N., Salmon, J., Shaw, J.E., Balkau, B., Magliano, D.J., Cameron, A.J., Zimmet, P.Z., Owen, N. (2010). Television viewing time and mortality: The australian diabetes, obesity and lifestyle study (ausdiab). *Circulation*, 121(3):384-391.

Ebara, T., Kubo, T., Inoue, T., Murasaki, G., Takeyama, H., Sato, T., Suzamura, H., Niwa, S., Takanishi, T., Tachi, N., Itani, T. (2008). Effects of adjustable sit-stand VDT workstations on workers' musculoskeletal discomfort, alertness and performance. *Industrial Health*, 46:497-505.

Fenety, A & Walker, JM. (2002). Short-term effects on workstation exercises on musculoskeletal discomfort and postural changes in seated video display unit workers. *Journal of the American Physical Therapy Association,* 82:578-589.

Fischer, S.L., Belbeck, A.L., Dickerson, C.R. (2010). The influence of providing feedback on force production and within-participant reproducibility during maximal voluntary exertions for the anterior deltoid, middle deltoid, and infraspinatus. *Journal of Electromyography and Kinesiology,* 20(1):68-75.

Gallagher, K.M., Nelson-Wong, E., Callaghan, J.P. (2011). Do individuals who develop transient low back pain exhibit different postural changes than non-pain developers during prolonged standing? *Gait and Posture*, 34(4) 490-495.

Gardiner, P.A., Healy, G.N., Eakin, E.G., Clark, B.K., Dunstan, D.W., Shaw, J.E., Zimmet, P.Z., Owen, N. (2011). Associations between television viewing time and overall sitting time with the metabolic syndrome in older men and women: the Australian diabetes obesity and lifestyle study. *Journal of the American Geriatics Society*, 59(5):788-796.

Garg, A. & Beller, D. (1990). One-handed dynamic pulling strength with special reference to speed, handle height and angles of pulling. *International Journal of Industrial Ergonomics*, 6:231-240.

Grandjean, E., Hünting, W. (1977). Ergonomics of posture – review of various problems of standing and sitting posture. *Applied Ergonomics*, 8(3)135-140.

Gregory, D.E., Dunk, N.M., Callaghan, J.P. (2005). Stability ball versus office chair: comparison of muscle activation and lumbar spine posture during prolonged sitting. *Human Factors*, 48(1):142-153.

Gregory, D.E. 2005. Prolonged standing as a precursor for the development of low back discomfort: An investigation of possible mechanisms. [Thesis]. University of Waterloo. Waterloo, ON.

Grieco, A. (1986). Sitting posture: an old problem and a new one. *Ergonomics*, 29:345-362.

Gordon, C.C., Churchill, T., Clauser, C.C., Bradtmiller, B., McConville, J.T., Tebbets, I., Walker, R. (1989). *1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Stastics.* Technical Report NATICK/TR-89/044. Natick, MA; U.S. Army Natick Research, Development and Engineering Center (AD A225 094).

Hagberg, M. (1981). Electromyography signs of shoulder muscle fatigue in two elevated arm positions. *American Journal of Physical Medicine,* 60(3):111-121.

Hagberg, M. & Jonsson, B. (1975). The amplitude distribution of the myoelectric signal in an ergonomic study of the deltoid muscle. *Ergonomics,* 18(3):311-319.

Hasegawa, T., Inoue, K., Tsutsue, O., Kumashiro, M. (2001). Effects of a sit-stand schedule on a light repetitive task. *Internation Journal of Industrial Ergonomics,* 28:219-224.

Healy, G.N., Matthews, C.E., Dunstan, D.W., Winkler, E.A.H., Owen, N. (2011). Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. *European Heart Journal,* 32:590-597.

Hedge, A., Morimoto, S., McCrobie, D. (1999). Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics,* 42(10):1333-1349.

Hedge, A., & Ray, E.J. (2004). Effects of an electric height-adjustable worksurface on a computer worker's musculoskeletal discomfort and productivity. *Proceedings of the Human Factors and Ergonomics 48th Annual Meeting,* 1091-1095.

Hedge, A., Jagdeo, J., Agarwal, A., Rockey-Harris, K. (2005). Sitting or standing for computer work – does a negative-tile keyboard tray make a difference? *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting,* 49:808-812.

Herberts, P., Kadefors, R., Broman, H. (1980). Arm positioning in manual tasks. An electromyographic study of localized muscle fatigue. *Ergonomics,* 23(7):655-665.

Hoozemans, M.J.M., van der Beek, A. J., Frings-Dresen, M.H.W., van Dijk, F.J.H., van der Woude, L.H.V. (1998). Pushing and pulling in relation to musculoskeletal disorders: A review of risk factors. *Ergonomics,* 41(6):757-781.

Hoozemans, M.J.M., van der Beek, A.J., Frings-Dresen, M.H.W., van der Woude, L.H.V., van Dijk, F.J.H. (2002). Pushing and pulling in association with low back and shoulder complaints. *Occupational and Environmental Medicine,* 59:696-702.

Husemann, B., Von Mach, C.Y., Borsotto, D., Zepf, K.I., Scharnbacker, J. (2009). Comparisons of musculoskeletal complaints and data entry between a sitting and a sit-stand workstation paradigm. *Human Factors,* 51(3):310-320.

Hutton, W.C., Stott, J.R.R., Cyron, B.M. (1977). Is spondylolysis a fatigue fracture? *Spine,* 2:202-209.

Inman, V.T., Saunders, J.B., Abbott, L.C. (1944). Observations on the function of the shoulder joint. *The Journal of Bone and Joint Surgery,* 26:1-30.

Imrhan, S.N. & Ramakrishnan, U. (1992). The effects of arm elevation, direction of pull and speed of pull on isokinetic pull strength. *International Journal of Industrial Ergonomics,* 9:265-273.

Jarvholm, U., Palmerud, G., Styf, J., Herberts, P., Kadefors, R. (1988). Intramuscular pressure in the supraspinatus muscle. *Journal of Orthopaedic Research,* 26:230-238.

Jarvholm, U., Palmerud, Karlsson, D., Herberts, P., Kadefors, R. (1991). Intramuscular pressure and electromyography in four shoulder muscles. *Journal of Orthopaedic Research*, 9(4):609-619.

Johnson, G., Bogduk, N., Nowitzke, A., House, D. (1994). Anatomy and actions of the trapezius muscle. *Clinical Biomechanics,* 9:44-50.

Jongkol, P. (2006 May). *A study of lower back and upper extremity muscle activities in push and pull tasks.* Paper presented at the 22nd Annual Conference of Asia Pacific Occupational Safety & Health Organization, Bangkok, TH.

Jonsson, B. (1988). Electromyographic studies of job rotation. *Scandinavian Journal of Work, Environment and Health,* 14(1):108-109.

Jorgensen, K., Fallentin, N., Krogh-Lund, C., Jensen, B. (1988). Electromyography and fatigue during prolonged, low-level static contractions. *European Journal of Applied Physiology,* 57:316-321.

Joseph, C., Beach, T.A.C., Callaghan, J.P., Dickerson, C.R. (2014). The influence of precision requirements and cognitive challenges on upper extremity joint reaction forces, moments and muscle force estimates during prolonged repetitive lifting. *Ergonomics,* 57(2):236-246.

Juul-Kristensen, B. & Jensen, C. (2005). Self-reported workplace related ergonomic conditions as prognostic factors for musculoskeletal symptoms: the "BIT" follow up study on office workers. *Occupationaland Environmental Medicine*, 62(3):188-194.

Kaptoge, D., Di Angelantonio, E., Lowe, G., Pepys, M.B., Thompson, S.G., Collins, R., Danesh, J. (2010). C-reactive protein concentration and risk of coronary heart disease, stroke, and mortality: an individual participant meta-analysis. *Lancet*, 375:132-140.

Kee, D. & Karwowski, W. (2001). The boundaries for joint angles of isocomfort for sitting and standing males based on perceived comfort of static joint postures. *Ergonomics*, 44(6):614-648.

Keir, P.J., Wells, R.P. (2002). The effect of typing posture on wrist extensor muscle loading. *Human Factors*, 44(3):392-403.

Korhonen, T., Ketola, R., Toivonen, R., Luukkonen, R., Häkkänan, M., Viikari-Juntura, E. (2003). Work related and individual predictors for incident neck pain among office employees working with video display units. *Occupational and Environmental Medicine*, 60(7):475-482.

Krijnen, R.M.A., de Boer, E.M., Ader, H.J., Bruynzeel, D.P. (1997). Venous insufficiency in male workers with a standing profession. Part 1: Epidemiology. *Dermatology,* 194:111-120.

Kronberg, M., Nemeth, G., Brostrom, L.-A. (1990). Muscle activity and coordination in the normal shoulder. A electromyographic study. *Clinical Ortopaedics and Related Research,* 257:76-85.

Kumar, S. (1995) Upper body push-pull strength of normal young adults in sagittal plane at three heights. *International Journal of Industrial Ergonomics*, 15:427-436.

Lannerstern, L. & Harms-Ringdahl, K. (1990). Neck and shoulder muscle activity during work with different cash register systems. *Ergonomics*, 33:49-65.

Lassek, W.D. & Gaulin, S.J.C. (2009). Costs and benefits of fat-free muscle mass in men: relationship to mating success, dietary requirements, and native immunity. *Evolution and Human Behaviour*, 30(5):322-328.

Laursen, B., Jensen, B.R., Sjøgaard, G. (1998). Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. *European Journal of Applied Physiology*, 78:544-548.

Lee, J. & Nussbaum, M.A. (2012). Experienced workers exhibit distinct torso kinematics/kinetics and patterns of task dependency during repetitive lifts and lowers. *Ergonomics*, 55(12):1535-1547.

Lehman, K.R., Psihogios, J.P., Meulenbroek, R.G.J. (2001). Effects of sitting versus standing and scanner type on cashiers. *Ergonomics*, 44(7):719-738.

Leivseth, G. & Drerup, B. (1997). Spinal shrinkage during work in a sitting posture compared to work in a standing posture. *Clinical Biomechanics*, 12:409-418.

Lis, A.M., Black, K.M., Korn, H. (2007). Association between sitting and occupational LBP. *European Spine Journal*, 16:283-298.

Macfarlane, G.J., Thomas, E., Papageougiou, A.C., Croft, P.R., Jayson, M.I.V., Silman, A.J. (1997). Employment and physical work activities as predictors of future low back pain. *Spine*, 22(10):1143-1149.

Macfarlane, G.J., Hunt, I.M., Silman, A.J. (2000). Role of mechanical and psychosocial factors in the onset of forearm pain: prospective population based study. *British Medical Journal*, 321(7262):676-679.

Mackinnon, S.N. & Vaughan, C.L. (2005). Effect of the reach distance on the execution on one-handed submaximal pull forces. *Occupational Ergonomics*, 5(3):161-172.

Manchikanti, L. (2000). Epidemiology of low back pain. *Pain Physician,* 3(2):167-192.

Marshall, P.W.M., Patel, H., Callaghan, J.P. (2011). Gluteus medius strength, endurance, and co-activation in the development of low back pain during prolonged standing. *Human Movement Science*, 30:63-73.

McCulloch, J. (2002). Health risks associated with prolonged standing. *Work*, 19:201-205.

McDonald, A., Picco, B.R., Belbeck, A.L., Chow, A.Y., Dickerson, C.R. (2012). Spatial dependency of shoulder muscle demands in horizontal pushing and pulling. *Applied Ergonomics*, 43(6):971-978.

McGill, S.M & Brown, S. (1992). Creep response of the lumbar spine to prolonged flexion. *Clinical Biomechanics*, 7:43-46.

McGill, S.M., Kavcic, N.S., Harvey, A. (2006). Sitting on a chair or an exercise ball: Various perspectives to guide decision making. *Clinical Biomechanics,* 21:353-360.

McLean, L., Chislett, M., Keith, M., Murphy, M., Walton, P. (2003). The effect of head position, electrode site, movement and smoothing window in the determination of a reliable maximum voluntary activation of the upper trapezius muscle. *Journal of Electromyography and Kinesiology*, 13(2):169-180.

Meszaros, K.A. (2013) Resolving the influence of work sequencing which includes overhead work: implications for job cycle designs. *University of Waterloo Master's Thesis.* https://uwspace.uwaterloo.ca/bitstream/handle/10012/7312/Meszaros_Kimberly.pdf?sequence=1

Milerad, E., Ericson, M.O. (1994). Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study. *Ergonomics*, 37:255-264.

Miranda, H., Viikari-Juntura, E., Martikainen, R., Riihimäki. (2002). A prospective study on knee pain and its risk factors. *Osteoarthritis and Cartilage,* 10:623-630.

Mortimer, J.T., Magnusson, R., Petersen, I. (1970). Conduction velocity in ischemic muscle: effect on EMG frequency spectrum. *American Journal of Physiology,* 219:1324-1329.

Nelson-Wong, E., Gregory, D.E., Winter, D.A., Callaghan, J.P. (2008). Gluteus medius activation patterns as a predictor of low back pain during standing. *Clinical Biomechanics*, 23:545-553.

Nelson-Wong, E. & Callaghan, J.P. (2010). Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. *Journal of Electromyography and Kinesiology*, 20(2):256-263.

Nerhood, H.L. & Thompson, S.W. (1994) Adjustable sit-stand workstations in the office, people and technology in harmony. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, Nashville, Tennessee, October 24-28. The Human Factors and Ergonomics Society, Santa Monica, California, 1:668-672.

National Institute of occupational Safety & Health. *Elements of Ergonomic Programs.* NIOSH Publication 97-117.

National Institute of Occupational Safety & Health. *Transportation, Warehousing, and Utilities Sector: Occupational Safety and Health Needs for the Next Decade of NORA.* NIOSH Publication 2010-106.

Onishi, N., Sakai, K., Kogi, K. (1982). Arm and shoulder muscle lead in various keyboard operating jobs of women. *Journal of Human Ergology,* 11:89-97.

Palmerud, G., Forsman, M., Sporrong, H., Herberts, P., Kadefors, R. (2000). Intramuscular pressure of the infra- and supraspinatus muscles in relation to hand load and arm posture. *European Journal of Applied Physiology*, 83:223-230.

Paul, R.D (1995a). Effects of office layout and sit-stand adjustable furniture: a field study. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting,* 1:422-426.

Paul, R.D. & Helander, M.G. (1995b). Effect of sit-stand schedule on spinal shrinkage in VDT operators, designing for the global village. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 1:563-567.

Paul, R.D. (1995c). Foot swelling in VDT operators with sitting and sit-stand workstations. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 1:568-572.

Peters, M. (1976). Prolonged practice of a simple motor task by preferred and nonpreferred hands. *Perceptual and Motor Skills*, 42(43):447-450.

Pope, M.H., Goh, K.L., Magnusson, M.L. (2002). Spine ergonomics. *Annual Review of Biomedical Engineering*, 4:49-68.

Psihogios, J.P. & Jones, M.R. (2001). Electromyographic analysis of cashiers in seated and standing postures in a store environment. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting,* 45:1123-1127.

Punnett, I., Gold, J., Katz, J.N., Gore, R., Wegman, D.H. (2004). Ergonomic stressors and upper extremity musculoskeletal disorders in automobile manufacturing: a one year follow up study. *Occupational and Environmental Medicine*, 61:668-674.

Raina, S.M. & Dickerson, C.R. (2009). The influence of job rotation and task order on muscle fatigue: A deltoid example. *Work: A Journal of Prevention, Assessment, and Rehabilitation,* 34(2):205-213.

Robertson, G. (2010). Electromyography: Processing. *University of Ottawa Courseware.* http://www.health.uottawa.ca/biomech/courses/apa4311/emg-p2.pdf ; Created November 18, 2010. Accessed April 1, 2014.

Roelen, C.A.M., Schreuder, K.J., Koopmans, P.C., Groothoff, J.W. (2008). Perceived job demands relate to self-reported health complaints. *Occupational Medicine,* 58(1):58-63.

Roelofs, A. & Straker, L. (2002). The experience of musculoskeletal discomfort amongst bank tellers who just sit, just stand or sit and stand at work. *Ergonomics SA*, 14(2):11-29.

Ryall, C., Coggon, D., Peveler, R., Reading, I., Palmer, K.T. (2006). A case-control study of risk factors for arm pain presenting to primary care services. *Occupational Medicine*, 56(2):137-143.

Sandsjö, L., Kadefors, R., Palmerud, G., Lundberg, U., Melin, B., Elfsberg-Dohns, I., Ekstrom, M., Parr, D. (1996). Trapezius muscle relation patterns in female supermarket cashiers. *25th International Congress on Occupational Health,* 102.

Sato, K., Kikucho, S., Yonezawa, T. (1999). In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. *Spine,* 24:2468-2474.

Schinkel-Ivy, A., Nairn, B., Drake, J.D.M. (2013). Investigation of trunk muscle co-activation and its association with low back pain development during prolonged sitting. *Journal of Electromyography and Kinesiology,* in press.

Seo, N.J. (2010). Effects of handle orientation, gloves, handle friction and elbow posture on maximum horizontal pull and push forces. *Ergonomics,* 53:92-101.

Sigholm. G., Herberts, P., Almström, C., Kadefors, R. (1984). Electromyographic analysis of shoulder load. *Journal of Orthopaedic Research,* 1(4):379-386.

Solomonow, M., Baratta, R.V., Banks, A., Freudenberger, C., Zhou, B.H. (2003). Flexion-relaxation response to static lumbar flexion in males and females. *Clinical Biomechanics,* 18:273-279.

Start, K.B., Holmes, R. (1963). Local muscle endurance with open and occluded intramuscular circulation. *Journal of Physiology,* 18:804-807.

Stobbe, T. The development of a practical strength testing program for industry. Unpublished Ph.D thesis (Industrial Engineering), University of Michigan, Ann Arbor, 1982.

Teras, L.R., Gapstur, S.M., Diver, W.R., Birmann, B.M., Patel, A.V. (2012). Recreational physical activity, leisure sitting time and risk of non-Hodgkin lymphoid neoplasms in the American Cancer Society Cancer Prevention Study II cohort. *International Journal of Cancer,* 131:1912-1920.

Tissot, F., Messing, K., Stock, S. (2009). Studying the relationship between low back pain and working postures among those who stand and those who sit most of the working day. *Ergonomics,* 52(11):1402-1418.

Todd, A.I. (2005 September-October). *Current trends in research focused on pushing and pulling.* Paper presented at the Fourth International Cyberspace Conference on Ergonomics, Johannesburg, ZA.

Todor, J.L., Kyprie, P.M., Price, H.L. (1982). Lateral asymmetries in arm, wrist and finger movements. *Cortex*, 18(4):515-523.

Tomei, F., Baccolo, T.P., Tomao, E., Palmi, S., Rosati, M.V. (1999). Chronic venous disorders and occupation. *American Journal of Industrial Medicine,* 36:653-665.

Twomney, L. & Taylor, J.J. (1982). Flexion creep deformation and hysteresis in the lumbar vertebral column. *Spine,* 7:116-122.

Videman, T., Nurminen, M., Troup, J.D.G. (1990). 1990 Volvo award in clinical sciences: Lumbar spinal pathology in cadaveric material in relation to history of back pain, occupation, and physical loading. *Spine*, 15(8):728-740.

Webb Associates, Anthropometric Source Book, Vol. I, NASA 1024, National Aeronautics and Space Administration, Washington DC, 1978.

Wiker, S.F., Chaffin, D.B., Langolf, G.D. (1989). Shoulder posture and localized muscle fatigue and discomfort. *Ergonomics*, 32(2):211-237.

Wiker, S.F., Chaffin, D.B., Langolk, G.D. (1990). Shoulder postural fatigue and discomfort. *International Journal of Industrial Ergonomics,* 5: 133-146.

Wilder, D.G., Frymoyer, J.W., Pope, M.H. (1985). The effects of vibration on seated individuals. *Automedica,* 6, 5-35.

Wilke, H-J., Neef, P., Caimi, M., Hoogland, T., Claes, L.E., (1999). New in vivo measurements of pressure in the intervertebral disc in daily life. *Spine,* 8(15):755-762.

Winter, D.A. (1991). Electromyogram recording, processing, and normalization: Procedures and considerations. *Journal of Human Muscle Performance*, 1(2):5-15.

Winter, D.A. (2009). *Biomechanics and Motor Control of Human Movement*. 4th Ed. Hoboken, New Jersey: John Wiley & Sons, Inc.

Workplace Safety Insurance Board of Ontario. (2011). *2011 Statistical Report*.

Wu, G., van Der Halm, F.C., Veeger, H.E., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B. (2005). ISB recommendation on definitions for the reporting of human joint motion – Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, 38:981-992.

Appendix A: Participant Forms

A1: Information Consent Form

INFORMATION CONSENT FORM

Study Title

Quantification of Upper Extremity Physical Exposures in Materials Handling Tasks while using Sit/Stand Workstations

Research Team

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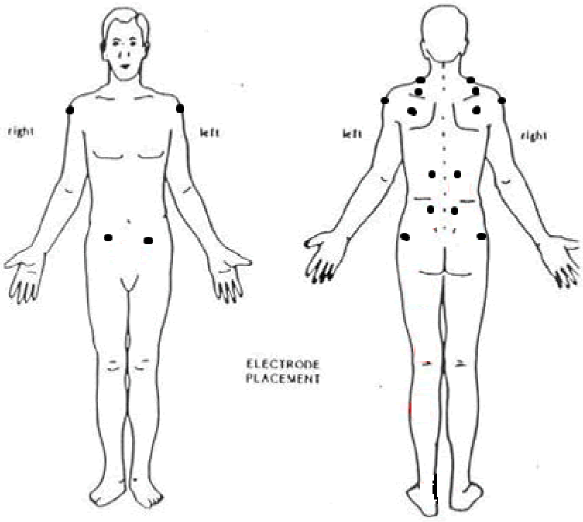
Purpose of the Study

The goal of this investigation is to determine how adjustments in posture between seated and standing positions affect in both arms for identical tasks. Many industrial workplaces involve workstations that switch between sitting and standing. Our aim is to quantify what kind of effect this has on the arms, and if this leads to shoulder muscle fatigue and pain resulting in the development of shoulder musculoskeletal disorders. Results from this investigation may provide ergonomists with additional strategies for mitigating injury risk.

Procedures Involved in this Study and Time Commitment

As a participant in this research study, you will be asked to attend two sessions, approximately 2.5 hours in duration each. During this session, you will be asked to complete basic manual materials handling tasks commonly found in industry (which include pushing and pulling on a handle, moving light plastic bottles across a table, and a light assembly task using wooden pegs on a pegboard. The testing session procedures are as follows.

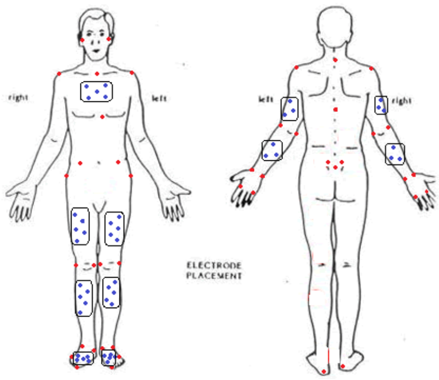


Instrumentation:

- Upon arrival, the skin overlying a total of 16 arm, shoulder and torso muscles will be shaved and cleansed with rubbing alcohol by a research investigator of the same sex as you, the participant. This shaving and cleansing is so that the surface electromyography (EMG) electrodes can be adhered to a surface with minimal interference through dead skin cells or hair. These electrodes are coated with an adhesive similar to a disposable bandage. A disposable razor will be used and discarded after shaving. EMG will be collected throughout the session using 16 bipolar electrodes (a 17th ground electrode will be placed onto the clavicle). The placement of these electrodes can be seen on the diagram above (filled circles). Electrodes will be placed bilaterally on the anterior deltoid, middle deltoid, supraspinatus, infraspinatus, upper trapezius, and lumbar erector spinae. Reflective markers will also be placed on bony landmarks on both limbs and the torso. These locations are indicated by the crosses on the diagram for you.

Procedures:

- Following application of the surface electrodes, you will be asked to perform three exertions where you push as hard as you can in 7 different postures. 3 of these postures will be while seated, and the other 4 will be lying face down on a therapist's massage table, either with your arm out to the side and supported by one of the research investigators or with your arm by your side. Examples of these include sitting with your arm out to the side, or with your elbow bent and tucked in by your side. These exertions are designed to determine your maximal output of each muscle being examined, allowing comparison between participants. A two minute rest period will be given in between each exertion.
- Following these maximal exertions, reflective markers will be place on your body on bony landmarks. These will be used to capture your movements during the task protocol. A total of 41 individual markers and 11 clusters will be placed on your body. Locations of these placements can be seen in the diagram to the right.



- After initial measures, collection of the task protocol will begin. You will be asked to stand or sit in front of a stationary robot arm with attached force transducer. This robot will remain shut off and locked down while you are in the collection space.
- Each position will involve one of four tasks: pushing on a handle attached to the force transducer, pulling on this same handle, a bottle transfer task

using weighted plastic bottles, or placing small wooden pegs into a pegboard. Each of these tasks will last approximately 10 minutes.

- Once the trial has been collected, the research investigators will ask you to step out of the robot collection space while the robot is moved to the next position. This is to ensure your safety as the robot is moving.
- Throughout the collection protocol, rest breaks will be provided for you to try and prevent you from being fatigued. These breaks are scheduled to be at least 2 minutes long after each 10 minute testing period. If you would like additional time in these breaks or additional rest breaks, please notify one of the research investigators and we would be happy to provide you with additional rest time.
- With your permission, photographs may be taken throughout the collection to demonstrate postures during each task and document the experimental setup. If these photographs would be used in publications or presentations, your face would be blackened in the picture, ensuring your anonymity in the photo.

Potential Risks and Associated Safeguards

- Some participants may experience skin irritation or redness from the adhesives used to adhere the electrodes to the skin. This is similar to irritation that may be caused by a disposable bandage and typically fades within 1-3 days. The occurrence of irritation is rare in participants.
- The portable parts of electrical recording systems are battery operated and isolate you from the main power lines. There is no risk of electrical shock.
- Some participants may experience fatigue or mild discomfort from the submaximal contractions. This discomfort should disappear in 1-3 days. As stated previously, if you feel fatigued at any time, simply notify one of the research investigators and we will be happy to provide you with a rest period.

Changing Your Mind about Participation

At any point in the study, you may withdraw from participating without penalty. To do so, indicate this to the investigators by saying, "I no longer wish to participate in this study."

Inclusion / Exclusion Criteria

Only university aged (18-35 years), right-handed males and females will be included in this study. Individuals who have had pain and/or injury in arm or shoulder, or the back within the past year, or those who experience back pain in prolonged sitting (like a long drive), or those who have a job that requires prolonged standing (>10 hours/week) will be excluded in this study. This will be asked by the research investigators prior to collection, and participants who have any of these criteria will not be able to participate in this study. Rubbing alcohol must be used to cleanse the skin prior to electrode placement. As this is a mandatory step in the procedure, anyone with an allergy to rubbing alcohol will not be able to participate in this study.

Potential Benefits of Participation

By participating in this study, you will have the opportunity to gain or further your knowledge and understanding of experimental procedures and theories of human movement research. Results from this investigation will provide insight into activity patterns of muscles in the upper extremity and potential fatigue patterns associated with various work postures. The knowledge gained from this research may assist in the reduction of upper extremity injury risk in the workplace, as well as more comprehensive treatment methods and rehabilitation approaches. Significant findings will be summarized to provide ergonomists with guidelines for the design of work tasks and work station layouts.

Remuneration

After completion of the testing session, you will receive **[something]** in appreciation for your help.

Confidentiality

Each participant will be assigned a 3 letter identification code instead of using your name for the purposes of this study. Only the investigators will have this code. All data will be stored indefinitely on password protected computer hard drives and/ or digital storage media (which will remain in the investigator's locked filing cabinet when not in use). Separate consent will be requested in order to use photographs for teaching, scientific presentations, or in publications of this work.

Concerns about Participation

We would like to assure you that this study has been reviewed by, and received ethics through the University of Waterloo's Office of Research Ethics (ORE). However, the final decision about participation is yours. In the event that you have any comments or concerns resulting from your participation in this study, please contact the Director of the ORE (Dr. Maureen Nummelin) at 519-888-4567 ext. 36005 or at maureen.nummelin@uwaterloo.ca .

Questions about the Study

If you have any further questions, or want any other information about this study, please feel free to contact Alan Cudlip or Dr. Clark Dickerson.

Sincerely yours,

Alan Cudlip
Department of Kinesiology
University of Waterloo
519-888-4567 x37495
accudlip@uwaterloo.ca

Clark Dickerson, PhD
Department of Kinesiology
University of Waterloo
519-888-4567 x37844
cdickers@uwaterloo.ca

A2: Consent to Participation

CONSENT OF PARTICIPATION

Project Title: Quantification of Upper Extremity Physical Exposures in Materials Handling Tasks while using Sit/Stand Workstations

Principal Investigator: Alan Cudlip

Faculty Supervisor: Dr. Clark Dickerson

I have read the information presented in the information letter about a study being conducted by Alan Cudlip (Principal Investigator) and Dr. Clark Dickerson (Faculty Supervisor) of the Department of Kinesiology at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through the University of Waterloo's Office of research Ethics (ORE). I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director of the ORE at 519-888-4567 ext. 36005.

With full knowledge of all foregoing, I agree, or my own free will, to participate in this study.

Participant's Name (Please Print): ____

Participant's Signature: ____

Date: ____

Witnessed: ____

A3: Consent to Photography

CONSENT TO USE PHOTOGRAPHS IN TEACHING, PRESENTATIONS, and/or PUBLICATIONS

Project Title: Quantification of Upper Extremity Physical Exposures in Materials Handling Tasks while using Sit/Stand Workstations

Student Investigator: **Alan Cudlip**

Faculty Supervisor: **Dr. Clark Dickerson**

Sometimes a certain photograph clearly demonstrates a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific conference or in a publication.

I agree to allow photographs in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name. I am aware that I may withdraw this consent at any time without penalty, and the photograph will be confidentially shredded.

I was informed that if I have any comments or concerns resulting from my participation in this study I may contact the Director of the ORE (Dr. Maureen Nummelin) at 519-888-4567 ext. 36005 or at maureen.nummelin@uwaterloo.ca .

Participant's Name (Please Print): ____

Participant's Signature: ____

Date: ____

Witnessed: ____

A4: Feedback Letter

Dear Participant,

We would like to thank you for your participation in this study. As a reminder, the purpose of the study was to examine the sitting and standing on the upper extremity during manual materials handling tasks.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data is collected and analysed for this study, it is our intent to share this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information regarding the results of this study, or if you have questions or concerns, please contact us via or e-mail (details listed at the bottom of this page). If you would like a summary of the results, please let us know by providing us with your contact information. When the study is completed, we will send it to you. The expected date for the study findings to be available is December 31, 2013.

As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through the University of Waterloo's Office of Research Ethics (ORE). Should you have any comments or concerns resulting from your participation in this study, please contact the Director of the ORE (Dr. Maureen Nummelin) at 519-888-4567 ext. 36005 or at maureen.nummelin@uwaterloo.ca .

Thank you again for your participation in this study.

Sincerely yours,

Alan Cudlip	Clark Dickerson, PhD
Department of Kinesiology	Department of Kinesiology
University of Waterloo	University of Waterloo
519-888-4567 x37495	519-888-4567 x37844
accudlip@uwaterloo.ca	clark.dickerson@uwaterloo.ca

I have participated in the study:

Quantification of Upper Extremity Physical Exposures in Materials Handling Tasks while using Sit/Stand Workstations

I would like a summary of the results.

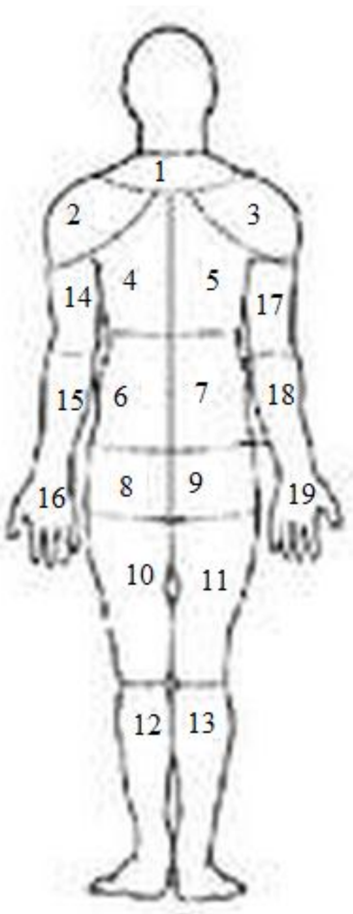
Name: ____

E-mail: ____

A5: Body Discomfort Scale

Body Discomfort Scale

To answer each question, place a vertical dash **[|]** **through** *the corresponding line.*



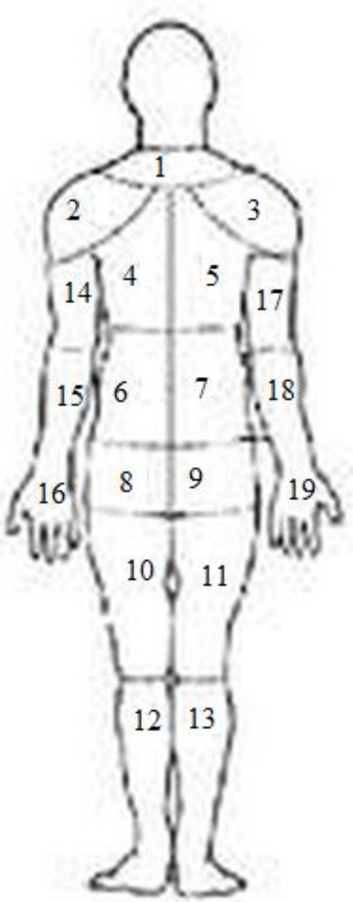
The number displayed in the regions in the diagram above correspond with the numbers in the survey to the right of the diagram.

	No Discomfort	Extreme Discomfort
1. Neck		
2. (L) Shoulder		
3. (R) Shoulder		
4. (L) Mid Back		
5. (R) Mid Back		
6. (L) Low Back		
7. (R) Low Back		
8. (L) Buttock		
9. (R) Buttock		

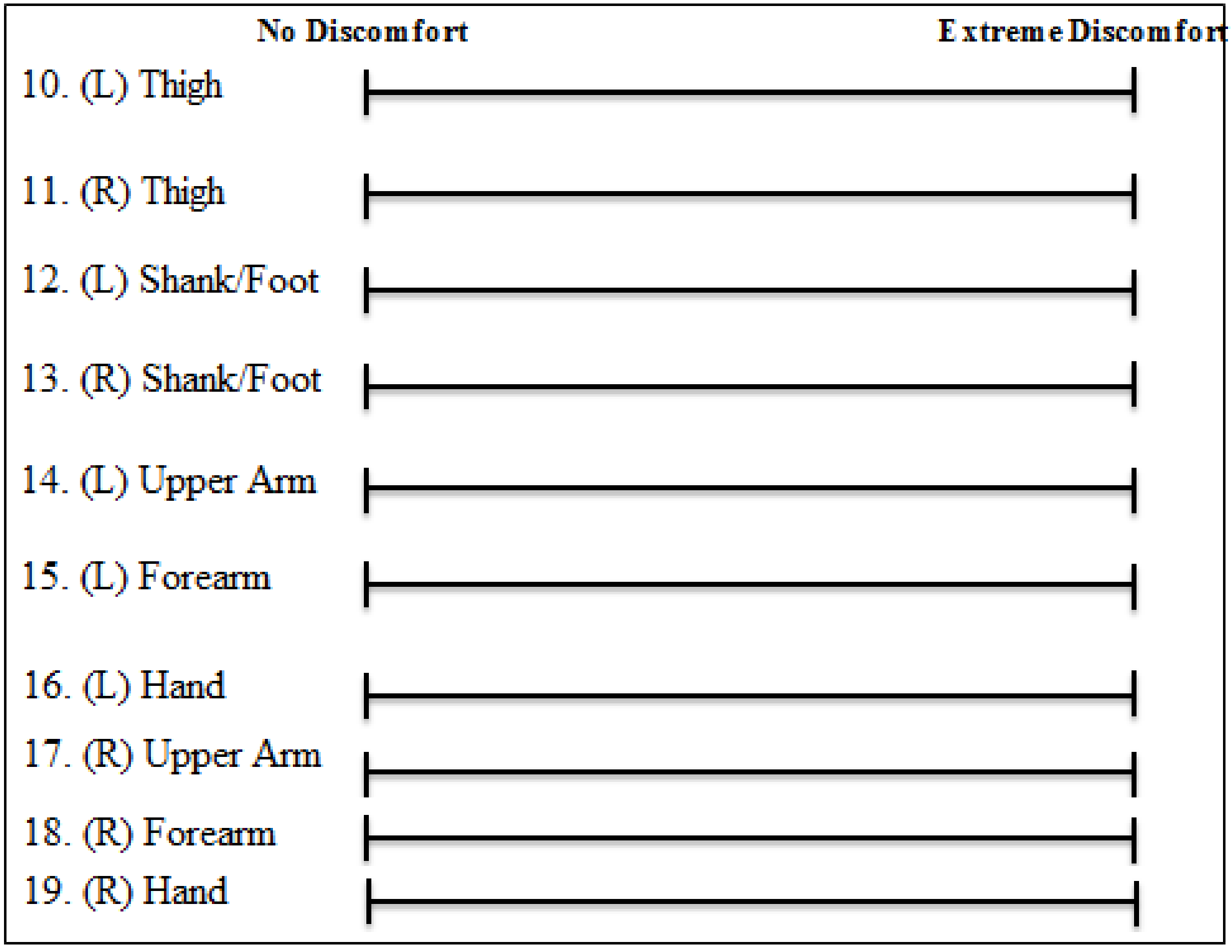
Scale continued on NEXT PAGE →

Body Discomfort Scale (Continued)

To answer each question, place a vertical dash **[|]** **through** *the corresponding line.*



The number displayed in the regions in the diagram above correspond with the numbers in the survey to the right of the diagram.



	No Discomfort	Extreme Discomfort
10. (L) Thigh		
11. (R) Thigh		
12. (L) Shank/Foot		
13. (R) Shank/Foot		
14. (L) Upper Arm		
15. (L) Forearm		
16. (L) Hand		
17. (R) Upper Arm		
18. (R) Forearm		
19. (R) Hand		

Appendix B: Normalized EMG Magnitudes by APDF Levels

B1: Left Middle Deltoid

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	3.7	4.3	4.7	5.2	5.9
Sit + Pull	1.6	1.8	2.0	2.1	2.4
Sit + Transfer	1.1	2.0	3.4	6.1	12.2
Sit + Assembly	0.9	1.4	2.0	2.7	3.8
Stand + Push	3.8	4.4	5.0	5.7	6.7
Stand + Pull	2.4	2.7	3.1	3.5	4.1
Stand + Transfer	1.2	2.5	4.2	7.4	14.9
Stand + Assembly	1.1	1.7	2.4	3.4	5.0

B2: Left Upper Trapezius

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	3.6	4.1	4.5	4.9	5.6
Sit + Pull	1.2	1.3	1.4	1.6	1.8
Sit + Transfer	2.3	4.3	7.1	11.0	17.2
Sit + Assembly	4.2	5.4	6.4	7.5	9.3
Stand + Push	1.8	2.1	2.3	2.6	3.0
Stand + Pull	1.0	1.1	1.2	1.3	1.5
Stand + Transfer	1.0	2.1	3.5	5.8	9.6
Stand + Assembly	2.1	2.8	3.3	3.9	4.8

B3: Left Supraspinatus

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	4.4	5.0	5.5	5.9	6.7
Sit + Pull	1.9	2.2	2.4	2.6	2.9
Sit + Transfer	3.1	5.2	7.9	11.5	17.0
Sit + Assembly	4.4	5.7	6.6	7.6	9.4
Stand + Push	3.6	4.1	4.5	4.9	5.6
Stand + Pull	2.2	2.5	2.7	3.0	3.4
Stand + Transfer	1.8	3.4	5.4	8.0	12.5
Stand + Assembly	2.8	3.7	4.4	5.1	6.4

B4: Left Infraspinatus

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	8.0	9.1	10.0	10.8	12.2
Sit + Pull	2.8	3.2	3.4	3.7	4.2
Sit + Transfer	1.1	2.3	5.8	10.5	18.1
Sit + Assembly	1.9	2.9	3.7	4.5	5.7
Stand + Push	7.1	8.2	9.0	9.8	11.2
Stand + Pull	2.7	3.1	3.4	3.7	4.2
Stand + Transfer	1.1	2.4	5.3	9.3	16.7
Stand + Assembly	1.5	2.1	2.6	3.2	4.1

B5: Right Middle Deltoid

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	4.6	5.3	5.9	6.5	7.5
Sit + Pull	1.7	1.9	2.0	2.2	2.4
Sit + Transfer	1.0	2.1	3.7	6.5	13.2
Sit + Assembly	0.8	1.3	1.8	2.4	3.5
Stand + Push	6.3	7.4	8.1	8.9	10.2
Stand + Pull	3.5	4.0	4.4	4.8	5.5
Stand + Transfer	1.9	3.5	5.6	9.8	19.2
Stand + Assembly	1.5	2.3	3.2	4.3	6.3

B6: Right Upper Trapezius

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	4.5	5.2	5.7	6.2	7.1
Sit + Pull	1.3	1.5	1.6	1.7	1.9
Sit + Transfer	3.0	5.4	8.3	12.1	18.0
Sit + Assembly	4.8	6.3	7.4	8.7	10.8
Stand + Push	3.2	3.9	4.4	4.9	5.8
Stand + Pull	1.1	1.4	1.5	1.7	2.0
Stand + Transfer	1.2	2.7	4.7	7.2	11.2
Stand + Assembly	2.3	3.4	4.1	4.9	6.1

B7: Right Supraspinatus

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	5.2	6.0	6.5	7.1	7.9
Sit + Pull	2.4	2.7	3.0	3.2	3.6
Sit + Transfer	3.3	5.6	8.3	11.9	17.5
Sit + Assembly	5.0	6.5	7.7	9.0	11.1
Stand + Push	5.3	6.1	6.7	7.4	8.4
Stand + Pull	2.6	3.0	3.3	3.6	4.0
Stand + Transfer	2.1	4.0	6.4	9.4	13.9
Stand + Assembly	2.7	4.0	5.0	6.0	7.5

B8: Right Infraspinatus

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	6.8	7.8	8.5	9.2	10.3
Sit + Pull	2.5	2.8	3.0	3.2	3.6
Sit + Transfer	0.7	1.7	5.1	9.3	15.9
Sit + Assembly	1.4	2.2	2.9	3.7	4.7
Stand + Push	7.3	8.3	9.1	10.0	11.6
Stand + Pull	3.1	3.5	3.8	4.2	4.9
Stand + Transfer	0.8	2.1	5.8	10.5	18.6
Stand + Assembly	1.4	2.1	2.9	3.7	5.1

Appendix C: Normalized Joint Moment Magnitudes by APDF Levels

C1: Left Wrist Radial/Ulnar Deviation

A positive moment represents radial deviation, while a negative moment represents ulnar deviation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-1.3	-1.2	-1.1	-1.1	-1.0
Sit + Pull	-1.6	-1.5	-1.5	-1.4	-1.3
Sit + Transfer	-1.3	-1.0	-0.6	0.1	0.9
Sit + Assembly	-2.1	-1.8	-1.4	-1.1	-0.8
Stand + Push	-2.9	-2.8	-2.6	-2.5	-2.3
Stand + Pull	-0.8	-0.6	-0.5	-0.3	-0.2
Stand + Transfer	-1.3	-0.9	0.3	3.4	4.7
Stand + Assembly	-1.9	-1.6	-1.2	-0.8	-0.5

C2: Left Wrist Pronation/Supination

A positive moment represents supination, while a negative moment represents pronation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-9.6	-9.5	-9.4	-9.4	-9.3
Sit + Pull	10.4	10.5	10.6	10.7	10.8
Sit + Transfer	-1.0	-0.7	-0.1	0.2	0.5
Sit + Assembly	-1.6	-1.4	-1.2	-1.0	-0.8
Stand + Push	-14.3	-14.2	-14.1	-14.0	-13.9
Stand + Pull	14.6	14.8	14.9	15.0	15.3
Stand + Transfer	-1.9	-0.9	0.2	0.7	1.3
Stand + Assembly	-1.6	-1.4	-1.2	-1.1	-0.9

C3: Left Wrist Flexion/Extension

A positive moment represents wrist flexion, while a negative moment represents wrist extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-11.3	-11.2	-11.1	-11.0	-11.0
Sit + Pull	13.6	13.8	13.9	13.9	14.0
Sit + Transfer	-2.2	-1.6	-0.3	0.3	0.6
Sit + Assembly	-0.9	-0.7	-0.5	-0.2	0.2
Stand + Push	-10.5	-10.3	-10.2	-10.1	-9.9
Stand + Pull	15.9	16.1	16.2	16.3	16.4
Stand + Transfer	-2.8	-1.8	-0.2	0.6	1.6
Stand + Assembly	-0.7	-0.5	-0.3	0.0	0.3

C4: Left Elbow Varus/Valgus

A positive moment represents elbow valgus, while a negative moment represents elbow varus.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	3.4	3.4	3.4	3.5	3.5
Sit + Pull	3.8	3.9	4.0	4.1	4.1
Sit + Transfer	-1.4	0.5	1.9	2.9	3.5
Sit + Assembly	3.8	4.2	4.4	4.5	4.8
Stand + Push	3.8	3.9	4.0	4.0	4.1
Stand + Pull	3.6	3.7	3.7	3.8	3.8
Stand + Transfer	-2.4	0.1	1.4	2.3	3.2
Stand + Assembly	3.4	3.7	3.9	4.0	4.3

C5: Left Elbow Internal/External Axial Rotation

A positive moment represents external axial rotation, while a negative moment represents internal axial rotation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	2.8	2.9	2.9	3.0	3.0
Sit + Pull	-3.1	-3.1	-2.9	-2.9	-2.8
Sit + Transfer	-2.9	-1.9	-1.0	-0.5	0.2
Sit + Assembly	-1.9	-1.3	-0.8	-0.1	0.6
Stand + Push	4.8	4.8	4.9	4.9	5.0
Stand + Pull	-5.2	-5.0	-4.9	-4.9	-4.8
Stand + Transfer	-3.5	-2.6	-1.6	-1.0	-0.5
Stand + Assembly	-1.5	-1.0	-0.6	0.0	0.7

C6: Left Elbow Flexion/Extension

A positive moment represents elbow flexion, while a negative moment represents elbow extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-6.5	-6.4	-6.4	-6.4	-6.3
Sit + Pull	7.7	7.7	7.9	7.9	8.0
Sit + Transfer	-0.9	0.0	0.5	1.4	2.4
Sit + Assembly	-1.0	-0.6	-0.2	0.5	1.4
Stand + Push	-6.3	-6.2	-6.1	-6.1	-5.9
Stand + Pull	8.7	9.0	9.1	9.1	9.2
Stand + Transfer	-0.7	0.3	0.9	1.6	2.6
Stand + Assembly	-0.7	-0.3	0.0	0.6	1.4

C7: Left Shoulder Abduction/Adduction

A positive moment represents shoulder adduction, while a negative moment represents shoulder abduction.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	10.0	10.0	10.1	10.2	10.3
Sit + Pull	-20.7	-20.6	-20.4	-20.4	-20.3
Sit + Transfer	-6.5	-4.4	-2.6	-0.6	1.0
Sit + Assembly	-5.3	-3.7	-2.2	-0.2	2.4
Stand + Push	9.7	9.9	10.0	10.1	10.3
Stand + Pull	-25.6	-25.3	-25.2	-25.2	-25.0
Stand + Transfer	-9.6	-7.6	-4.8	-2.0	0.3
Stand + Assembly	-5.2	-3.8	-2.5	-0.6	1.8

C8: Left Shoulder Internal/External Rotation

A positive moment represents external rotation, while a negative moment represents internal rotation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-14.4	-14.3	-14.3	-14.2	-14.1
Sit + Pull	-0.7	-0.7	-0.5	-0.3	-0.1
Sit + Transfer	-4.9	-3.0	-2.0	-1.0	0.2
Sit + Assembly	-8.5	-7.5	-6.1	-5.2	-4.4
Stand + Push	-19.7	-19.6	-19.6	-19.5	-19.4
Stand + Pull	6.4	6.7	6.8	7.0	7.2
Stand + Transfer	-3.8	-1.4	0.1	1.4	3.9
Stand + Assembly	-8.9	-7.9	-6.6	-5.8	-5.2

C9: Left Shoulder Forward Flexion/Extension

A positive moment represents forward flexion, while a negative moment represents extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-16.6	-16.5	-16.5	-16.4	-16.3
Sit + Pull	-2.7	-2.6	-2.5	-2.4	-2.2
Sit + Transfer	-6.8	-5.3	-4.0	-1.8	2.9
Sit + Assembly	-12.8	-12.4	-12.0	-11.7	-11.1
Stand + Push	-15.3	-14.9	-14.8	-14.7	-14.6
Stand + Pull	1.6	1.8	1.9	2.1	2.3
Stand + Transfer	-7.5	-5.0	-2.8	-0.1	5.6
Stand + Assembly	-11.6	-11.2	-10.9	-10.6	-10.0

C10: Right Wrist Radial/Ulnar Deviation

A positive moment represents ulnar deviation, while a negative moment represents radial deviation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-0.1	-0.1	-0.1	-0.1	-0.1
Sit + Pull	-0.1	-0.1	-0.1	-0.1	-0.1
Sit + Transfer	-0.2	-0.1	0.0	0.1	0.3
Sit + Assembly	0.0	0.0	0.0	0.0	0.1
Stand + Push	0.0	0.0	0.0	0.0	0.0
Stand + Pull	-0.1	-0.1	-0.1	-0.1	-0.1
Stand + Transfer	-0.1	-0.1	0.0	0.0	0.1
Stand + Assembly	0.0	0.0	0.0	0.0	0.1

C11: Right Wrist Pronation/Supination

A positive moment represents pronation, while a negative moment represents supination.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-0.1	-0.1	0.0	0.0	0.0
Sit + Pull	0.0	0.0	0.0	0.0	0.0
Sit + Transfer	-0.1	-0.1	0.0	0.0	0.1
Sit + Assembly	-0.1	-0.1	0.0	0.0	0.0
Stand + Push	0.3	0.3	0.3	0.3	0.3
Stand + Pull	0.0	0.0	0.1	0.1	0.1
Stand + Transfer	-0.1	-0.1	0.0	0.0	0.1
Stand + Assembly	-0.1	0.0	0.0	0.0	0.0

C12: Right Wrist Flexion/Extension

A positive moment represents wrist flexion, while a negative moment represents wrist extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-0.3	-0.3	-0.3	-0.2	-0.2
Sit + Pull	-0.2	-0.1	-0.1	-0.1	-0.1
Sit + Transfer	-0.2	0.0	0.0	0.1	0.2
Sit + Assembly	0.0	0.0	0.0	0.0	0.0
Stand + Push	-0.2	-0.2	-0.2	-0.2	-0.2
Stand + Pull	-0.2	-0.2	-0.2	-0.2	-0.2
Stand + Transfer	0.0	0.0	0.0	0.1	0.1
Stand + Assembly	0.0	0.0	0.0	0.0	0.0

C13: Right Elbow Varus/Valgus

A positive moment represents varus, while a negative moment represents valgus.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	4.3	4.7	4.9	5.3	5.9
Sit + Pull	-3.1	-2.1	-1.8	-1.6	-1.4
Sit + Transfer	-1.3	-1.0	0.5	1.7	2.0
Sit + Assembly	1.6	1.9	2.0	2.1	2.2
Stand + Push	2.9	2.9	3.3	3.5	3.7
Stand + Pull	-0.7	-0.7	-0.7	-0.3	-0.2
Stand + Transfer	-1.4	-1.1	0.4	1.5	1.9
Stand + Assembly	1.6	2.0	2.2	2.3	2.4

C14: Right Elbow Internal/External Axial Rotation

A positive moment represents internal axial rotation, while a negative moment represents external axial rotation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-9.0	-8.9	-8.8	-8.7	-8.6
Sit + Pull	9.2	9.3	9.4	9.4	9.5
Sit + Transfer	-1.7	-0.8	0.1	0.5	0.9
Sit + Assembly	-1.1	-0.6	0.1	0.6	0.8
Stand + Push	-10.3	-10.2	-10.1	-10.0	-9.9
Stand + Pull	9.9	9.9	9.9	10.1	10.1
Stand + Transfer	-1.4	-0.7	0.0	0.5	0.8
Stand + Assembly	-1.1	-0.7	-0.1	0.3	0.4

C15: Right Elbow Flexion/Extension

A positive moment represents elbow flexion, while a negative moment represents elbow extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-1.5	-1.4	-1.4	-1.3	-1.2
Sit + Pull	-2.3	-2.2	-2.1	-2.1	-2.0
Sit + Transfer	-1.3	-0.6	-0.2	0.2	0.6
Sit + Assembly	-0.4	-0.1	0.2	0.6	1.1
Stand + Push	-1.1	-1.0	-1.0	-0.9	-0.8
Stand + Pull	-3.0	-3.0	-3.0	-2.7	-2.7
Stand + Transfer	-1.7	-0.9	-0.5	0.3	0.7
Stand + Assembly	-0.8	-0.4	-0.1	0.4	0.9

C16: Right Shoulder Abduction/Adduction

A positive moment represents shoulder abduction, while a negative moment represents shoulder adduction.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-8.1	-8.0	-7.9	-7.7	-7.5
Sit + Pull	7.3	7.8	8.0	8.1	8.2
Sit + Transfer	-1.2	0.3	0.8	1.2	2.2
Sit + Assembly	0.0	0.4	0.8	1.1	1.5
Stand + Push	-8.0	-7.9	-7.8	-7.7	-7.6
Stand + Pull	8.3	8.3	8.3	8.6	8.7
Stand + Transfer	-1.1	0.1	0.5	0.9	1.9
Stand + Assembly	-0.4	0.0	0.2	0.5	0.8

C17: Right Shoulder Internal/External Rotation

A positive moment represents internal rotation, while a negative moment represents external rotation.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-7.3	-7.3	-7.0	-6.9	-6.7
Sit + Pull	4.0	4.1	4.2	4.4	4.9
Sit + Transfer	-4.0	-2.5	-1.7	-0.7	-0.1
Sit + Assembly	-3.8	-3.3	-2.9	-2.5	-2.0
Stand + Push	-4.6	-4.6	-4.4	-4.3	-4.2
Stand + Pull	3.0	3.1	3.3	3.3	3.3
Stand + Transfer	-3.7	-2.2	-1.3	-0.3	0.2
Stand + Assembly	-3.1	-2.7	-2.4	-2.0	-1.6

C18: Right Shoulder Forward Flexion/Extension

A positive moment represents forward flexion, while a negative moment represents extension.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-7.6	-7.6	-7.3	-7.1	-6.7
Sit + Pull	6.9	7.3	7.5	7.6	7.7
Sit + Transfer	-1.9	-1.4	0.2	1.9	5.0
Sit + Assembly	0.1	0.5	1.2	2.3	3.6
Stand + Push	-8.5	-8.4	-8.1	-8.1	-7.9
Stand + Pull	9.6	9.6	9.7	9.9	9.9
Stand + Transfer	-1.8	-1.2	0.1	1.3	3.9
Stand + Assembly	0.2	0.6	1.1	2.0	2.9

C19: Torso Lateral Bend

A positive moment represents a lateral bend to the right, while a negative moment represents a lateral bend to the left.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	7.1	7.4	7.7	8.0	8.5
Sit + Pull	8.8	9.1	9.3	9.8	10.2
Sit + Transfer	3.5	7.5	11.5	18.9	39.8
Sit + Assembly	8.4	10.3	11.9	13.9	17.3
Stand + Push	-5.8	-5.3	-5.1	-4.8	-3.6
Stand + Pull	4.7	5.8	5.9	6.1	6.3
Stand + Transfer	-5.8	-2.0	1.8	7.4	28.3
Stand + Assembly	-6.9	-4.5	-2.8	-0.3	2.9

C20: Torso Axial Twist

A positive moment represents axial twist to the left, while a negative moment represents axial twist to the right.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-6.6	-6.6	-6.5	-6.5	-6.5
Sit + Pull	-5.9	-5.8	-5.8	-5.8	-5.7
Sit + Transfer	-7.5	-6.5	-5.9	-5.5	-4.8
Sit + Assembly	-6.9	-6.6	-6.3	-6.1	-5.7
Stand + Push	-5.7	-5.6	-5.5	-5.5	-5.5
Stand + Pull	-4.3	-4.0	-3.9	-3.9	-4.0
Stand + Transfer	-6.9	-6.1	-5.7	-5.4	-4.6
Stand + Assembly	-6.4	-6.0	-5.8	-5.3	-4.8

C21: Torso Flexion/Extension

A positive moment represents torso extension, while a negative moment represents torso flexion.

	APDF Level				
Configuration + Task	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
Sit + Push	-2.0	-1.7	-1.3	-1.0	-0.5
Sit + Pull	1.7	2.2	2.6	3.0	3.3
Sit + Transfer	-13.8	-4.8	0.9	7.6	23.9
Sit + Assembly	-14.0	-5.5	-0.6	5.0	9.7
Stand + Push	3.0	4.7	5.0	5.4	6.5
Stand + Pull	8.8	8.8	9.0	9.2	13.6
Stand + Transfer	7.9	18.0	23.1	29.0	41.7
Stand + Assembly	5.1	13.7	21.2	24.6	29.1