A BIOMECHANICAL ANALYSIS OF A SPECIALIZED LOAD CARRIAGE TECHNIQUE AND THE DEVELOPMENT OF AN ASSISTIVE LOAD CARRIAGE DEVICE

by

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A thesis submitted to the School of Kinesiology and Health Studies

in conformity with the requirements for the degree

Master of Science

Queen's University

Kingston, Ontario, Canada

September, 2008

Abstract

During a field observation of professional movers, it was noticed that some experienced movers carried loads by placing them posterior to their pelvis and holding them against their back. There is ample load carriage research in biomechanics and ergonomics regarding backpack usage in both civilian and military populations. However, there is a void of literature that investigates hand-held load carriage. The purpose of this study was two-fold: (1) to assess the biomechanical differences between hand-held load carriage anterior and posterior to the pelvis; and, (2) to determine if an assistive load carriage device could reduce muscle effort while carrying loads either anterior or posterior to the pelvis.

To compare the biomechanical differences between anterior load carriage (AC) and posterior load carriage (PC) postures, an electromyographic (EMG) analysis was conducted on each carrying posture while participants carried a load on a treadmill. A specialized box, loaded with 20% of the subject's body weight, was carried by ten male volunteer subjects who had no previous back injury or moving experience. Isometric maximum voluntary exertions (iMVE) were measured for each muscle tested. The subjects then conducted three trials of AC and PC techniques, while EMG data were being collected. All trial data were normalized to their respective iMVE values. An amplitude probability distribution function (APDF) was used to compare EMG amplitudes at the 10^{th}, 50^{th}, and 90^{th} percentiles.

Results indicated that PC significantly reduced EMG activity of the erector spinae (>50% reduction), trapezius, and anterior deltoid ($p<0.05$) as well as increasing EMG

activity in the posterior deltoid ($p<0.05$). Such large reductions in the erector spinae muscle activity may lead to substantial reductions in spinal compression forces. Although there were significant reductions in erector spinae activity, 80% of the subjects reported that the PC method felt awkward and cumbersome. Due to its awkwardness, many individuals may not use the PC technique, even though it may be beneficial to back health. Based on this subjective response, the second purpose of this thesis was to design an assistive movers' pack that would not only aid in AC and PC techniques, but also make the PC method easier to perform.

The second study in this thesis involved 10 male subjects with no previous back injury and no prior moving experience. Subjects were asked to walk unloaded while EMG was recorded. The subjects then performed the AC and PC methods with and without the assistive device. All EMG signals were normalized to unloaded gait followed by EMG APDF analyses of the testing conditions.

Results confirmed the findings from the first study, in that PC significantly reduced erector spinae activity ($p<0.05$) and moved the shoulder load from the trapezius and anterior deltoid and focused it on the posterior deltoid. The assistive device effectively reduced flexor digitorum activity (>40% reduction, $p<0.03$) and anterior deltoid activity (>75% reduction, $p=0.5$) in both AC and PC. Only small increases in external oblique activity occurred with device use in AC. Erector spinae EMG remained similar to the respective unassisted condition. These results provide evidence that the assistive load carriage device used in this study can be an effective ergonomic tool to alleviate grip effort and shoulder activity in both AC and PC conditions. Additionally,

subjective surveys indicate that the assistive device decreased the awkwardness and difficulty in performing the PC technique among less experienced movers.

Authorship

Ian A. Kudryk was solely responsible for the processing and statistical analysis of all survey, electromyogram, accelerometer, and anthropometric data and is the sole author of all findings and manuscripts within the thesis document.

Acknowledgements

I would first like to thank my supervisor, Dr. Joan Stevenson, for taking me under her wing during these past years. Her biomechanical and ergonomic wisdom provided me with more experience than I could have ever hoped of achieving in a masters level program. Through holiday dinners, lectures and unexpected phone calls, Joan feeds her students' bellies with nourishment, minds with knowledge, and hearts with nurturing guidance. I hope to never lose the lessons she has taught me inside and outside the classroom.

I would like to thank my parents, Bill and Kathy, who from my early days in grade school have instilled in me the value of education. From teaching me to read as a little boy, to listening to me banter on about EMG normalization as an adult, they have been the cornerstone of my education.

To my friends, both inside and outside the department: I could not have made it through these times if it were not for your ridiculous humour and your ability to listen. You have regarded me solely for *who* I am and not by what I have accomplished (thank goodness).

To my girlfriend, Katie Chan: you came with me to Kingston to share our dreams. You have made this small town a home. You have tirelessly supported me everyday. This accomplishment may not have been possible without your strong character and love. You are small but mighty. You are steadfast. You are my rock. I cannot thank you enough.

To my dog, Ted: you cannot read this; however, your furry hugs and frequent face lickings melted the stress when I needed it most. Woof.

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Definition of Terms and Abbreviations

Testing Conditions

Posterior Load Carriage (PC) - unassisted posterior load carriage. Load is held posterior to the pelvis.

Anterior Load Carriage (AC) - unassisted anterior load carriage. Load is held anterior to the pelvis.

Posterior Load Carriage with Device (PCD) - assisted load carriage. Device is used to hold load posterior to the pelvis.

Anterior Load Carriage with Device (ACD) - assisted load carriage. Device is used to hold load anterior to the pelvis.

Muscle Groups

Trapezius (TR); **Anterior Deltoid** (AD); **Posterior Deltoid** (PD); **Thoracic Erector Spinae** (TES); **Lumbar Erector Spinae** (LES); **Rectus Abdominus** (RA); **External Oblique** (EO); **Flexor Digitorum** (FD).

Measurements and Abbreviations

Electromyography (EMG) - refers to the electrical signal measured from a muscle of interest.

Maximum Voluntary Contraction (MVC) - maximal force produced by a muscle during an isometric contraction.

Maximal Voluntary Exertion (MVE) - refers to the maximal electromyographic amplitude achieved during isometric contraction.

Amplitude Probability Distribution Function (APDF) - a cumulative probability curve laying out the frequency/probability of encountering a particular EMG amplitude during a task.

Manual Material Handling (MMH) - refers to the act of transferring or transporting a material load with human force.

Chapter 1

Introduction

During an ergonomic observation of professional movers, it was noted that some experienced professional movers placed the moving boxes posterior to their pelvis and held the load against their backs with extended arms. Questioning the individuals revealed that they believed that this moving posture felt "easier" on their backs. There have been numerous biomechanical and ergonomic studies regarding MMH in fields such as warehousing (Waters et al., 1998), retail markets (Lehman et al., 2001), and construction (Holmstrom and Ahlborg, 2005) that involve job tasks such as lifting, lowering, twisting, and carrying. Occupational epidemiology studies have indicated that occupations involving load carriage do, in fact, increase the incidence of reported back pain and injury (Kelsey et al., 1984; Pietri et al., 1992; Kuiper et al., 1999). However, when reviewing current scientific literature, it becomes evident that the professional moving industry has not received specific biomechanical investigation. Furthermore, there is a lack of biomechanical research investigating hand-held load carriage in the anterior and posterior load placements.

Many load carriage studies have been conducted on backpack or rucksack usage. Biomechanical studies directly comparing anterior-placed load carriage and posterior-placed load carriage found that anterior-placed loads produced kinematics more similar to 'unloaded' gait (Fiolkowski et al., 2006). However, they found that anterior-placed loads elicited over twice the erector spinae EMG amplitude in comparison to the posterior-

placed loads (Cook and Neumann, 1987; Motmans et al., 2006). It is believed that the increased erector spinae EMG activity may indicate increased magnitudes of detrimental muscular spinal compression forces (McGill and Norman, 1987; Potvin et al., 1996; Marras et al., 1999). Thus it would be beneficial to reduce muscular compression forces during load carriage by placing loads posterior to the pelvis. However, the conclusions drawn from the load carriage studies were based on the use of some form of a pack system to secure the load during posterior load carriage. In professional moving, no assistive pack system is used during posterior load carriage, and thus the conclusions drawn from the previous load carriage studies may not apply to this specific load carriage task.

Based upon a lack of specific scientific literature, the investigators sought to investigate biomechanically this specialized moving technique and confirm the anecdotal comments of experienced movers who claimed the technique was easier on their backs. Furthermore, the investigators proposed that, if the specialized technique did reduce back muscle activity, it would be feasible to design a device to assist the movers in performing this carrying technique. If the device could further reduce muscular effort required to perform the PC technique, it may encourage movers to use the technique more frequently.

Order of Sub-Studies

The chronological progression of the study involved four main sub-studies. The first stage of investigation involved surveying professional movers using formal written questionnaires (n=30) and needs-assessment discussions (n=42). The written

questionnaires were used to determine regions of musculoskeletal pain or fatigue and the tasks believed to cause the conditions. The needs-assessment discussions were used to determine the environmental constraints and internal constraints that the movers encountered while performing their job. The results from the written questionnaire were used to determine the type and extent of musculoskeletal disorders and what main factors contributed to these injury rates. The results of the questionnaires and needs-assessments indicated that load carriage in professional moving applications warranted further ergonomic study.

The second stage involved an in-laboratory electromyography (EMG) study. This was conducted to test the musculoskeletal effects of using a posterior-placed load carriage technique (PC), in comparison to the traditional anterior-placed load carriage technique (AC). It was hypothesized that the PC method will reduce muscular effort of the back below that of the AC method. These results will be used to indicate whether or not the PC method significantly reduced erector spinae muscle activity compared to AC.

The third stage involved the investigators conducting multiple onsite observations of the professional movers during work. During these periods, digital photos and load measurements were made to determine common carrying postures used and loads encountered while workers conducted residential moves. These results, in combination with the questionnaires and needs-assessments, were used in the design phase of the assistive device. Three prototype design iterations were conducted, and each one was tested in the field by professional movers. Information gained from the movers was used in the next design iteration, which was used for the second in-laboratory EMG study. However, the results of this stage are not presented as part of the thesis.

The fourth and final stage of investigation involved testing the effect of the device on muscle activity in both PC and AC methods. It was also hypothesized that the assistive device will reduce muscular effort of the shoulders, trunk, wrist, and finger flexors during both AC and PC methods. The results from this study will be used to determine whether or not the assistive device created any beneficial reductions in muscle activity.

The implications of this study will validate or invalidate the claims made by professional movers regarding the musculoskeletal benefits of the PC method. If the PC technique does produce biomechanical advantages over the AC method, workers should be encouraged to use the technique within the professional moving industry. Finally, the use of an assistive device may encourage the use of the specialized PC technique among novice movers.

Chapter 2

Literature Review

2.0 Manual Material Handling

Despite advances in process technology, manual material handling (MMH) remains an integral task within various industries. Factors such as the nature of the work, spatial limitations, and the financial costs of implementing automation make MMH an often-necessary component of modern work (Mital et al., 1997). For over half a century, MMH has been a focus of various scientific disciplines due to the pathological effects it can have the human body (Ayoub and Mital, 1989; Dempsey, 1998).

The prevalence of musculoskeletal injuries due to MMH within industry is substantial and presents a large economic burden in most industrialized nations (Punnett et al., 2005). In a sample of 883,015 workers' compensation claims, Lehman and Murphy (1994) found that 37% of all compensation claims were due to MMH. Furthermore, these claims accounted for 40% of all compensation costs. Similar findings were found in an American sample by Murphy et al. (1996) in which MMH accounted for 32% of all claims and 36% of all compensation costs thus making it the largest source of compensatory costs. A longitudinal study by Dempsey and Hashemi (1999) also found that 36% of all injury claims to an American compensation board were due to MMH and accounted for direct cost of $750 million dollars. Therefore, MMH is a

significant and expensive cause of compensable musculoskeletal injury and thus an apt topic for biomechanical inquiry.

2.1 The Prevalence of Low Back Pain due to MMH

A prevalent musculoskeletal injury symptom due to MMH is low back pain (LBP). Numerous biomechanical and epidemiological studies have reported LBP to be highly correlated with MMH (Chaffin, 1987; Kumar and Mital, 1992; Waters et al., 1993; Dempsey and Hashemi, 1999; Kuiper et al., 1999). The direct cost of occupational LBP within the American population totaled $11.4 billion dollars in 1989 (Webster and Snook, 1994), with these costs rising to $26.3 billion dollars by 1998 when total health care expenses for back pain reached $90.7 billion dollars (Luo et al., 2004). Dempsey and Hashemi (1999) reported that 29.5% of all reported MMH claims were due to LBP, producing 41.6% of MMH claims costs. These findings quantified low back injury (LBI) as the most common form of MMH musculoskeletal injury in America (Dempsey and Hashemi et al., 1999). A similar result was found in a statistical report of "Lost time claims by body part affected" in Ontario from the Workers' Safety and Insurance Board (WSIB, 2005). From the years 1996 - 2005, back injury comprised 29.2% - 30.9% of all lost-time claims (WSIB, 2005). Epidemiological findings, such as these, highlight the importance of reducing the prevalence of LBP within the working population.

2.2 MMH Work Factors Leading to LBP

It has been found that 85% of back pain diagnoses are termed 'idiopathic', as no underlying anatomical deformations can be identified (Deyo et al., 1992). However, the common diagnosis of idiopathic LBP has made it difficult to link a specific job factor to a specific anatomical or biomechanical failure (Abraham and Killackey-Jones, 2003). In spite of vague diagnoses, various physical job characteristics have been found to increase the incidence of LBP symptoms. In a review of previous studies, Marras et al. (1995) listed the five main biomechanical factors that they believed lead to LBP symptoms: (1) high force, (2) static loaded posture, (3) dynamic bending and twisting, (4) specific MMH activities (lifting, carrying, pushing, and pulling), and (5) high repetition. Other MMH studies have also found these factors to be significant predictors of LBP (Bernard, 1997; Hoogendoorn et al., 1999).

The five common MMH activities that are related to LBP do not directly cause pain symptoms or low back injury. Rather, it is the biomechanical spinal forces caused by these MMH actions that impart tissue damage to the spine and its surrounding tissue and thus cause symptoms of LBP (Marras, 2005). This biomechanical explanation of LBP is referred to as the tissue load-tolerance relationship (McGill, 1997). Injury will not occur when an applied load stays below a specific tissue load-tolerance threshold; however, once the applied load exceeds the tissue load-tolerance threshold, tissue injury is likely to occur (McGill, 1997). Spinal loads are usually expressed in terms of compressive and shear forces: compressive forces conduct axially along the length of the spine (Herrin et al., 1986), while shear forces act in anterior/posterior/lateral directions through the spine (Potvin et al., 1991b). Compressive force has been shown to be a

significant indicator of LBP in industrial field studies (Herrin et al., 1986; Norman et al., 1998). However, *in vitro* analysis of vertebral specimens has shown that pure compression shows little risk of generating clinically relevant vertebral disc injury (Brinkman, 1986; Adams et al., 1987). Shear force has been shown to be a significant indicator of LBP in industrial field studies (Kumar, 1990; Norman et al., 1998; Kerr et al. 2001). However, Sherazi-Adl (1989) found that compression in combination with shear forces through spine bending produced a greater risk of vertebral disc injury than compression alone. Therefore, vertebral forces created by bending of the trunk, place the vertebrae at a greater chance of encountering injury.

Compressive and shear forces and the body movements that create them can be measured in terms of peak and cumulative magnitudes in order to infer the possibility of musculoskeletal injury. Peak magnitudes may indicate increased probability for an acute injury, and cumulative magnitudes may indicate increased probability for a repetitive strain injury (Pope et al., 1991). Peak and cumulative tissue-loading mechanisms differ in their modality for injury causation; however, they both employ the same biomechanical theory of the 'tissue load-tolerance relationship' (Marras, 2000). Therefore, due to the similar biomechanical theory underlying both peak and cumulative based injuries, scientific debate has occurred over whether peak or cumulative loading is the primary predictor of occupational LBP.

2.3 Peak Kinetic and Kinematic Magnitudes Related to LBP

Many studies have identified peak spinal compressive and shear force as significant independent predictors of LBP (Snook, 1978; Bringham and Garg, 1983;

Herrin et al., 1986; Waters et al., 1993; Norman et al., 1998; Granata and Marras, 1999; Kerr et al., 2001). The basic biomechanical explanation for an injury related to peak magnitude is described as the point at which a brief applied force (slope >0) exceeds the load-tolerance value of the tissue (linear, slope = 0) resulting in tissue failure (McGill, 1997; Marras, 2000). In a field study of over 400 industrial jobs, Marras et al. (1995) used a unique Lumbar Motion Monitor to identify five main work characteristics that independently increased the odds ratio (OR) for incidence of LBP. Two of these motion characteristics were peak trunk moment (OR=4.04) and peak trunk velocity about all three axes (OR=1.36). Marras et al., (1995) proposed that quantifying these measures provided the most effective discriminators of occupational LBP. Marras et al., (1995) further demonstrated that peak forces, moments and velocities were implicated in tasks involving cumulative loading that also increased the incidence of LBP. An effective LBP prevention strategy would, therefore, aim to minimize peak spinal compression and shear forces and well as minimize trunk velocities on all three axes. However, additional scientific evidence exists that indicates that peak magnitudes are not exclusive injurious factors for the human spine.

2.4 Cumulative Kinetic and Kinematic Factors Leading to LBP

Cumulative loading has also been identified as a potential biomechanical risk factor for LBP (Adams and Hutton, 1985; Hansson et al., 1987; Kumar, 1990; Lotz and Chin, 2000). The biomechanical explanation of cumulative loading injuries is described best when plotted on a stress-strain curve with respect to a time domain. When a repetitive, submaximal, applied static or dynamic force is applied to the tissue (linear

slope = 0), it reduces the tissue's load-tolerance curve (slope < 0) over time. Eventually, a point in time is reached when the tissue load-tolerance curve intersects the applied force level, resulting in tissue injury (Marras, 2000). It is believed that this mechanism may be responsible for the physical deformations found in those with LBP (Kelsey et al., 1984; Adams and Hutton, 1985). In a large industrial field study, Norman et al. (1998) identified that cumulative loading work factors were significant and independent predictors of LBP. While peak magnitudes were also found to be significant LBP predictors, the use of an orthogonal loading matrix proved that cumulative loading correlations were not dependent on the magnitude of the peak values. Norman et al. (1998) concluded that cumulative loading was not simply an expression of peak loading distributed over time, but rather its own significant predictive factor. This finding was contrary to the hypothesis put forward by Marras et al. (1995).

Though both proposed methods of tissue injury are theoretically sound, it is unlikely that peak or cumulative loading are exclusive and independent sources of tissue injury. In occupational settings, both cumulative and peak forces are experienced and may combine their effect to cause injury to tissue (Norman et al., 1998). Therefore, for an effective analysis of occupational muscle loading, both peak and cumulative forces should be considered equally.

2.5 The Internal Muscle Component of Compressive and Shear Forces

During MMH tasks, muscular effort is required to manipulate the materials. With regards to the trunk, this required muscular effort accounts for the majority of the

compressive force applied to the intervertebral discs during MMH (Potvin et al., 1991a; Dolan and Adams, 1993; Hughes et al., 1994). The primary motive muscles in the trunk for performing MMH are the erector spinae muscles which contain the iliocostalis, longissimus and spinalis (McGill and Norman, 1986). The moment generated by these muscles is typically estimated as the moment required to counteract the moment generated by the external load being held and the mass of the upper body (McGill and Norman, 1986). These muscles often act through a disadvantageous moment arm in comparison to the external load and thus generate high reactive compression forces on the spine (Dolan and Adams, 1993). Also, the erector spinae muscles have been found to offset the anterior shear forces of the lumbar vertebrae, thus providing a protective benefit against spine pathologies related to shear forces (Potvin et al., 1991b; McGill et al., 2000). However, due to the line of insertion of the erector spinae muscles, a large compressive force component is generated during this offset of shear forces (McGill et al., 2000).

More recent research has determined the important role of co-contraction of the trunk musculature in the stabilization of the spine. Specifically, the simultaneous activation of the obliques, rectus abdominus and erector spinae leads to increases in the stability of the spine (Cholewicki et al., 1997; Gardner-Morse and Stokes, 1998; Dolan and Adams, 2001). However, there is concern about the mechanism of increasing spinal stability as it may lead to an increase in spinal compression (Dolan et al., 2001). In an analysis of their back model, Granata and Marras (2000) stated that a 34% - 64% increase in stability due to co-contraction of the trunk musculature led to a concomitant 12% to 18% increase in spinal compression. Therefore, MMH tasks that require increased

stability may further increase the compressive forces acting on the intervertebral discs, adding to pre-existing compression necessary to counteract the upper body and external load moment.

In summary, the trunk musculature responds to changes in the magnitude of external and upper body moment and system stability. Thus, trunk muscle activity provides an indication of the internal spinal moment as well as spinal stability and the resultant forces they impart on the spine. Therefore, studying trunk musculature EMG may provide a relative indication of the amount of spinal compressive forces being generated when performing various MMH tasks (Hughes et al., 1994).

2.6 Use of Electromyography for Studying MMH

Since muscular effort is the primary component in generating intervertebral disc compression, the electromyogram (EMG) can be a useful indicator of relative disc compression between tasks. It is known that increasing EMG amplitude is correlated to increasing muscular force (Liu et al., 1999; Alkner et al., 2000) because of: (1) greater firing rates for active motor units, (2) more and larger motor units are recruited, (3) increased chance of motor unit summation, and (4) higher probabilities of activating motor units close to the electrodes (Sanders et al., 1996). Such correlations have also been made for the erector spinae and surrounding trunk musculature (Dolan and Adams, 1993). Based on this EMG-force correlation for trunk musculature, estimates of lumbar disc compression have been developed using EMG-based spine models (McGill and Norman, 1987; Potvin et al., 1996; Marras et al., 1999). However, as with many spine models, limitations exist when using EMG to estimate spine compression forces. For

example, the muscle force-length relationship modifies the amount of force that can be generated per amplitude unit of EMG. As a muscle moves above or below its optimal length, force production begins to decrease per unit of EMG amplitude (DeLuca, 1997). Therefore, when studying MMH tasks that involve segments moving through a range of motion, the muscle length changes, and thus its correlation between EMG amplitude and force will also change. Another kinematic factor affecting the force-EMG relationship is the muscular force-velocity relationship (Marras and Mirka, 1990). Dolan and Adams (1993) observed that, when they controlled for the force-length relationship, the more rapidly the trunk extended, the greater was the relative EMG amplitude. This is relevant to the study of MMH tasks because the majority of MMH involves changing velocities in the sagittal trunk angle. Therefore, when comparing EMG amplitude between various MMH tasks, the trunk velocity must be considered or controlled before drawing any conclusions based on EMG amplitudes.

Despite these various EMG-force limitations, there have been significant correlations between surface EMG, muscle force, and compressive spinal forces. In an EMG-compression model developed by Potvin et al. (1996), the researchers found that EMG estimates of spinal compression consistently underestimated the compression values by 9.1% and 25.7% in eccentric and concentric contractions, respectively. However, not all studies have used the same methodology or reported the same levels of EMG underestimation. Dolan et al. (1999) found that their EMG-based spine compression model produced similar spinal compression estimates to those of dynamic linked-segment model during slow trunk movements, and that it underestimated faster dynamic movements by only 4%. Thus, in absolute terms, EMG-based models tend to

underestimate spinal compression force because factors such as segment velocity and acceleration are difficult to account for in the model. However, in relative terms, when comparing two similar tasks, variables such as segment velocity and acceleration are often experimentally controlled and thus EMG may offer an effective task comparison. Therefore, when conducting direct comparisons between various MMH tasks, EMG-based analysis may provide an effective comparison of spinal compression based upon the tasks possessing similar kinematic parameters.

The EMG-based amplitude probability distribution function (APDF) method is used to collect EMG amplitude samples during a selected time period and then re-order the amplitudes into a histogram (Jonsson, 1982). The histogram identifies how frequently each specific EMG amplitude is encountered during the sample period. These data are then plotted as a cumulative probability curve (Jonsson, 1982). The EMG amplitude existing at the 10^{th} percentile of the cumulative probability curve is known as the static EMG value; the EMG amplitude at the 50^{th} percentile is known as the median (dynamic) EMG value; and, the EMG amplitude at the 90^{th} percentile of the curve is known at the peak EMG value (Jonsson, 1982). It is believed that each EMG percentile range indicates a specific type of loading that is occurring in a muscle. Static EMG values (at the 10^{th} percentile) are believed to indicate the constant muscle effort that is linked to the posture used during a task (Hagg, 1991; Sommerich et al., 1998). Static levels of muscle EMG have been used as effective indicators of work-related myalgia (Aaras, 1994), with higher static APDF values suggest that muscle is not truly resting and recovering between duty cycles (Veiersted et al., 1993). Median EMG values typically indicate the average function of the muscle in terms of its dynamic motion (Ankrum,

2000). Peak values of EMG (90th percentile) indicate the higher, yet less frequent forces encountered by the muscle (Jonsson, 1982). Since Potvin et al. (1996) have shown that increased EMG amplitude is related to increased spinal compression, peak EMG APDF values can thus be considered indicative of peak spinal loading. Therefore, EMG APDF analysis allows a more effective utilization of EMG data to determine both static load-related and peak load-related pathologies during MMH tasks.

As previously stated in this section, EMG-based methods for providing spinal compression estimates cannot provide accurate absolute force estimates. However, EMG-based methods can perform as relative indicators of spinal loading between two or more testing conditions within the same subject during the same data collection session. Using EMG in this manner can control inter-subject variability and unique motor behaviours (Mirka, 1991). Therefore, surface EMG APDF analysis may provide effective insight as to the internal forces experienced by a subject between relative MMH testing conditions.

2.7 Load Carriage as a MMH task

Many biomechanical studies of MMH specifically investigate lifting tasks (Kumar, 1990; Norman et al., 1998; Kerr et al. 2001). However, not as much consideration has been given to MMH that involves load carriage. Although many studies have investigated the effects of load carrying through the use of "packs" on the musculoskeletal system (Harman et al., 1992; Lloyd and Cooke, 2000), little literature exists where researchers have investigated load carrying without the use of a pack, but rather just in the hands. Kuiper et al. (1999) conducted an epidemiological review of

studies that indicated load carriage was related to reporting of LBP. In a patient-control study, Kelsey et al. (1984), reported that carrying loads over 11.3kg more than 25 times per day resulted in an increased odds ratio of 2.7 for developing an intervertebral disc prolapse when compared to controls who did not carry loads at all. In a cross-sectional study Pietri et al. (1992), found a smaller odds ratio of 1.3 for developing LBP when the variables compared were simply 'carrying' or 'no carrying'. However, Kelsey et al. (1984) showed that clearly defined exposure to substantial loads while carrying can result in greater incidence of low back injury. Therefore, further biomechanical inquiry into this field of MMH may be beneficial in terms of finding ways to reduce musculoskeletal disorders related to load carriage.

2.8 Load Carriage Techniques and their Musculoskeletal Effects

With regards to load carriage, there are a multitude of studies that test pack or rucksack configurations to determine their physiological and biomechanical effects. However, after a recent search of literature, no articles were found that specifically investigated carrying loads in various positions without the use of packs or other assistive devices. In a MMH work environment, not all loads may be placed in a pack before they are carried, and thus only the hands are used to secure a load. Fortunately, knowledge gained in the biomechanical studies of various pack configurations is still applicable to hand-held load carriage. Conclusions drawn from pack studies allow researchers to infer theories about load placement with respect to the body's centre of gravity for non-pack conditions. Therefore, a review of pertinent studies has been conducted to understand the

biomechanical and physiological effects of anterior and posterior load placement during load carriage.

With regards to posterior load placement, Stuempfle et al. (2004) investigated the effects of placing loads at the thoracic or lumbar levels of the spine. The authors concluded that loads placed on the thoracic regions of the back induced less physiological fatigue. They recommended that heavier loads be packed higher in the pack and lighter loads be packed closer to the lumbar level. This study's finding was similar to that of Obusek et al. (1997) who concluded that the most efficient load placement in a backpack is the highest possible configuration that is closest to the centre of gravity. However, these studies do not discuss the effects of high load placement on the mechanics of the back. A study by Bobet and Norman (1984) revealed that as a load approaches the region of the cervical vertebrae, EMG activity of the erector spinae increases. If EMG amplitudes increase without a change in the weight or length of the moment arm, then an increase in EMG may be due to a change in spinal stability. Granata and Orishimo (2001) found that, while maintaining a constant moment arm about the spine, increasing the height of the external load led to increases in paraspinal muscle activity. The authors state that, as the external load elevates relative to the subject's centre of gravity, the spine becomes more unstable. As a result, the trunk musculature increases its levels of co-contraction to stabilize the spine (Granata and Orishimo, 2001). Similar findings occurred in the spine model by El-Rich and Shirazi-Adl (2005); however, they also found that kyphotic spine posture increased paraspinal muscle activity and thus could increase spinal stability when load height was increased (El-Rich and Shirazi-Adl, 2005). As stated earlier, increased co-contraction of the trunk musculature induces higher

compressive forces along the spine. Therefore, higher load placement may prove to be physiologically efficient, despite the mechanical consequence of increased spinal loading and spinal instability that may result in buckling (Granata and Orishimo, 2001; El-Rich and Shirazi-Adl, 2005).

There is substantial load carriage research that has compared the effects of anterior packs, posterior packs, and combined anterior/posterior packs. It has been found that anterior/posterior packs are the most physiologically efficient packs as they place equal loads in front of and behind the body (Lloyd and Cook, 2000). Furthermore, Motmans et al. (2006) found that these packs produced the least change in trunk muscle EMG levels compared to a neutral standing posture. This is because the external moments are balanced and require no generation of an internal muscle moment to maintain system equilibrium. However, the benefits of using an anterior/posterior pack system are offset by the discomfort and increased heat stress they develop in comparison to back packs (Knapik et al., 1997).

Many studies of load carriage have used kinematic variables to determine a pack's biomechanical effects. In a comparison of front packs and back packs, Fiolkowski et al. (2006) concluded that back packs produce greater hip flexion and neck flexion in comparison to unloaded gait. They proposed that the greater postural deviations observed in the back pack condition may be responsible for the increased incidence of LBP concomitant with their use. This conclusion was based on the observation that front packs produced gait kinematics similar to unloaded gait and thus reduced the anterior shear forces on the spine in comparison to the forward-leaning posture used with back packs (Fiolkowski et al., 2006). The authors concede that the kinematics may not

accurately describe the forces occurring in the spine and that myoelectric comparison of these conditions may elucidate the underlying effects of various pack usage.

An electromyographic comparison between anterior packs, posterior packs, and anterior/posterior packs was conducted by Motmans et al. (2006). Their results did not entirely concur with those of Fiolkowski et al. (2006). While they did notice that the front pack produced kinematics more similar to 'unloaded' gait, they found that the front pack elicited over twice the erector spinae EMG amplitude in comparison to the back pack (Motmans et al., 2006). Furthermore, they found that the back pack condition reduced erector spinae activity below the levels found in unloaded standing (Motmans et al., 2006). Similar results were found in a study by Cook and Neumann (1987) where erector spinae EMG amplitudes were half the amplitude of the anterior load carriage method. However, unlike the EMG study conducted by Motmans et al. (2006), the anterior loads were supported by hand and the posterior loads were supported with a rigid back pack frame and padded shoulder straps. Therefore, the testing conditions were not equally paired in terms of anterior and posterior load placement. Nonetheless, both the Cook and Neumann (1987) and the Motmans et al. (2006) studies support the argument that posterior-placed loads reduce erector spinae activity in comparison to anterior-placed loads. Furthermore, forward-leaning postural deviation made with the posterior load placement is rather adaptive in that it offsets the external posterior moment generated by the load. This reduces the need for an internal muscle moment to be generated about the low back in order to balance the system center of gravity. Thus, by reducing internal muscular moment and reducing the EMG amplitude of the erector spinae, posterior load

placement may reduce compressive forces of the lumbar vertebrae compared to anterior load placement.

2.10 Purpose of Thesis

When reviewing current scientific literature, it becomes evident that the professional moving industry has not received specific biomechanical investigation. There have been numerous biomechanical and ergonomic studies in other MMH fields, such as warehousing (Waters et al., 1998), retail markets (Lehman et al., 2001) and construction (Holmstrom and Ahlborg, 2005), that involve job tasks such as lifting, lowering, twisting and carrying. However, there is a surprising absence of studies involving professional movers, especially since their job demands and specialized load carriage techniques provide interesting opportunities for biomechanical analyses.

The motivation behind this study was the observation that some experienced professional movers place the moving boxes behind their pelvis and hold the load against their backs with extended arms. Upon questioning several individuals, they believe that this moving posture is "easier" on them. Although there are many studies investigating load carriage placement strategies, they focus on using pack systems. There is a complete lack of biomechanical research investigating hand-held load carriage in the anterior and posterior load placements

Because of this lack of research on industrial movers, three main purposes were developed for this study. The first study, Chapter 3, was designed to acquire background data on the musculoskeletal aches and pains of professional movers, identify which body parts encountered muscular fatigue, and relate these conditions to work-related factors.

The purpose of the second study, Chapter 4, was to test the biomechanical and musculoskeletal variations between hand-held anterior and posterior load carriage in order to determine if the posterior load placement method provided any biomechanical benefit. The purpose of the third study, Chapter 5, was to develop and test an assistive load carriage device for both the anterior and posterior load placement methods. It was hypothesized that posterior load carriage would require less muscular effort and that an assistive device would make load carriage easier in both the anterior and posterior load placements. The studies involving muscular effort, as measured by means of surface EMG amplitudes through APDF analyses, were used to infer biomechanical effects from the various amplitude percentile values in each muscle measured.

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Chapter 3

A Survey of Professional Movers to Aid in the Biomechanical Study of a Specialized Load Carriage Technique

3.1 Introduction

There have been numerous ergonomic and epidemiological studies regarding manual material handling (MMH) in fields such as warehousing (Waters et al., 1998), retail markets (Lehman et al., 2001), and construction (Holmstrom and Ahlborg, 2005) that involve job tasks such as lifting, lowering, twisting, and carrying. In epidemiology studies of occupations involving load carriage, researchers report an increase in the incidence of reported back pain and injury (Kelsey et al., 1984; Pietri et al., 1992; Kuiper et al., 1999). In a matched load carriers versus controls study, Kelsey et al. (1984), reported that carrying loads over 11.3kg more than 25 times per day resulted in an increased odds ratio of 2.7 for developing an intervertebral disc prolapse when compared to those who did not carry loads at all. In a cross-sectional study, Pietri et al. (1992) found a smaller odds ratio of 1.3 of developing LBP when the variables compared were simply 'carrying' or 'no carrying'. Regardless of the level of risk, biomechanical inquiry into this field of MMH is warranted if further research be used to reduce musculoskeletal disorders related to load carriage. However, when reviewing the scientific literature, it becomes evident that the professional moving industry has not received specific biomechanical investigation. Therefore, it is not known if professional movers incur the same level of risk for LBP as found in other studies of MMH.

A survey of professional movers was conducted as part of a larger study to investigate specialized load carriage techniques and specialized assistive devices. The intent of this study was to obtain background data about musculoskeletal pain, symptoms of fatigue and work-related factors that cause these problems. To attain such information, the investigator used formal written questionnaires (n=30) and needs-assessment discussions (n=42). The written questionnaires were designed to ask movers specific questions that would capture precise body regions of pain, fatigue, and the work factors that most commonly led to these symptoms. The needs-assessment was designed to identify impediments to proper ergonomic work strategies aimed to reducing musculoskeletal pain or fatigue. It was not intended to test correlations between variables but rather data were collected with the intent of developing descriptive information about the prevalence of symptoms within the sampled population. Such information would be helpful in focusing in-laboratory biomechanical analyses on body regions that are most effected by load carriage techniques or assistive devices.

3.2 Methods

Sample

The managers/owners of three large moving companies in Kingston, Ontario were asked if they wished to participate in the study by allowing their workforce to volunteer if interested. The inclusion criterion for participation was that each mover was officially a full-time employee of the moving company, even if full-time meant summer months

only. The exclusion criteria were: one-day assistants whose main occupation was not involved in the actually physical moving process; employees with diagnosed diseases (diabetes, congestive heart disease etc.), physical disability (cerebral palsy, amputations etc.), and idiopathic pain symptoms (fibromyalgia, recurrent migraines, etc.).

With management present, the researchers met with all interested employees to describe the study verbally and distribute an ethics consent forms to those who were interested in participation (Appendix D). Then, the investigator returned at a time that was suitable to the managers/owners to conduct one-on-one interviews and a host a focus group discussion with the volunteers.

Questionnaire Procedure

The questionnaire was administered over a two month period according to schedules developed by management. The location for interviews were in private, either the company's warehouse or onsite at breaks during residential moves. The investigator approached volunteers again to see if they were still interesting in participation and to remind them of the objectives of the questionnaire. For new volunteers, the complete ethics process was repeated and informed consent gathered before participation.

The questionnaire contained four main components: (1) personal information such as anthropometry, health status, and general perceptions of the job, (2) work information such as scheduling issues a nd use of tools and ergonomic aids, (3) a modified Standardized Nordic Questionnaire, (Korinka et al., 1987), and (4) a modified pain visual analog scale (VAS) (Downie et al, 1978; Huskisson, 1983; Echternach, 1987). The Standardized Nordic Questionnaire included the principle questions of: "Have you

ever had pain in your (specific joint)? The answers to these questions begin with 'yes" and "no" followed by questions relating to frequency of pain (i.e., last week, last year) (Appendix F). The modifications included questions asking the participant to identify: (1) if they knew what caused the pain, (2) whether the joint was tired at the end of the shift, (3) frequency of actions causing the pain, (4) frequency of awkward postures of the joint, (5) if they ever sought medical attention for the joint, and (6) whether the pain prevented them from working. Following the segment-by-segment questioning, the subject was asked to rank the severity/intensity of their reported regions of pain from greatest to least. The pain VAS was modified to be a diagram of the anterior and posterior aspects of the body where participants circled regions of pain and reported its intensity by means of a number from 1-10 with one being a small amount of pain and ten being unbearable pain (Appendix F). The pain VAS has been shown to have good validity and reliability when its psychometric properties were examined in a systematic review (Swinkels et al., 2005). Pooled coefficients ranged from 0.73 to 0.80 for intra-rater reliability while the pooled value for construct validity was 0.82 (Swinkels et al., 2005).

Questionnaire Analysis

All verbal response information from the survey was coded in a Microsoft Excel spreadsheet and descriptive tables were made of sample averages and percentages. Analyses also consisted of ranking the responses on the questionnaire by most to least frequent or by average for quantitative factors.

Needs-Assessment Procedure

The second aspect of the participants' interviews involved a focus group discussion of the same sample population within each moving company. In total, there were six discussion groups of seven movers. These focus groups were held in an open location at the warehouses before the start of the shift. Discussions were time-restricted at 20 minutes per session and movers were encouraged to speak freely. A controlled-memorized script was used to introduce the topics for discussion to ensure no bias occurred between focus groups (Appendix G). A voice recorder was used to store the entire discussion. To maintain confidentiality, no participant names or company names were used on the voice recorder.

The first question was focused on identifying the physical and personal limitations of the job followed by asking participants to identify equipment and/or strategies to overcome some of these limitations. The second question was focused on identifying possible ergonomic solutions to these limitations. The sessions were concluded with another script that informed the members that their input was highly valued and that they could contact the lead investigator at any time with further questions or comments.

Needs-Assessment Analysis

After each discussion, the voice recorder was played back and the responses for each question were paraphrased and tabled into an Excel spreadsheet based on the types of responses. For every similar response, a marker was added to the paraphrased statement, thus indicating how many times that type of response was made. Upon coding

all six focus group discussions, the responses were ranked from most frequent to least frequent. For question 1 involving limitations, the responses were divided into three categories: (1) Environmental Limitations, (2) Physical Load Limitations, and (3) Personal Limitations. The responses for question 2, all ideas for task redesign and ergonomic changes were collectively ranked.

3.3 Results

Questionnaire

A total of 30 movers who were fairly evenly distributed across the three companies participated in the questionnaires. Of the movers surveyed, 93% reported some form of work-related musculoskeletal pain over their entire moving career. Movers reported the most frequent work-related pain at the shoulder joints (63.3%) followed by work-related back pain (60.0%) and hand pain (56.7%) (Table 3.1). There was an approximate 10% and 30% drop in frequency of job-related pain over the past year and past week, respectively.

When asked which work-related factor induced the shoulder pain, 46.7% reported that moving heavy loads in awkward postures induced the pain. With regard to the back, 63.3% reported that constant repetitive strain was the source of the induced pain (Table 3.2). For the hands, the most commonly identified cause (76.3%) was some form of work-related accident.

When ranking the most severe/intense pain of their reported musculoskeletal regions, 26.7% said it was the back, 23.3% said it was the shoulders, and 20.0% said it was the knees (Table 3.3). In summary, shoulders and back pain ranked as both the most frequent and most severe pain within the sample of professional movers surveyed.

Table 3.1 – A summary regions reported to have experienced musculoskeletal pain within specific time frames.

JOB RELATED PAIN (n=30)					
"EVER"		**"PAST YEAR"**		**"PAST WEEK"**	
Shoulders	63.3%	Shoulders	56.7%	Back	33.3%
Back	60.0%	Back	50.0%	Knees	33.3%
Hands	56.7%	Hands	46.7%	Shoulders	30.0%
Neck	46.7%	Neck	40.0%	Hands	30.0%
Wrists	46.7%	Wrists	40.0%	Neck	16.7%
Knees	36.7%	Ankles	40.0%	Ankles	13.3%
Ankles	36.7%	Knees	36.7%	Wrists	9.0%
Elbows	10.0%	Elbows	3.0%	Elbows	0.0%
Hips	3.3%	Hips	3.0%	Hips	0.0%

Table 3.2 – A summary of the most commonly reported work factor to have caused pain within a certain musculoskeletal region.

MOST COMMON CAUSE OF PAIN (n=30)		
REGION	**CAUSE**	**% REPORTED**
Back	"Constant Effort / RSI"	63.30%
Shoulders	"Heavy Awkward Loads / Acute"	46.70%
Knees	"Constant Effort / RSI"	90.90%
Wrists	"Constant Effort / RSI"	85.60%
Ankles	"Work-Related Accident"	63.30%
Hands	"Work-Related Accident"	76.30%

Table 3.3 – A summary of the most severe/intense region of musculoskeletal pain.

REGION OF MOST SEVERE PAIN (n=30)	
Back	26.7%
Shoulders	23.3%
Knees	20.0%
Wrists	10.0%
Ankles	6.7%
Hands	3.3%

Needs-Assessment Focus Groups

Table 3.4 provides a summary of categories and most frequent responses of movers (n=42) during the needs-assessment discussions with focus groups. The most frequently reported responses dealt with Environmental Limitations (a total of 14 responses). Workers reported that the main environmental difficulties were traversing stairs and navigating narrow or small spaces. The ramp attached to the truck was also considered problematic due to instability or slipperiness. The second most frequent response was under the category of Personal Limitations (a total of 7 responses) where movers reported either musculoskeletal pain/fatigue, followed by anthropometric limitations, (e.g., body too large, arms too short) and coordinating lifts wit their partner. The third most frequent response was under Physical Load Limitations (a total of 6 responses); the workers most frequently reported that variation in load parameters posed difficulty in the moving process such as the size of the load or unbalanced loads. Comments were also made about no upper load limits.

The focus groups were also asked to think of ergonomic solutions to the limitations identified above. Unfortunately, no new viable or realistic solutions were presented, but instead, members highlighted technologies that were already in use within the moving industry. Therefore, no significant responses can be reported.

Table 3.4 – Ranking and number of responses to question 1 of the needs-assessment discussion. Responses are divided into 3 groups; Environmental, Personal and Physical Load limitations. Specific comments are provided beneath each group heading.

NEEDS-ASSESSMENT DISCUSSION RESPONSES (n=42)

Environmental Limitations	
Rank	Response (# of responses)
1	Stair Difficulties (6)
2	Spatial Limitations (5)
3	Truck Ramp Width and Instability (3)

Physical Load Limitations	
Rank	Response (# of responses)
1	Load Dimension Variations (3)
2	No Upper Weight Limitations (2)
3	Unbalanced Loads (1)

Personal Limitations	
Rank	Response (# of responses)
1	Musculoskeletal Pain and/or Fatigue (3)
2	Anthropometric Limitations (2)
3	Coordinating Load Carriage with Partner (2)

3.4 Discussion

Questionnaire

The purpose of the questionnaire was to provide focus for the in-laboratory study of load carriage techniques and provide direction to the design of an assistive ergonomic device. The most frequently causes related to regions of musculoskeletal pain were back, shoulders, knees and wrists (See Table 3.2). The back and shoulders were ranked as regions with the most severe/intense pain that were induced by high musculoskeletal forces, repetitive lifting or lifting in awkward postures. It would be possible to study these particular regions when using various load carriage techniques or assistive devices to determine if muscle forces are being reduced. Therefore, the questionnaire helped focus the aim of the ergonomic study onto regions of the back, shoulders and wrists, in particular, and validate the importance of biomechanical research directed toward MSD injuries of movers.

Needs-Assessment Discussion

After identifying regions of musculoskeletal pain and causal work-related factors, it may be possible to consider ergonomic solutions to the identified problems. The purpose of the needs-assessment discussion was to gain insight about the constraints/limitations in the moving profession. Such information would create a hierarchy of needs and constraints to consider when designing assistive devices. From

the needs-assessment discussion, it was clearly identified that the moving environment posed the greatest challenge to movers when in the field; specifically traversing stairs as well as fitting and moving through spatial constraints were reported as highly difficult and limiting (See Table 3.4). This suggested that any assistive devices must occupy minimal space and reduce visual obstruction for traversing stairs and hallways.

Further discussion highlighted that personal limitations, such as pain/fatigue, and anthropometry, such as size and arm length, are also common challenges within the moving industry. This implies that any load carriage techniques or assistive devices must reduce muscular effort and easily allow various anthropometric dimensions to perform effectively.

Limitations

The goal of this study was not intended to provide epidemiological information regarding the professional moving industry; rather the study was intended to provide insight into the musculoskeletal effects and physical environment of the professional moving industry. However, at least four limitations did exist in this survey. 1) The sample consisted only of moving companies within a select region of the country. It is possible that other moving companies in other regions commonly encounter homes with different architecture that present different environmental constraints. 2) The ability to communicate with each worker within every company was not possible, and therefore the investigators may have sampled a biased group of professional movers. 3) The investigator did not have access to movers who were not currently active due to work-

related injury, and thus it may have been just the "survivor" population of professional movers. 4) The questionnaire was based on professional movers identifying their own regions of pain and not on reports from health care professionals. Some participants may have forgotten certain musculoskeletal injuries or enhanced the severity of the symptoms, thus biasing their responses.

3.5 Conclusion

The professional movers sampled using this survey commonly encountered some form of work-related musculoskeletal injury. With the propensity of research in other MMH occupations, it is surprising that there is no specific ergonomic or biomechanical investigation related to the moving industry.

The questionnaire and needs-assessment focus groups provided clarity and direction for the ergonomic study of load carriage within the professional moving industry. From the questionnaire, professional movers identified that the back, shoulders, wrists and knees would have the greatest benefit from an ergonomic study and intervention program because their pain was mainly reported to be caused by force- and repetition-related factors. Furthermore, a successful ergonomic intervention related to load carriage strategies would be highly effective because shoulder and back pain were ranked as the most severe. The needs-assessment discussion also produced effective design guidelines to improve the efficacy of potential ergonomic interventions.

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Chapter 4

An Electromyographic Analysis of Unassisted Load Carriage With Anterior and Posterior Load Placements

4.1 Introduction

A significant need still exists for manual material handling (MMH) despite the presence of modern process engineering that is intended to reduce human workloads. Factors such as the nature of the work, spatial limitations and large financial costs of implementing automation are what make MMH an often-necessary component within modern work (Mital et al., 1997). The primary focus of biomechanical analysis regarding MMH has been on lifting and lowering tasks. Indeed, these are noteworthy tasks to analyze as many epidemiological and biomechanical field studies have shown how lifting and lowering significantly increase the incidence of low back pain (LBP) and low back injury (Kumar, 1990; Norman et al., 1998; Kerr et al. 2001). Load carriage is another MMH task that has also been a popular field of research in biomechanics and ergonomics, especially regarding backpack usage in both civilian and military populations (Harman et al., 1992; Knapik et al., 1997; Lloyd & Cooke, 2000; Stuempfle et al. 2004; Fiolkowski et al., 2006; Motmans et al., 2006). However, there is a void in the literature that investigates hand-held load carriage. Generally, in a work setting, it is not possible or time efficient to place a load into a backpack, and so only the hands are used to secure the load for carrying.

In a cross-sectional study of professional transporters, by Pietri et al. (1992), it was found that jobs that involved carrying had an increased risk (OR=1.3) of developing LBP compared to jobs that do not involve carrying. However, their criterion for load-

carriage exposure was simply 'carrying' or 'no carrying'. In a patient-control study by Kelsey et al. (1984), it was found that carrying loads over 11.3kg more than 25 times per day resulted in a strong and significantly increased risk (OR=2.7) for workers developing an intervertebral disc prolapse compared to those who did not carry at all. They showed that clearly defined exposure thresholds to loads during carrying can elicit a more significant correlation between low back injury and load carriage. Thus, hand-held load carriage is a viable candidate for further biomechanical research.

Studies by Gagnon (1997) and Authier et al. (1995; 1996) showed that experienced manual material handlers used different load handling techniques (e.g., box tilting and knee bending) when compared to novices in their occupation. Many of the experienced handlers' techniques were believed to reduce the mechanical loads imposed during load handling. The researchers concluded that the biomechanically advantageous work methods of the experts should be taught to novice workers in an attempt to reduce musculoskeletal injuries in MMH.

A similar observation was made by the author of this paper regarding load carriage performed by professional movers (Section 3.0). It was observed that some experienced professional movers carry moving boxes on their backs by reaching backward to grasp the box and then leaning forward at the hips so that the box rests against their pelvis and back (figure 4.1). When individuals were questioned about this technique, they believed that this moving posture, compared to carrying the box in front of the pelvis, was "easier" on them.

Figure 4.1 - An experienced professional mover using the unassisted posterior load carriage method during a residential move.

There have been pack studies investigating anterior versus posterior load carriage placement strategies. It was determined that anterior load placement packs produce gait patterns most similar to unloaded walking, while posterior load placement packs require a forward lean to equalize the moment created by the external load (Fiolkowski et al., 2006). However, it was found that anterior load carriage packs produce greater erector spinae muscle activity compared to posterior load placement packs (Cook & Neumann, 1987; Motmans et al., 2006). It is possible that, during posterior load carriage, the moment generated by the external load reduces the magnitude of the internal muscle moment typically generated by the erector spinae in order to maintain a vertical thorax during gait (Cook & Neumann, 1987). Furthermore, Motmans et al. (2006) concluded that the increased EMG activity of the erector spinae during anterior load carriage may increase the compressive forces on the spine in comparison to posterior load carriage. Many studies and biomechanical models have shown that increases in paraspinal muscle activity increase compression along the vertebrae (Potvin et al., 1991; Dolan & Adams, 1993; Hughes et al., 1994). Therefore, apart from the deviated kinematics involved in posterior load carriage, this strategy may offer an effective reduction in spinal compression in comparison to anterior load carriage.

The purpose of this paper is to compare biomechanical outcomes of hand-held anterior and posterior load carriage techniques. To date, there has been no biomechanical research regarding hand-held anterior and posterior load carriage and the implications these techniques may have on electromyography of the low back and the upper extremities. Similar to Gagnon (1997) and Authier et al. (1995; 1996), if the hand-held posterior load carriage method is found to reduce paraspinal and/or upper extremity

muscle activity, it may serve as an effective worker strategy for reducing work-related musculoskeletal injuries.

4.2 Methods

Subjects

Ten male subjects who were 28 ± 9 years old, 1.76 ± 0.12m tall and weighed 78 ± 9kg volunteered to participate in the study. The inclusion criteria consisted of male subjects 18-50 years of age. Exclusion criteria consisted of a history of major musculoskeletal injuries in the past, especially any history of pain or injury to the lower back. Additionally, the study excluded subjects with any experience in the professional moving industry or knowledge of any specialized load carriage techniques used in the moving industry. Having passed inclusion and exclusion criteria, the subjects signed an informed consent document to participate in the study. Subjects' body weights and heights were then measured on a balance scale, and assessment of hand dominance was determined.

EMG and Kinematics Setup

There were eight unilateral surface EMG recording sites on the dominant side of the subjects' body: the upper trapezius (TR) (midsection of line between the C7 and acromion); the anterior deltoid (AD) (2cm superior to the midline of muscle belly); the posterior deltoid (PD) (2cm superior to the midline of the muscle belly); the thoracic vertebrae erector spinae (TES) (5cm lateral to the T9 vertebrae); the lumbar erector spinae (LES) (3cm lateral to the L3 vertebrae); the rectus abdominus (RA) (3cm lateral

and 2cm superior to the umbilicus); the external oblique (EO) (15cm lateral to the umbilicus at 45 degrees from horizontal); and the flexor digitorum (FD) (7cm distal along line between medial epicondyle and wrist midline). A ground electrode was placed on the C7 spinous process (C7). These regions were identified, lightly abraded, and cleansed with a swab containing a commercial blend of 70% rubbing alcohol and 30% water. A pair of circular Ag-AgCl Meditrace electrodes were placed on the cleansed areas parallel to the muscle fibers with a 3cm inter-electrode distance. Once the electrode application was completed, a commercial voltage meter was used to test the inter-electrode impedance. Before testing began, the inter-electrode impedance was confirmed to be less than 100 kOhm.

An accelerometer was attached to the lateral side of the subjects' heel on their left shoe with double-sided tape and covered with a layer of athletic tape. The accelerometer was connected to the A/D board and streamed with the EMG data at a sampling rate of 1000Hz.

The electrodes were connected to a Bortec AMT-8 with a signal gain of 1000K-5000K, a band pass filter of 20-500Hz, and a sampling frequency of 1000Hz. All data were streamed into a 16-bit National Instruments A/D board at a sampling frequency of 1000Hz. As a digital signal, the data were saved onto a computer using NIAD (commercially developed software by Labview). NIAD saved data as ASCII files at a frequency of 1000Hz.

As the subjects lay supine on a foam-padded bench, three 10-second silent periods were selected to measure noise and DC offset of the EMG channels. During these silent

periods, the subjects were instructed to close their eyes and take relaxing breaths; once the subjects were completely still and relaxed, data collection was initiated. Following silent periods, the subjects performed maximum voluntary contractions (MVCs) for all eight muscle sites. Subjects elicited three maximal voluntary efforts (MVEs) for each muscle group by contracting their muscles as intensely as possible against an applied isometric resistance for 5 seconds.

The specific protocols for maximal efforts are described below. For the trapezius, subjects stood erect with arms hanging at the waist. They grasped a bar attached to an isometric dynamometer with both hands and were instructed to "shrug" their shoulders as high and hard as possible. For the anterior deltoid, subjects stood with a staggered foot placement. They were instructed to raise their arm just above 45º directly in front of them, with a neutral hand posture. They were then told to meet the resistance of the investigator as downward pressure was placed 5cm distal to the cubital fossa on the arm, until maximal flexion moment was generated at the shoulder. For the posterior deltoid, subjects stood with a stable foot placement. They were instructed to raise their arm posteriorly to an angle of 15 degrees directly behind them, with a neutral hand posture. They were then told to meet the resistance of the investigator as downward pressure was placed on the arm proximal to the elbow against the subject's maximal extension force at the shoulder. For the TES and LES, subjects lay prone on a padded bench with their legs firmly secured to the bench with two straps just above the ankles and the knees. The subjects were instructed to place their hands behind their head and extend the back as hard as possible against the resistance of the investigator; resistance was applied directly between the shoulder blades with both hands (one on top of the other). For the rectus

abdominus, subjects lay supine on the foam-padded bench with their legs firmly secured with straps just above the ankles and knees. They were instructed to cross their arms at their chest and flex the abdomen (perform a "crunch") as hard as possible against the resistance applied by the investigator at both shoulders. For the external oblique, subjects lay supine in the same setup. However, they were instructed to raise their shoulders and twist. The investigator applied resistance to the shoulder on the same side as the external oblique electrode to oppose the twisting motion. For the flexor digitorum, subjects sat in a chair, placed their supinated arm on a table and grasped a dense foam cylinder. The subjects were instructed to both squeeze the cylinder and flex at the wrist with maximal effort against the investigator's resistance. The investigator applied resistance by pushing down on the clenched hand of the subject.

Test Protocol

After the isometric MVEs (iMVEs), all subjects rested until they felt they were ready to perform the carrying tasks. A cardboard file box was fitted with weight equaling 20% of the subject's body weight. The weight was positioned and secured directly in the centre of the box (in x, y, z axes) with cutout Styrofoam inserts. Any spaces remaining between the weight plates were filled with packing foam to prevent the weights from moving around and accelerating inside the box. The subjects walked with no load at a rate of 2m/s for 2 minutes in order to familiarize themselves with the treadmill and the required walking speed and to test the functioning of the accelerometer. Subjects then rested for 1min and performed the three anterior carrying and three posterior carrying trials with the prescribed load. Random selection determined whether

the anterior or posterior carrying style would be performed first. Once this was determined, the anterior and posterior trials were performed in alternating order until three trials of each style were recorded.

During the anterior carrying trials, the investigator placed the load in the subjects' hands and increased the treadmill velocity to 2km/h. The subjects had been instructed to position themselves in a comfortable carrying posture, that they believed they could perform while actually carrying boxes to and from a house. The subjects carried the load for 20s with a regular four-finger grip (figure 4.2 below), at which point data collection of the EMG and accelerometer began and continued for 10s. In all, the subjects carried the load for a total of 30s per trial. At 30s, the treadmill was stopped, and the investigator removed the load from subjects' hands. Subjects were then allowed to rest for two minutes in a chair. For the purpose of safety, they were then asked whether they were sensing any pain or discomfort. If they answered "no", the study continued. After the two-minute rest, subjects began the posterior trial.

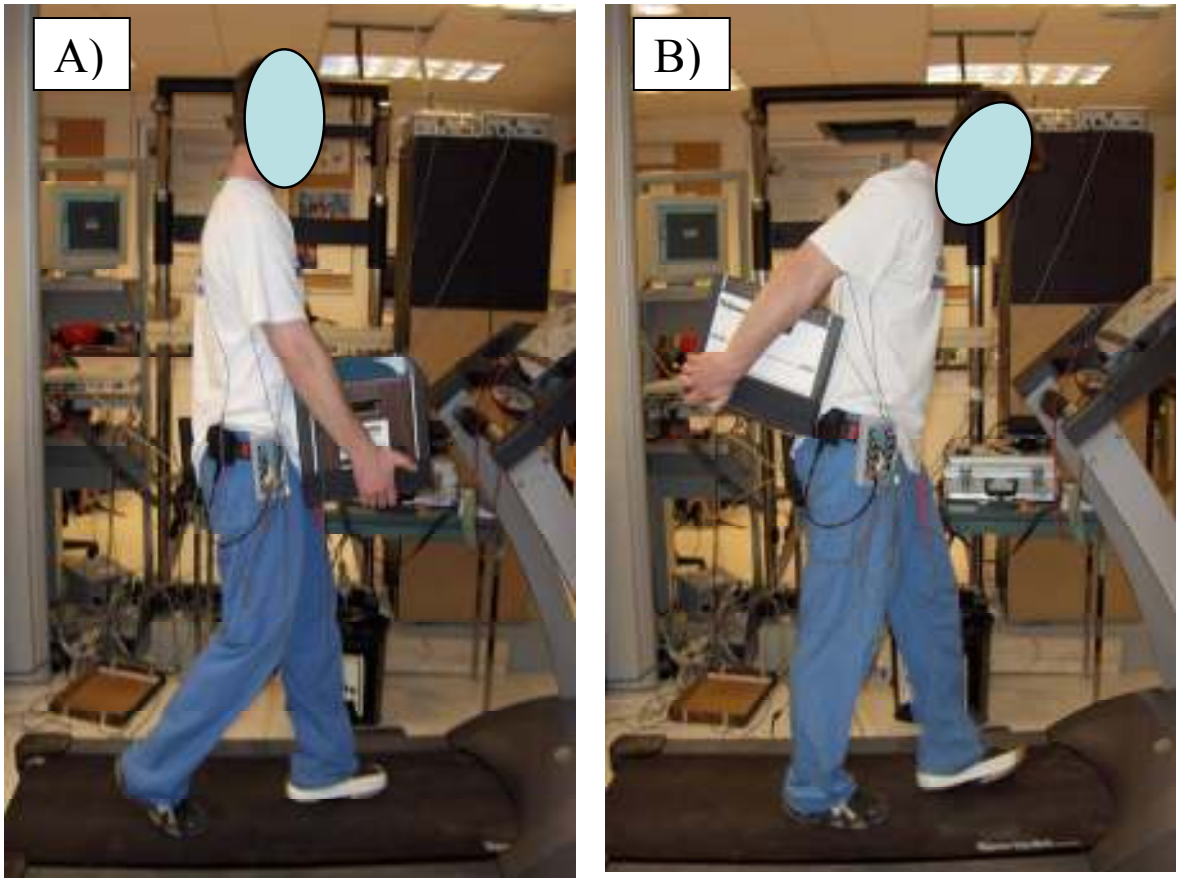

Figure 4.2 - a) Load was placed in front of pelvis for the anterior load carriage posture. b) Load was placed behind pelvis and held against the back for the posterior load carriage

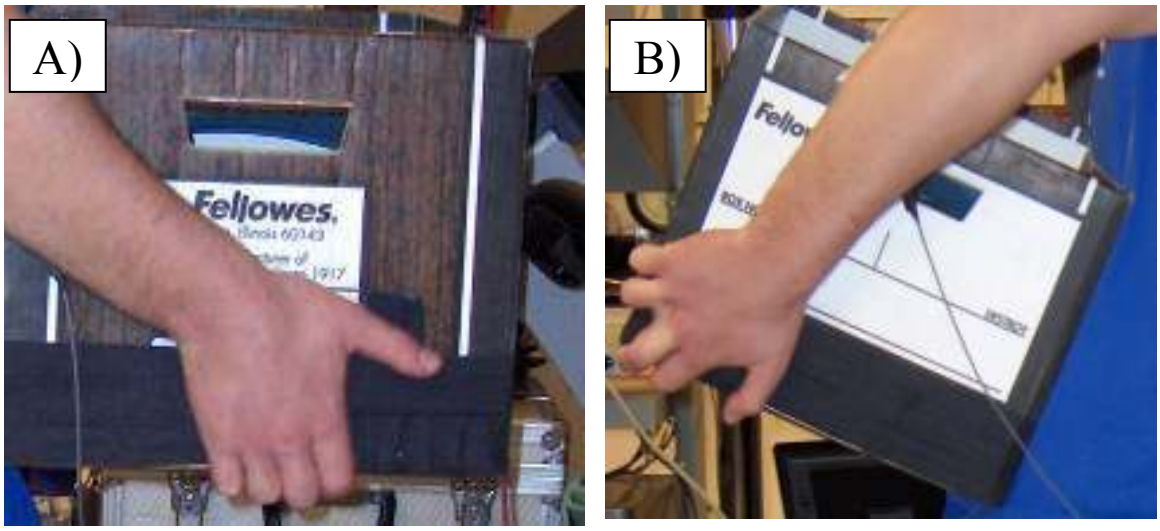

Figure 4.3 - a) 4 finger grip used in the anterior carrying method. b) Split finger grip used in the posterior carrying method.

During the posterior carrying trials (figure 4.2.b), the investigator placed the load in the subjects' hands behind their back and increased the treadmill velocity to 2 km/h. The subjects were instructed to position themselves in a comfortable carrying posture that they believed they could perform while actually carrying boxes to and from a house. The subjects were told to utilize a split finger grip (figure 4.3.b) for this trial, as it was commonly observed in the original sample of professional movers. Other than the grip technique, no other instruction was given regarding posterior carrying technique. The data collection procedure was the same as in the anterior carrying trials.

At the completion of the trials, subjects were asked to give their opinion of the advantages and disadvantages of the two carrying postures through two questions; (1) "Which posture would you use next time you move", and (2) "Do you find the posterior carriage method to be awkward." Their opinions were recorded in a spreadsheet. At this point the subjects were released from the study.

Data Analysis

The accelerometer produced sharp voltage spikes every time heel contact was made. Since the accelerometer data was time synchronized to the EMG data, the voltage spike on the accelerometer channel was used to identify five heel strikes on the right foot. Therefore, starting with the first voltage spike, five spikes were counted, thus identifying five gait cycles. This isolated section of EMG data was used for the analysis. This EMG sectioning procedure was used for all trial data.

Similar to other EMG studies, the mean DC values within the signal recordings were calculated and the DC offsets were determined (Brinkworth and Turker, 2003). For all data recording sessions, it was verified that the DC offset was less than 0.01% of the

total signal. The silent period signal was then rectified and used to determine signal noise for each channel (Brinkworth and Turker, 2003). The noise for each channel was then deducted from the respective trial data within each individual subject. A second order Butterworth filter was performed both forwards and backwards on all data with a low pass cutoff frequency of 6Hz. To avoid filter ramping effects, the filter was applied to the data at least 100 samples before the first heel strike and visual analysis was also used to confirm minimal ramping distortion.

The highest MVE values were determined for each muscle group within a subject. These MVE values were then used to normalize all subsequent trial data for each muscle group from 0% to 100% MVE values.

Then, an Amplitude Probability Distribution Function (APDF) was performed. Bins from 1-100 were created to represent 0% - 100% MVE values. A histogram record was created that totaled the number of EMG data samples occurring in each 1% increment between 0% and 100% MVE. The histogram data was then converted to a cumulative probability curve for each trial. From plotting the curve for samples collected in the trial, an amplitude probability for the entire trial was determined at the 10th (static), 50th (median) and 90th (peak) percentile values. The APDF values for the three trials within one test condition were averaged for each muscle group measured.

The APDF values for each subject and each postural condition were submitted to a Repeated Measures ANOVA test using SPSS 13.0 (SPSS Inc.). The differences between the anterior and posterior carrying conditions were compared within each subject. Through the use of a Bonferroni correction, the level of statistical significance was calculated for the differences between the carrying postures at the 10th, 50^{th} and 90th

percentile values. The means and the significance values were tabled and graphed for these percentiles. For further analysis of the effects of the posterior load carriage method (PC) in comparison to the anterior load carriage method (AC) on the erector spinae, percent differences were calculated for the thoracic erector spinae (TES) and lumbar erector spinae (LES) between the PC and AC methods.

4.3 Results

Table 4.1 provides the mean APDF values for each muscle in the two carrying postures. Differences existed in the APDF values of the observed muscles between the anterior and posterior load carriage postures, most significantly in the PD, TES and LES muscles of the body. In detail, AC created lower muscle activity in the PD (10^{th}, 50^{th} and 90^{th} percentiles, $p<0.05$) yet created higher muscle activity in the TES (50^{th} and 90^{th} percentiles, $p<0.05$) and LES (10^{th}, 50^{th} and 90^{th} percentiles, $p<0.05$) regions of the back. Inversely, PC caused higher muscle activity in the PD yet lowered muscle activity in the TES and LES regions of the erector spinae. Across all APDF percentiles, the TES and LES muscle activity was reduced by more than 50% when using the PC method in comparison to the AC method (Table 4.2).

The trapezius muscle showed a trend of decreased muscle loading in the PC method ($p=0.10$ at the 50^{th} percentile); however, it only reached statistical significance ($p<0.05$) at the 90^{th} percentile APDF level. Refer to Figures 4.4, 4.5 and 4.6 for graphical comparisons between the AC and PC methods at the 10^{th}, 50^{th} and 90^{th} percentiles.

Contrary to the objective EMG data, at the conclusion of the study 80% of subjects reported that the PC method felt awkward. A common statement they made was

that the AC posture was more familiar and thus much easier to perform in comparison to the PC method. Nevertheless, 50% of subjects reported that they would try to use the PC method the next time they move a load. Those who said they would not use the PC method mentioned that they would not be patient enough to master the proper PC technique.

Table 4.1 - A comparison of surface EMG during anterior load carriage (AC) and posterior load carriage (PC) at the 10th, 50th and 90th percentile APDF levels. Significant values are $p<0.05$.

	Muscle Groups per Carrying Posture (n=10)															
	TR		AD		PD		TES		LES		RA		EO		FD	
	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC
10th Percentile																
%MVE	**3.08**	**2.45**	**0.31**	**0.13**	**0.37**	**1.38**	**2.95**	**1.13**	**5.45**	**0.65**	**0.86**	**0.42**	**0.74**	**1.32**	**2.25**	**2.09**
SD (+/-)	2.74	1.51	0.62	0.26	0.25	1.05	2.36	1.73	6.36	0.79	1.06	0.70	0.58	1.65	1.87	2.29
Sig. (p=x)	**0.359**		**0.41**		**0.007**		**0.081**		**0.029**		**0.215**		**0.237**		**0.752**	
50th Percentile																
%MVE	**5.66**	**4.35**	**0.69**	**0.34**	**0.98**	**2.94**	**7.79**	**2.78**	**10.90**	**1.87**	**1.97**	**1.42**	**2.31**	**2.95**	**3.83**	**3.66**
SD (+/-)	3.18	2.20	0.39	1.75	0.76	1.78	4.34	3.64	7.95	1.92	3.26	1.40	1.64	3.25	2.70	3.13
Sig. (p=x)	**0.103**		**0.276**		**0.002**		**0.015**		**0.002**		**0.624**		**0.527**		**0.8**	
90th Percentile																
%MVE	**8.78**	**6.51**	**1.36**	**0.80**	**1.99**	**5.02**	**14.12**	**6.42**	**18.64**	**6.49**	**3.84**	**3.59**	**4.44**	**6.11**	**6.29**	**6.13**
SD (+/-)	4.45	3.03	1.75	0.57	1.36	2.48	5.92	5.83	1.92	12.52	7.04	4.15	2.41	5.56	3.35	3.95
Sig. (p=x)	**0.049**		**0.331**		**0.001**		**0.01**		**<0.001**		**0.907**		**0.231**		**0.877**	

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

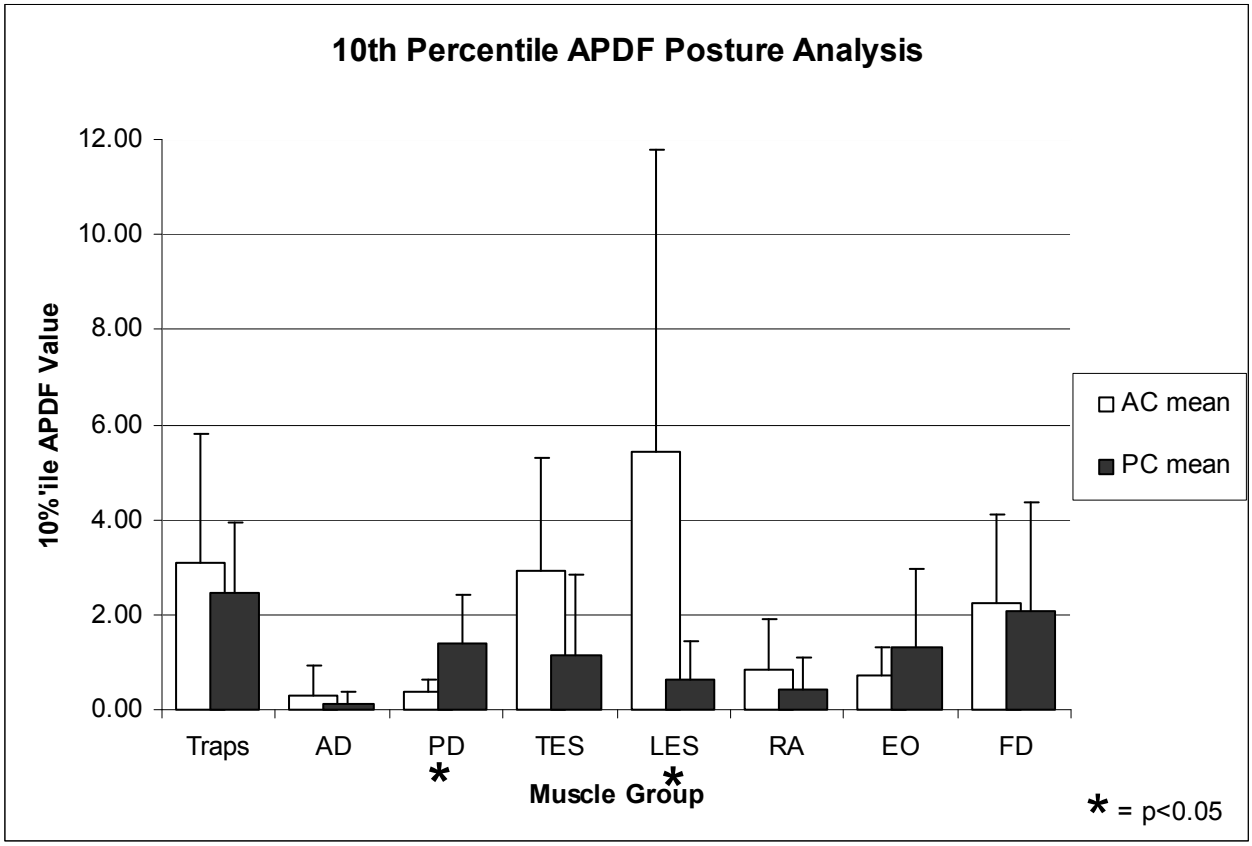

Figure 4.4 - Displays the mean APDF values for each muscle group measured in the 10th percentile. At the 10th percentile muscle activity, the Posterior Deltoid activity was significantly lower and the Lumbar Erector Spinae activity was significantly higher during the anterior load carry ($p<0.05$). Low static EMG activity in the LES indicates lower postural muscle demand when using the PC method.

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

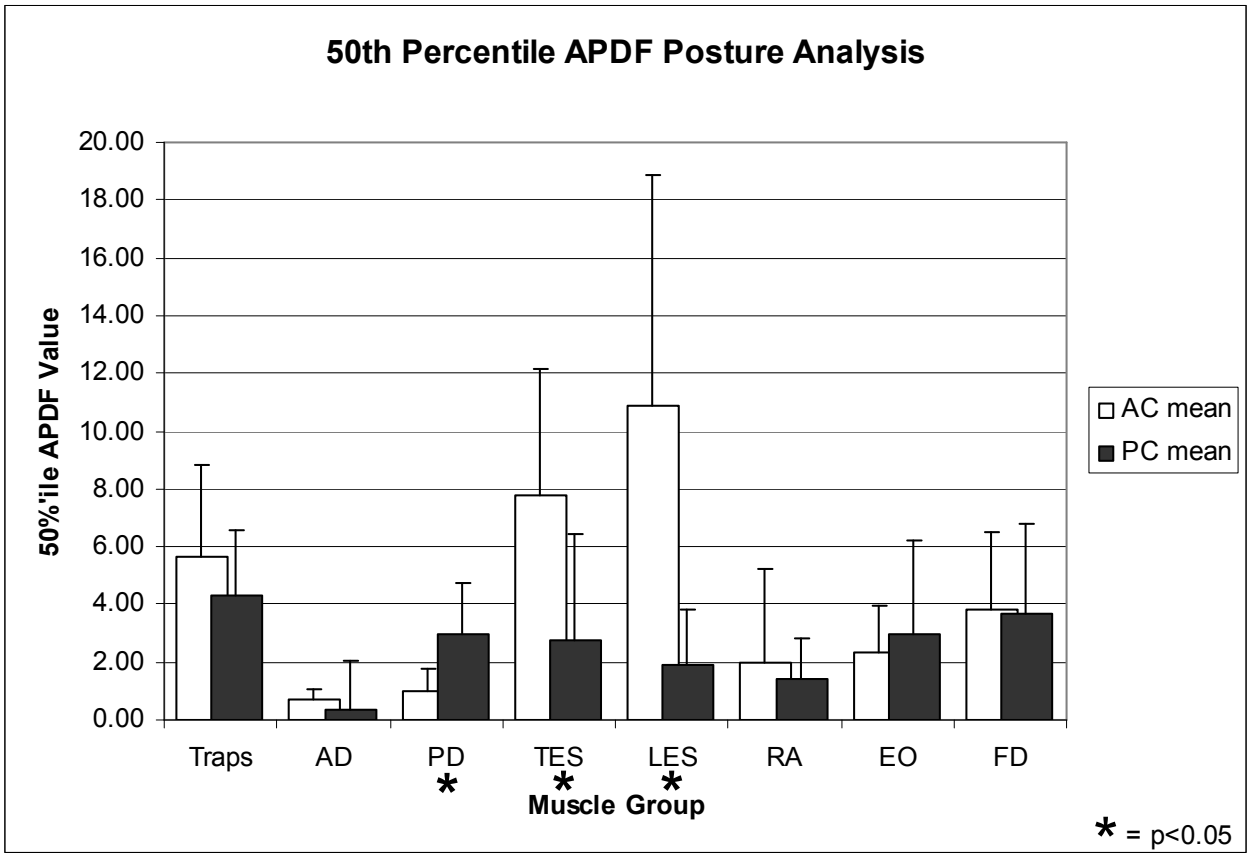

Figure 4.5 - Displays the mean APDF activity for each muscle group measured in the 50th percentile. At the 50th percentile muscle activity, both TES and LES muscle activities were significantly less active in the PC method, and the PD activity was significantly more active in the PC method than the AC method. Lower median levels of erector spinae EMG activity indicate that the average back effort involved in the PC method is less than that of the AC method.

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

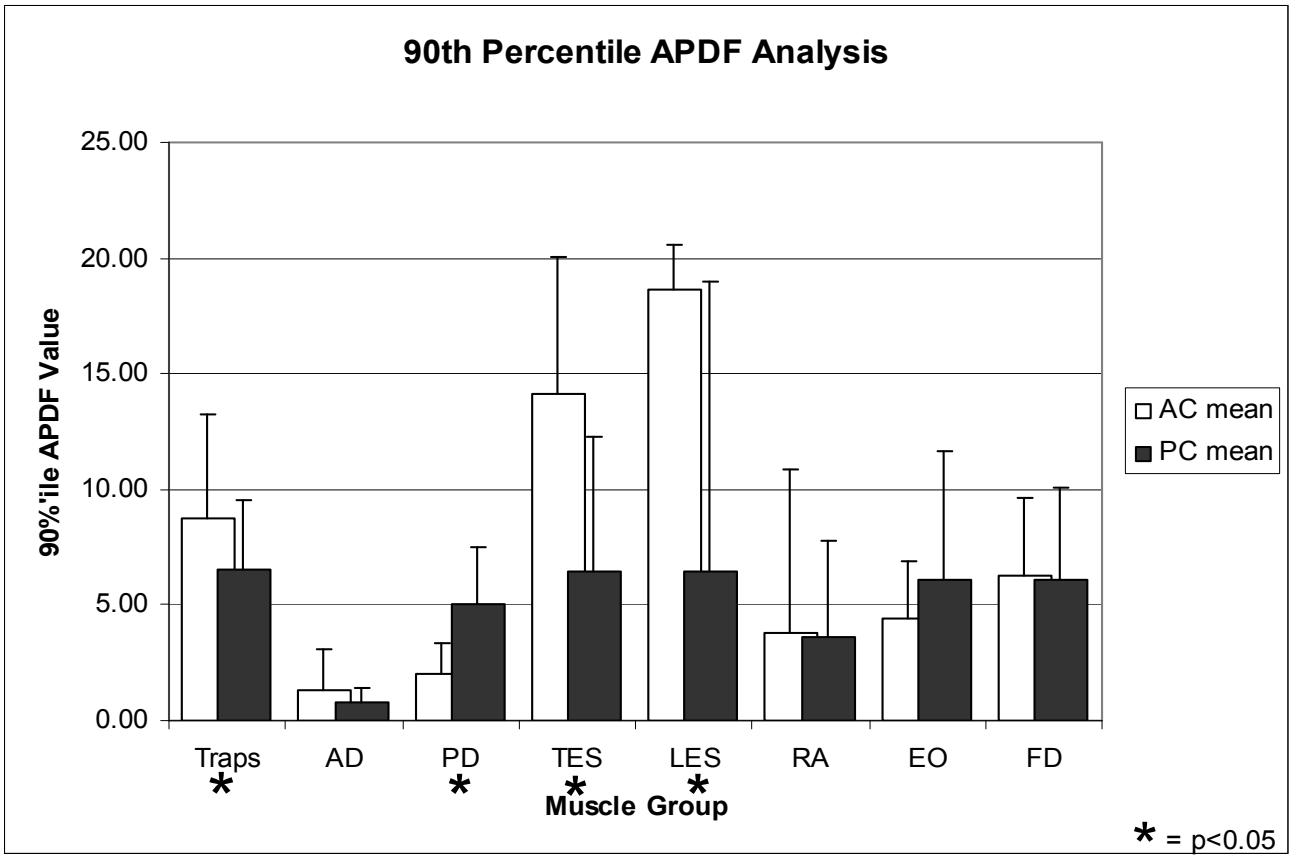

Figure 4.6 - Displays the mean APDF activity for each muscle group measured in the 90th percentile. At the 90th percentile, the erector spinae activity is significantly lower in the PC method than the AC method. The trapezius also shows reductions in the peak muscle activity during the PC method. Lower peak levels of erector spinae EMG activity indicate that the peak back forces involved in the PC method are less than that of the AC method..

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

Table 4.2 - Percent reduction in %MVE EMG values when using PC in comparison to AC. The percentages were a result of dividing the difference between AC and PC %MVE values by the AC %MVE value. Thus the percentages for thoracic erector spinae (TES) and lumbar erector spinae (LES) were representative of the change in muscle activity when using the PC method, relative to the AC method. Significant changes ($p<0.05$) are indicated by grey boxes.

Percent Reduction Using PC		
	TES	LES
10th%'ile	61.6%	88.1%
50th%'ile	64.3%	82.8%
90th%'ile	54.5%	65.2%

4.4 Discussion

The analysis of the EMG APDF data showed that some regions of the observed musculoskeletal system were significantly affected by the PC method, while other regions remained insignificantly affected between the two load carriage techniques. Activity levels in the flexor digitorum, rectus abdominus, external oblique, and anterior deltoid were not significantly different between the two carrying conditions. However, the trapezius, posterior deltoid, thoracic erector spinae and lumbar erector spinae muscle activities did show significant differences in various APDF percentiles. Below is a discussion of these results and their possible implications in regard to the forces and motor behaviour processes occurring within the musculoskeletal system.

Erector Spinae Activity

The results of this study were similar to those of Motmans et al. (2006), in that PC loads significantly reduced LES activity more so than AC loads. Furthermore, the results also showed that the TES EMG activity was reduced with the PC method at the median and peak levels of the APDF. In all percentile groups, the mean erector spinae EMG amplitudes were reduced at least 50% (Table 4.2).

It was apparent that the greatest reduction in erector spinae EMG occurred in the LES (EMG activity reduced by 88.1% at 10^{th}, 82.8% at 50^{th} and 65.2% at 90^{th} percentile). The back musculature produces the majority of compressive spinal force in MMH tasks due to disadvantageous muscle moment arms in comparison to external loads (Dolan & Adams, 1993; Hughes et al., 1994). Furthermore, various back models have shown that

an increase in back muscle surface EMG has also been an indicator of increased magnitudes of muscle contraction intensity and thus increased magnitudes of muscle-induced spinal compression (McGill & Norman, 1986; Potvin et al., 1990; Dolan et al., 1999). Reductions in erector spinae EMG values through the use of the PC method indicate potential reductions in spinal compression. Spinal compression has been shown to be a significant predictive factor for the development of low back pain (Norman et al., 1998). This implies that the reduced LES and TES activity in the PC method may produce reductions in muscle-induced spinal compression and prevalence of back pain in comparison to the AC method. Although yet to be proven epidemiologically, the PC method may offer an effective alternative load carriage technique to reduce compressive spinal forces.

Differences Between Load Carriage Mechanics

Previous literature has noted that the PC method does induce a significantly forward flexed posture (Cook & Neumann, 1987; Fiolkowski et al., 2006; Motmans et al., 2006; Devroey et al., 2007). Although not quantitatively measured in this study, the forward flexed posture during PC was visually apparent. Previous literature has concluded that the posterior load placement in the PC method produces an external extension moment (Bobet & Norman, 1984). This external extensor moment effectively minimizes the required muscle extensor moment produced by the erector spinae to achieve moment equilibrium during gait. Therefore, the forward-leaning posture observed in the PC method (Fiolkowski et al., 2006) is an effective method of using an external moment to balance the system centre of gravity during gait (Bloom & Woodhull-

McNeal, 1987). In so doing, PC reduces erector spinae muscle activity beyond that of the AC method.

Fiolkowski et al. (2006) found that AC produced kinematics most similar to unloaded gait. They further proposed that the deviated kinematics used in PC may result in increased anterior shear forces and be responsible for the high incidence in low back pain in adolescents who use backpacks on a daily basis (Fiolkowski et al., 2006). However, they did consider the importance of EMG investigation to confirm this hypothesis. Although the erector spinae EMG amplitude was lower during the PC method, it was not completely absent. Therefore, the erector spinae were still actively contracting and producing a reactive posterior shear force due to their insertion angles on the vertebrae (McGill et al., 2000). These results suggested that the pathological anterior shear forces, proposed by Fiolkowski et al., might be offset by the muscle activity of the erector spinae (Potvin et al., 1991b). Further spine model analysis may indicate whether the reactive posterior shear forces of the erector spinae equilibrate the potentially detrimental anterior shear force created by the forward-leaning posture during the PC method.

Differences between Pack-secured and Hand-secured Posterior Load Carriage

Previous studies on pack systems have shown that PC reduced erector spinae activity more than did AC (Cook & Neumann, 1987; Motmans et al., 2006). However, there was concern about whether or not hand-secured loads in the PC method would alter the effect noticed in the pack studies.

The results of this study also produced similar results to the pack studies regarding erector spinae activity. However, this study did not produce similar results with previous pack literature regarding the rectus abdominus. Motmans et al. (2006) found that load carriage with a posterior pack produced significant increases in the rectus abdominus EMG activity in comparison to an anterior pack. This study did not show any differences in rectus abdominus activity between the AC and PC methods. The disparity between these two studies may be due to three factors: i) the forward lean, ii) the exclusive use of the hands for securing the load, and/or iii) a load of 20% bodyweight with a large volume in this study compared to 15% bodyweight held close to the body by a pack used by Motmans et al. (2006). The heavier and larger load may have elicited a greater forward lean to further balance the moment about the low back, thus reducing the need for the rectus abdominus to produce a forward moment. Also, in an effort to reduce necessary grip effort, the subjects may have increased their forward lean so that more of the load was directed into a normal force acting against the surface of the back. Further study is needed to determine the effect of percent body weight and load volume on hip and lower back flexion during the PC method.

Therefore, regardless of whether packs or the hands are used to secure the load, PC reduces muscular activity of the LES and TES in comparison to AC. These results indicate that reductions in erector spinae activity during the PC method are dependent on a forward-leaning posture and independent of the method for securing the load.

Posterior Load Carriage Effects on Spinal Stability

The results of the rectus abdominus, external oblique, and erector spinae EMG activity also provide information regarding spinal stability. An increase in spinal stability is produced by increased co-contraction of the trunk muscles that produce opposing moments (Cholewicki et al., 1997; Gardner-Morse & Stokes, 1998; Dolan & Adams, 2001; Vera-Garcia, 2006). However, the increase in spinal stability comes at the cost of increased compression of the spine through component vector forces acting along the axis of the vertebrae (Granata & Marras, 2000; Dolan & Adams, 2001; Vera-Garcia, 2006). When comparing the AC and PC methods, it is seen that the PC method significantly reduces erector spinae activity while maintaining similar levels of rectus abdominus activity. Thus, the decreased erector spinae activity combined with maintained abdominal activity suggest that there is no increased co-contraction when using the PC method. This result further suggests that the PC method does not create a need for increased muscular spinal stabilization

Another muscle proven to be effective in stabilizing the spine is the external oblique (Cholewicki et al., 1997; Gardner-Morse & Stokes, 1998; Cholewicki et al., 2000; Granata & Orishimo, 2001). During graded extensions of the low back, Gardner-Morse and Stokes (1998) found that the external oblique produced the greatest increase in stability per unit of force. Additionally, the external oblique can also be used to produce flexion of the spine (McGill, 1996) and provide ipsilateral support to the weight-bearing side during gait (Murray et al., 1984). As previous literature suggests (Cook & Neumann, 1987), forward flexion is used to maintain system moment equilibrium while holding the external load. Hence, the increased external oblique EMG activity suggests that it is

aiding in the production of necessary flexion forces during PC. However, changes in joint angles of the hips may also create hip hiking to ensure that the toes in the swing foot gain sufficient clearance (Winter & Rodgers, 1992). Since hip hiking methods activate the hip abductor system and the external oblique, it is possible that the increased oblique activity in the PC method is due to increased forward flexion and more effortful hip hiking while providing ipsilateral support during gait. Further investigation into the EMG data in static and dynamic functions is warranted to resolve the source of the increased EMG activity in the external oblique.

The above arguments suggest that the PC does not produce a need for increased spine stability while carrying the same load. Therefore, the PC method may offer further benefit by minimizing the need for muscular increases in spinal stability, and thus it minimizes the effects of stability-induced spinal compression.

Shoulder EMG Differences

The only observable drawback of the PC method was the increased posterior deltoid (PD) activity. Studies have shown that increased static EMG activity in the shoulder region may increase local muscle fatigue or induce myalgia in the affected muscles (Westgaard et al., 1986; Veiersted et al, 1993). When comparing shoulder EMG patterns between the two carrying postures, it can be seen that the AC method had the highest static EMG values for the trapezius ($p=0.36$) and anterior deltoid ($p=0.41$) activity, while the PC method has the highest static EMG value for the posterior deltoid ($p<0.01$). It may be possible that a trade-off exists between these two methods' shoulder activation patterns, in that shoulder activity is more focused on the posterior deltoid

muscle in the PC method and more dispersed between the trapezius and anterior deltoid in the AC method. It is difficult to predict if one method's shoulder EMG activity pattern predisposes a user to a greater incidence of local muscle fatigue or myalgia. Further study is needed to determine the outcomes of such shoulder EMG activity disparities.

In their confidential questionnaires, many movers reported shoulder and neck pain as being a common source of musculoskeletal pain (Section 3.0). Many believed that the shoulder pain was induced by work-related heavy and awkward lifting. This indicates that the etiology of the shoulder pain may be due to high shoulder forces and/or pathological postures. Studies have shown that workers exposed to high shoulder loading and awkward postures are more likely to report work-related shoulder pain (Bjelle et al., 1981; Dimberg et al., 1989; Johansson et al., 1993; Frost et al., 2001; Miranda et al., 2001). Therefore, it would be beneficial to reduce peak shoulder muscle activity. Electromyography-based shoulder literature in this area measures the trapezius muscle and indicates that large 90^{th} percentile EMG APDF values in the trapezius lead to increased incidence of shoulder pain (Fethke et al., 2007). It can be seen that the PC method significantly increased peak posterior deltoid activity ($p<0.01$) and reduced trapezius activity ($p<0.05$) and anterior deltoid activity ($p=0.33$), in comparison to the AC method. Thus, based on current literature, the AC method poses the greatest risk of developing shoulder pain due to the elevated trapezius muscle activity. However, this hypothesis is not conclusive as there is a lack of literature investigating the effects of focusing shoulder activity on the posterior deltoid in comparison to the surrounding musculature.

Distal Extremity Loading

Significant occupational factors have been shown to increase the incidence of wrist and carpal tunnel syndrome (CTS) such as: force, posture, and repetition (Silverstein et al., 1987; Herbert, 2000). In a survey of the general population, Atroshi et al. (1999) found that 14.4% of the population believed that they had symptoms relating to CTS, while only 3.8% of the population had clinically diagnosable CTS. Within certain industrial sectors, the prevalence of CTS was found to be as high as 61% in occupations involving low temperature, high force, and high repetition (Hagberg et al., 1992). In the professional moving industry, workers experience high static forces and awkward grip postures over long durations. During the survey of professional movers (Section 3.0), 34% reported having significant pain in the wrists and stiffness in the fingers in the morning. Consequently, it was decided to observe the wrist flexor activity during the carrying postures as it may elucidate any wrist pathologies occurring during the load carriage postures.

Concern about the affect of PC on the wrists arose because the altered load-carriage mechanics may cause differences in the wrist flexor activity between the two carrying postures. The PC method may alter the necessary grip force needed to secure the load due to the forces occurring between the load and the surface of the back. This could potentially alleviate grip forces necessary to secure the load. Furthermore, somatosensory input is known to moderate motor behaviour that controls grip force (Macefield et al., 1996; Jenmalm & Johansson, 1997). Additionally, visual information is used in a feed-forward manner to parametrically load motor control models before an object is contacted (Flanagan &Wing, 1997). Sainburg et al. (1993) demonstrated that

deafferented patients markedly increased motor performance given visual feedback of limb and hand position. Therefore, when holding an object behind the back, and thus outside of the visual field, visual parameters cannot be continuously loaded into the motor behaviour model. This may cause difficulties in predicting the necessary grip force to secure the object manually and thus result in excessive grip forces.

The results of this study indicated that the flexor digitorum muscle group did not show any significant differences between the two carrying postures. The data from this study showed that even though the subjects relied mainly on somatosensory feedback for load control during PC, there was no excessive generation of grip forces during PC relative to AC. Therefore, it is hypothesized that the PC method does not produce any pathological increases in wrist flexor activity. This hypothesis will need to be tested in future epidemiological studies.

Usability of Posterior Load Carriage in Professional Moving Applications

Similar to the results of Gagnon (1997) and Authier et al. (1995; 1996), it is probable that the load-handling techniques of experienced manual material handlers do provide a biomechanical advantage to novices' techniques. Subjects in this study had no previous professional moving experience or knowledge of specialized load-carriage techniques. Furthermore, except for grip type, subjects were not given detailed instruction on how to carry the load posteriorly. Despite the lack of experience and lack of instruction, the PC method still provided a noticeable biomechanical benefit on the back and surrounding musculature of the novice test subjects. Therefore, it is

recommended that the load carriage techniques of experienced movers be used by novice movers.

Limitations

The load carriage data was collected in a lab setting and thus produced methodological limitations. First, the box used in this study was not of the dimensions of a common 2 cu. ft. moving box in that it had the same width measurements but less depth. This may have altered the relative angles of the joints involved in gripping the load. Furthermore, the edges of the box contained hockey tape to increase the durability of the box. This tape could have increased the coefficient of friction on the surface of the box and further reduced necessary grip forces. Gait was simulated on a treadmill at a controlled speed. However, in field data, the gait speed may not be so linear depending on inclination or obstacles.

A total of five gait cycles were analyzed for this study. It may have been beneficial to measure more gait cycles to capture a greater spectrum of the step variability. Belli et al. (2004) found that the best representation of full gait variability was after 16-32 strides. Therefore, it may be possible that the gait cycles measured may have occurred at one biased end of the step variability spectrum.

Previous literature has shown that the motor behaviour between novice and expert MMH subjects is significantly different. Their different handling techniques can alter the biomechanical properties of certain tasks (Authier et al., 1995; Authier et al., 1996; Gagnon, 1997). Furthermore, it has been shown that excessive muscle force may be

generated when learning new motor behaviours, and such excessive force will decrease with greater experience (Witney et al., 2000; Flanagan et al., 2003). Therefore, it is possible that the results of this study may have been different had the subjects been professional movers with greater amounts of experience. Future study with an experienced subject pool may elucidate differences between inexperienced and experienced manual material handlers.

Finally, the sample size was relatively small and hence may have underestimated some of the advantages of the PC carry. For example, the trapezius muscle had marginal significance ($p=0.103$). Based on a power analysis, a sample size of only $n=14$ may have resulted in significantly lower median trapezius EMG activity. Therefore, future investigations should involve at least twice the sample size of this study.

4.5 Conclusion

In conclusion, when compared to the anterior carriage method, the posterior carriage method reduces erector spinae activity and focuses shoulder loading onto the posterior deltoid, but does not alter grip forces. The PC method may offer an effective alternative to traditional AC methods, especially for occupations with high tendencies for low back pain.

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Chapter 5

An Electromyographic Analysis of Unassisted and Assisted Load Carriage with Anterior or Posterior Load Placement

5.1 Introduction

Manual material handling (MMH) tasks, such as lifting and lowering, have been studied extensively through epidemiology and biomechanics (Kumar, 1990; Norman et al., 1998; Kerr et al. 2001). Load carriage is considered to be a sub-task of manual material handling (MMH). Many studies have investigated the physiological and biomechanical effects of assistive load carriage devices (Bobet & Norman, 1984; Harman et al., 1992; Knapik et al., 1997; Lloyd & Cooke, 2000; Stuempfle et al., 2004; Fiolkowski et al., 2006; Motmans et al., 2006). These studies have produced important pack design concepts regarding the optimal load placement, load arrangement and harnessing strategies.

Three main types of packs have been studied in the scientific literature: anterior packs (load secured in front of the body), posterior packs (load secured behind the body) and anterior/posterior packs (equal distribution of load in front and behind the body). It has been found that anterior/posterior packs are the most physiologically efficient packs as they do not alter the system moment equilibrium (Lloyd & Cook, 2000). Furthermore, Motmans et al. (2006) found that these packs produced the least change in trunk muscle EMG levels compared to a neutral standing posture. This is so because the external moments are balanced and require no generation of internal muscle moment to maintain system moment equilibrium. However, the benefits of using this pack are offset by the

discomfort, increased heat stress, and difficulty in proper load distribution in comparison to back packs (Knapik et al., 1997).

In an electromyographic comparison between front packs and back packs, Motmans et al. (2006) found that the front pack produced more 'unloaded' gait kinematics; however, they found that that the front pack elicited over twice the erector spinae EMG amplitude in comparison to the back pack. Furthermore, they found that the back pack condition reduced erector spinae activity below the levels found in unloaded standing (Motmans et al., 2006). Cook & Neumann (1987) found that carrying a load in a posterior arrangement decreased erector spinae EMG amplitude by half in comparison to the anterior carriage method. Furthermore, they found that the mean EMG amplitude of the erector spinae (when carrying 10%BW and 20%BW in a posterior location) was less than that of the mean for unloaded gait (the lowest being at 20%BW) (Cook & Neumann, 1987). More recently, a pack study by Devroey et al. (2007) also found that posterior load placement produce lower erector spinae activity than unloaded gait conditions. Therefore, regardless of static (standing) or dynamic (walking) conditions, posterior load placement significantly reduces erector spinae activity below that of anterior load placement and unloaded posture.

The forward-leaned postural deviation made with posterior load placement is adaptive because it equilibrates to the external posterior moment generated by the load (Bobet & Norman, 1984). Furthermore, the external posterior moment occurs in the same direction as the internal muscle moment generated by the erector spinae, thus reducing muscular effort of the erector spinae (Cook & Neumann, 1987). Thus, by reducing internal muscular moment and reducing the EMG amplitude of the erector

spinae, posterior load placement may reduce compressive forces of the lumbar vertebrae compared to anterior load placement (Potvin et al., 1991; Dolan & Adams, 1993; Hughes et al., 1994).

In a previous study (Chapter 3) conducted by the author of this paper, it was found that hand-held posterior load carriage produced similar findings to the pack studies by Cook & Neumann (1987) and Motmans et al. (2006). Even when only using the hands to secure the load, the posterior load placement reduced erector spinae EMG activity more than 50% of the anterior load placement method. However, hand-held posterior load carriage was found to alter the effort distribution of the shoulders and to focus more of the shoulder loading on the posterior deltoid. Thus, the authors concluded that unassisted posterior load carriage may benefit the lumbar vertebrae and erector spinae muscle groups, but focus shoulder loading onto the posterior deltoid.

In studies of experienced manual material handlers, Gagnon (1997) and Authier et al. (1995;1996) showed that expert load handling techniques often provide biomechanical advantages in comparison to novice load handling techniques. These authors believed that the years of practice in MMH gave experienced workers a psychophysical procedure to determine the most mechanically efficient techniques. From a previous electromyographic analysis (Chapter 3), the author of this paper also observed that hand-held posterior carriage (PC) used by experienced manual material handlers was more effective at reducing muscle loading of the back. However, from observations in a previous field study (Chapter 2), some movers did not use the PC technique when carrying loads. A sample of movers reported that the technique felt awkward and unsecured. Similar to Gagnon (1997) and Authier (1995;1996), the authors believe that

these workers should use the expert techniques earlier in their career to prevent the onset of work-related musculoskeletal disorders (WRMSD). However, in order to accomplish such a goal, posterior load carriage must be adapted to feel more comfortable and must increase the perception of load security.

There was an absence of evaluations regarding on-body ergonomic aids for professional movers in the scientific literature. Using information provided by professional movers (Chapter 3), an assistive load carriage device was made to aid the use of the PC method. However, the assistive device could also be oriented to assist in anterior carriage (AC). Therefore, the purposes of this study were: (1) to determine the differences in muscle effort between AC and PC conditions while using a larger moving box and different grip technique in comparison to Chapter 4, (2) to determine if the assistive device reduced muscle effort during AC, and (3) to determine if the assistive device reduced muscle effort during PC.

5.2 Methods

Subjects

Sixteen male subjects who were 25 ±5 years of age, 1.77±0.06m tall and weighed 82±12kg volunteered upon investigator request to participate in the study. The inclusion criteria consisted of male subjects 18-50 years of age. Exclusion criteria required no history of major musculoskeletal injuries in the past, especially any history of pain or injury to the lower back. Additionally, the study excluded subjects with any experience in the professional moving industry or knowledge of any specialized load carriage

techniques used in the moving industry. Having passed inclusion and exclusion criteria, the subjects completed an informed consent document to participate in the study.

Subjects' body weights and heights were then measured on a balance scale, and assessment of hand dominance was determined. Due to hardware complications with the EMG collection system, six subjects were excluded from the study leaving a total of ten subjects for analyses.

Variables

The independent variables in this study consisted of four load carriage conditions. The four independent variables were as follows: (1) unassisted anterior load carriage (AC), (2) unassisted posterior load carriage (PC), (3) assisted anterior load carriage using a specialized moving device (ACD), (4) assisted posterior load carriage using a specialized moving device (PCD).

The dependent variables in this study consisted of surface electromyography amplitudes measured from eight separate muscle sites. Additionally, one extra channel was collected containing a foot accelerometer used to identify gait cycles. Therefore, a total of nine channels of dependent variables were collected. Furthermore, a brief subjective survey was given to the subjects following the completion of the testing protocol that determined their somatosensory perception when using the assistive moving device.

EMG and Kinematics Setup

The surface EMG recording sites consisted of: the upper trapezius (TR) (midsection of line between the C7 and acromion); the anterior deltoid (AD) (2cm superior to the midline of muscle belly); the posterior deltoid (PD) (2cm superior to the midline of the muscle belly); the thoracic vertebrae erector spinae (TES) (5cm lateral to the T9 vertebrae); the lumbar erector spinae (LES) (3cm lateral to the L3 vertebrae); the rectus abdominus (RA) (3cm lateral and 2cm superior to the umbilicus); the external oblique (EO) (15 cm lateral to the umbilicus at 45 degrees from horizontal); and the flexor digitorum (FD) (7cm distal along line between medial epicondyle and wrist midline). A ground electrode was placed on the C7 spinous process (C7). These regions were identified, lightly abraded and cleansed with a swab containing a commercial blend of 70% rubbing alcohol and 30% water. A pair of circular Ag-AgCl Meditrace electrodes were placed on the cleansed areas in parallel with the muscle fibers with a 3cm inter-electrode distance.

A tri-axial accelerometer was attached to the lateral side of the subjects' heel on the left shoe with double-sided tape and covered by a layer of athletic tape. The accelerometer was connected to the A/D board and streamed with the EMG data at a sampling rate of 1000Hz.

The subjects' electrodes were connected to a Bortec AMT-8 with a signal gain of 1000K-5000K, a band pass filter of 20-500Hz and a sampling frequency of 1000Hz. All data were streamed into a 16-bit National Instruments A/D board at a sampling frequency of 1000Hz. As a digital signal, the data were saved onto a computer using NIAD

(commercially developed software by Labview). NIAD saved data as ASCII files at a frequency of 1000Hz.

The subjects lay supine on a foam-padded bench, and a 10-second silent period was collected. During the silent period, the subjects were instructed to close their eyes and take relaxing breaths. Once the subjects were completely still and relaxed, the silent-period data collection was initiated.

Following the silent periods, the subjects performed moderate level contractions for all eight muscle sites. The gains on the EMG collection system were adjusted to ensure maximal resolution without saturating the channels.

The subjects then moved to the treadmill. They walked unloaded on the treadmill at a speed of 2km/h for a total of two minutes. The accelerometer was monitored to ensure that it was correctly indicating heel strikes. All EMG channels were monitored to ensure that they were tracking their appropriate muscle correctly. After completing two minutes of walking, the subjects were asked if they felt comfortable and safe while on the treadmill. Upon answering "yes" the subjects were given a one-minute rest and asked to stand up on the treadmill again. The treadmill was once again brought to a speed of 2km/h. Ten seconds of natural and stable gait data were collected for three 10 second intervals. Subjects were not notified when the data were being collected. Once the data were collected, subjects safely dismounted the treadmill and were allowed to rest to full recovery.

Load Preparation

A 2 cu. ft. cardboard moving box, the type most commonly used by moving companies, was fitted with weight equaling 20% of each subject's body weight. The load

weight was positioned and secured directly in the centre of the box (in x, y, z axes) with cutout foam inserts. Any space remaining between weight plates was filled with packing foam to prevent the weights from moving around and accelerating inside the box.

Assistive Device Design and Specifications

The assistive device consisted of two main components: (1) a rigid set of aluminum stays fastened to a nylon backing plate and (2) a harnessing system to fix the stays on the body surface (Figure 5.1). The vertical force component of the load was primarily supported by the two aluminum stays, which projected outward from the body by 10.1cm. They were covered with a high friction mat coating to increase the friction between the box and the resting surface. The vertical portion of the stays (25.4cm) were attached to a dense and flexible nylon backing with three bolts per stay. The nylon backing was then used to attach all harnessing straps.

The harnessing system primarily consisted of 7.6cm wide shoulder straps and a padded hip belt. Additionally, an elastic strap was used at the top of the backing to prevent it from pulling away while under load. All straps were length adjustable that fit various types of anthropometry. The hip belt consisted of broad padding that evenly distributed the forces acting along the sacrum (during AC) or abdomen (during PC). The assistive device did require readjustment when switching between anterior and posterior methods; however, such adjustments were rapid (<20 seconds).

Figure 5.1 – Photographs of the assistive device used in this study. Part A) displays the side of the assistive device that articulates with the load being carried. B) displays the harnessing that secures the device to the body. C) Shows the device being used by a subject during PCD. Note how the aluminum stays project outward from the lower sacrum to support the vertical force component of the load

Test Condition Organization

Random selection was used to determine the order of the four independent variable testing conditions (AC, PC, ACD, PCD). The trials were performed until three trials of each testing condition were recorded, creating a total of 12 test condition iterations for the entire study. The subjects performed each testing condition once for 60s to familiarize themselves with each unique testing condition. The subjects were also given instructions regarding load carriage technique; see below for details.

Load Carriage Technique and Device Adjustment

The following descriptions of load carriage instructions and device adjustments given to the subjects were based upon investigator observation, surveys (n=30) and needs assessments (n=42) across three independent moving companies. Thus, the techniques used by the subjects are representative of the techniques used by professional movers.

For the unassisted anterior load carriage technique (AC), the subjects were told to hold the box naturally at waist level so that it did not interfere excessively with leg movement. They were asked to grip the box as they normally would in common load carrying tasks.

For the unassisted posterior load carriage technique (PC), the subjects were told to hold the centre of the box at the level of their sacrum. The subjects were also instructed to use their dominant hand to hold the mid-vertical edge furthest from their body and their non-dominant hand held the bottom corner of the box closest to their body. They were told to keep both arms straight and relaxed.

For the assisted anterior load carriage with the specialized assistive device (ACD), the device was adjusted according to the above criteria to ensure a consistent fit. The midline of the hip belt was adjusted so that it lay overtop the anterior superior iliac crest. The thoracic strap was placed at the level of the T10 vertebrae. The tension in the shoulder straps was adjusted so that the aluminum stays did not shift under the load of the box. When the box was placed into the moving device, subjects were told to grip the box at the top two corners furthest from their body and let the pack support the bottom of the load.

For the assisted posterior load carriage with a specialized device (PCD), subjects were fitted to ensure a standardized fit across all trials. The midline of the hip belt was again placed over the anterior superior iliac spine to the front and the top line of the sacrum at the back. The thoracic strap was placed below the xiphoid process. The tension of the shoulder straps was adjusted so that the hip belt did not move under the load of the moving box. The subjects were instructed to grip the box using a similar technique to the unassisted posterior load carriage trials.

Test Condition Procedural Protocol

The four load carriage conditions were randomized prior to data acquisition. For all load carriage trials, the investigator placed the load in the subjects' hands and increased the treadmill velocity to 2km/h. The subjects used the load carriage techniques listed above for each respective condition. The subjects carried the load for 20s with a regular four-finger grip. After 20s, data collection of the EMG and accelerometer began and continued for another 10s. The subjects were not notified when data were being

collected during the trial. The subjects carried the load for a total of 30s per trial after which the investigator stopped the treadmill and removed the load from their hands and seated subjects so they may rest for two minutes. For safety purposes, subjects were asked whether they were sensing any pain or discomfort. Upon answering "no" the subjects then stood on the treadmill to begin the next trial.

Subjective Survey

At the completion of the trials, the subjects were once again asked if they were experiencing any pain or discomfort. They were also asked to give their opinion of the advantages and disadvantages of the two carrying techniques and the assistive device through four questions: (1) "Which posture would you use next time you move?", (2) "Did you find the posterior carriage method to be awkward?", (3) "Did the assistive device make anterior load carriage easier?", (4) "Did the assistive device make posterior load carriage easier?". Their opinions were recorded in an Excel spreadsheet. At this point the subjects were released from the study.

Data Analyses

A data analysis program developed in Labview 7.0 (National Instruments, Austin, TX) was used to process the data. The accelerometer produced sharp voltage spikes every time heel contact was made. Since the accelerometer data were time synchronized to the EMG data, the voltage spike on the accelerometer channel was used to identify eight heel strikes on the right foot. Therefore, starting with the first voltage spike, eight

spikes were counted, thus identifying eight gait cycles. This isolated section of EMG data was used for the analysis, and this EMG sectioning procedure was used for all trial data.

A second-order Butterworth filter was performed both forwards and backwards on all data with a low pass cutoff frequency of 6Hz. Only the data for the section of eight isolated gait cycles were used for the analyses.

Then an Amplitude Probability Distribution Function (APDF) was performed. Bins from 1-2000 were created to represent 0 – 1999 mV values. A histogram record was created that totaled the number of EMG data samples occurring in each 1 mV increment between 0 and 1999 mV. From the histogram data, a cumulative probability curve was made for each trial. From plotting the curve for samples collected in the trial, an amplitude probability for the entire trial was determined at the 10th (static), 50th (median), and 90th (peak) percentile values. The APDF values for the three trials within one test condition were averaged for each muscle group measured.

The APDF values determined for the unloaded walking condition became the basis for data normalization. All 10th percentile values for the test condition trials were normalized to the 10th percentile values during the unloaded walking. The same normalization procedure was completed for the 50th and 90th percentiles. Thus, all test condition APDF EMG values were represented as a ratio of their APDF percentile values during unloaded walking.

The data were then tabulated and loaded into SPSS for a repeated measures ANOVA statistical test. Through multiple pair-wise comparisons and a Bonferroni correction, the data were tested for significant differences between the various test

conditions at the 10th, 50th, and 90th percentiles. The means, standard deviations, and significance values were tabulated and graphed for analysis. For further analysis of the effects of the PC method in comparison to the AC on the erector spinae, percent differences were calculated for the TES and LES between the PC and AC methods. Furthermore, Grubb's test for significant outliers (z-score cutoff = 2.29, n=10) was performed on all subjects within a muscle group for each test condition (AC, PC, ACD, PCD), to determine if subjects responded to the assistive device in the same manner.

5.3 Results

Below, is a description of the significant and notable results found in this study. For further information, graphic results are shown in Figures 5.2-5.6, with summary data in Tables 5.1-5.4. Appendix A and B contain further summary tables and figures that display all four test conditions in one plot.

Comparing Unassisted Anterior to Unassisted Posterior Load Carriage

Graphic results are shown in Figure 5.2, with summary data in the Table 5.1. In comparing both the AC and PC conditions, the results were similar to those of the initial unassisted load carriage study (Section 4.0). Both the thoracic erector spinae (TES) and lumbar erector spinae (LES) had significant reductions (>50%) in their muscle activity at the 10^{th}, 50^{th} and 90^{th} percentiles in the PC condition when compared to the AC condition ($p<0.05$) (Figure 5.2a, 5.2b and 5.2c). In contrast to the previous study (Section 4.0), the PC condition did not achieve significant increases in EMG activity in the posterior deltoid compared to the AC condition ($p>0.384$). The trapezius and anterior deltoid showed larger EMG amplitudes in the AC condition compared to the PC condition; however, significance was only reached for the trapezius at the 90^{th} percentile ($p<0.05$). The PC condition did produce higher EMG amplitudes in the rectus abdominus and external oblique, although significance was only achieved for the external oblique at the 90^{th} percentile ($p<0.05$). Lastly, there were no significant differences between the AC and PC conditions with regards to the flexor digitorum EMG amplitudes.

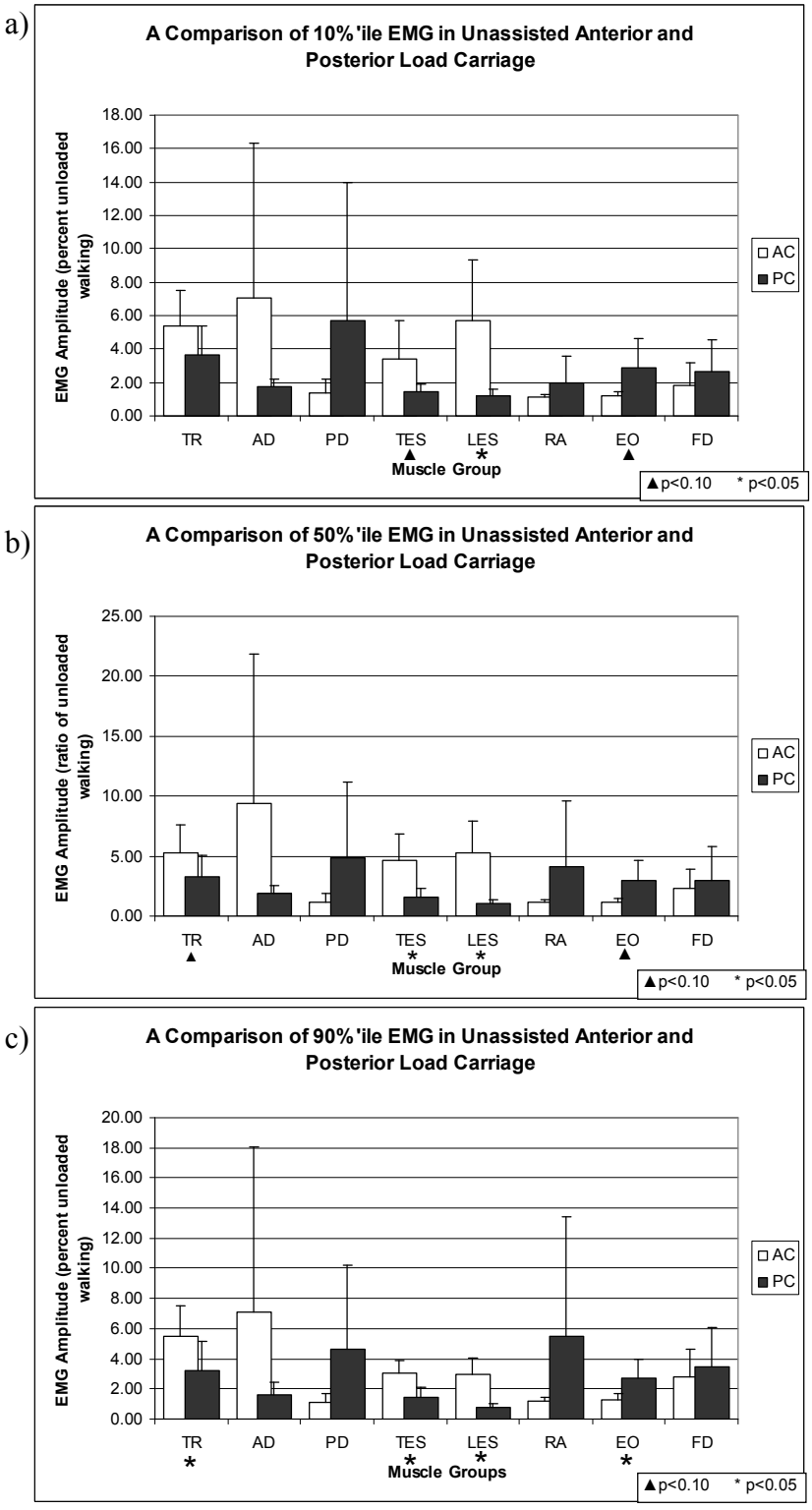


Figure 5.2 - A comparison between AC and PC carriage methods for the a) 10th b) 50th and c) 90th percentile EMG amplitudes. [1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum

Table 5.1 - The EMG APDF values comparing unassisted anterior and unassisted posterior load carriage. Significant values are $p<0.05$.

EMG APDF percentile means for unassisted anterior and unassisted posterior load carriage (n=10)

	TR		AD		PD		TES		LES		RA		EO		FD	
	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC	AC	PC
10th Percentile																
Mean	**5.39**	**3.62**	**7.09**	**1.77**	**1.36**	**5.73**	**3.41**	**1.43**	**5.72**	**1.25**	**1.15**	**2.01**	**1.18**	**2.91**	**18.60**	**26.40**
SD(+/-)	±2.11	±1.74	±9.21	±0.40	±0.80	±8.23	±2.32	±0.49	±3.61	±0.33	±0.15	±1.57	±0.22	±1.74	±13.0	±18.9
p-value	**0.379**		**0.584**		**0.618**		**0.094**		**0.018**		**0.632**		**0.079**		**0.860**	
50th Percentile																
Mean	**5.30**	**3.29**	**9.43**	**1.88**	**1.19**	**4.88**	**4.61**	**1.55**	**5.32**	**1.04**	**1.17**	**4.06**	**1.16**	**2.92**	**23.20**	**29.50**
SD(+/-)	±2.33	±1.78	±12.41	±0.61	±0.67	±6.28	±2.28	±0.82	±2.63	±0.31	±0.20	±5.54	±0.31	±1.68	±16.1	±29.0
p-value	**0.095**		**0.493**		**0.479**		**0.004**		**0.003**		**0.774**		**0.077**		**1.000**	
90th Percentile																
Mean	**5.45**	**3.23**	**7.11**	**1.59**	**1.11**	**4.65**	**3.05**	**1.40**	**2.96**	**0.76**	**1.16**	**5.52**	**1.26**	**2.70**	**27.57**	**34.29**
SD(+/-)	±2.08	±1.91	±10.97	±0.84	±0.60	±5.56	±0.86	±0.73	±1.09	±0.29	±0.26	±7.87	±0.42	±1.24	±18.8	±26.1
p-value	**0.017**		**0.845**		**0.384**		**0.014**		**0.002**		**0.664**		**0.047**		**1.000**	

Muscle Group Abbreviations

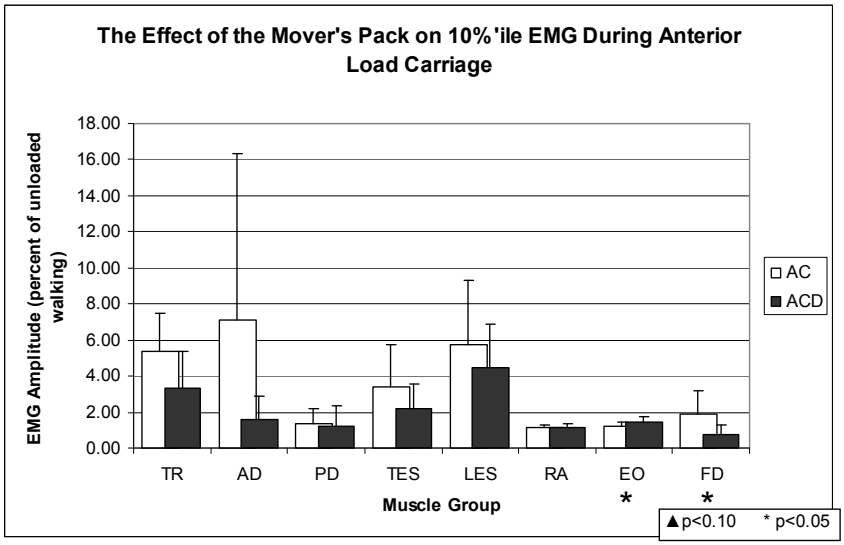
TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

Comparing Assisted to Unassisted Anterior Load Carriage

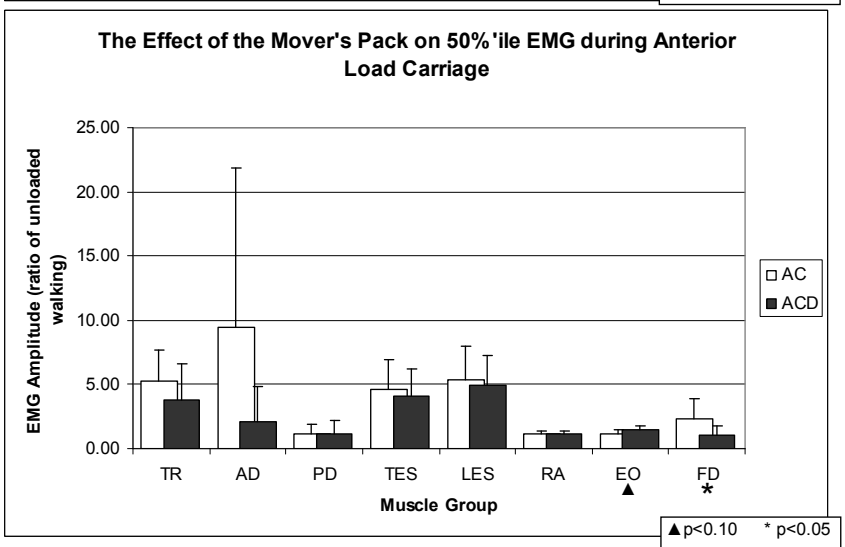
Graphic results are shown in Figure 5.3a, 5.3b and 5.3c, with summary data in the Table 5.2. The most significant effect of using the assistive device during anterior load carriage was the reduction in the flexor digitorum activity. A minimum of a 56% reduction ($p<0.05$) in FD activity was found across all percentile ranges with the greatest reduction of 61% occurring in the peak 90^{th} percentile range ($p=0.015$). Thus, the use of the assistive device significantly reduces grip effort during AC.

The trapezius means attained at least a 25% reduction in all APDF ranges; however, it only displayed a strong trend ($p=0.08$) in the 90^{th} percentile range. The means for anterior deltoid were reduced by more than 75% when using the assistive device, however, the difference in means were not significant ($p=0.51$). The posterior deltoid appeared to be unaffected by the use of the assistive device during anterior load carriage. The assistive device appeared to not create any significant differences in the means of the erector spinae and abdominal muscle groups.

a)



b)



c)

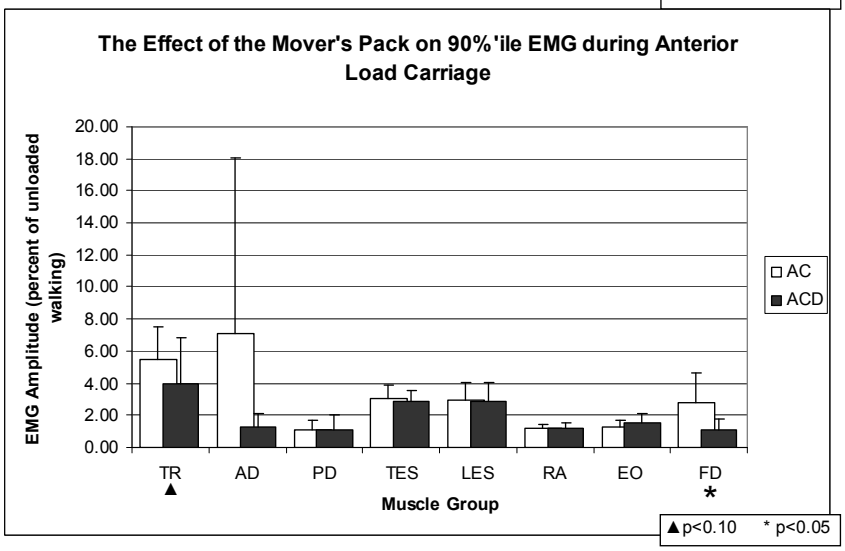


Figure 5.3 - A comparison between AC and ACD carriage methods for the a) 10^{th} b) 50^{th} and c) 90^{th} percentile EMG amplitudes. [1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Table 5.2 - The effect of the assistive moving device on the EMG APDF values during anterior load carriage. Significant values are $p<0.05$.

EMG APDF percentile means for unassisted anterior and assisted anterior load carriage (n=10)

	TR		AD		PD		TES		LES		RA		EO		FD	
	AC	ACD	AC	ACD	AC	ACD	AC	ACD	AC	ACD	AC	ACD	AC	ACD	AC	ACD
10th Percentile																
Mean	**5.39**	**3.31**	**7.09**	**1.57**	**1.36**	**1.24**	**3.41**	**2.20**	**5.72**	**4.50**	**1.15**	**1.16**	**1.18**	**1.44**	**18.60**	**7.70**
SD(+/-)	±2.11	±2.09	±9.21	±1.29	±0.80	±1.08	±2.36	±1.37	±3.61	±2.35	±0.15	±0.17	±0.22	±0.30	±13.0	±5.3
p-value	**0.261**		**0.514**		**1.000**		**0.143**		**0.147**		**1.000**		**0.034**		**0.026**	
50th Percentile																
Mean	**5.30**	**3.78**	**9.43**	**2.06**	**1.19**	**1.18**	**4.61**	**4.06**	**5.32**	**4.91**	**1.17**	**1.16**	**1.16**	**1.46**	**23.20**	**10.10**
SD(+/-)	±2.33	±2.88	±12.41	±2.77	±0.67	±1.05	±2.28	±2.17	±2.63	±2.32	±0.20	±0.21	±0.31	±0.36	±16.1	±8.1
p-value	**0.230**		**0.513**		**1.000**		**0.373**		**0.382**		**1.000**		**0.072**		**0.017**	
90th Percentile																
Mean	**5.45**	**3.96**	**7.11**	**1.24**	**1.11**	**1.13**	**3.05**	**2.89**	**2.96**	**2.89**	**1.16**	**1.19**	**1.26**	**1.52**	**27.60**	**10.60**
SD(+/-)	±2.08	±2.89	±10.97	±0.84	±0.60	±0.87	±0.86	±0.66	±1.09	±1.17	±0.26	±0.32	±0.42	±0.57	±18.8	±7.6
p-value	**0.083**		**0.754**		**1.000**		**1.000**		**1.000**		**1.000**		**0.213**		**0.015**	

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

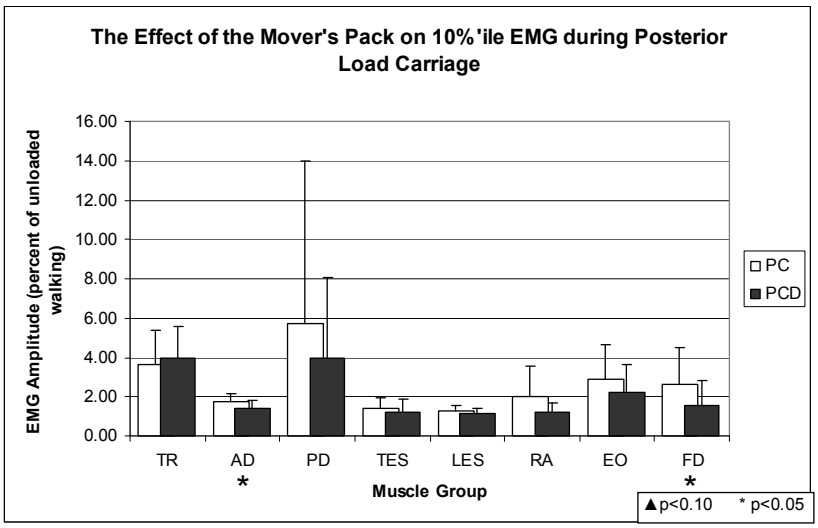
Comparing Assisted to Unassisted Posterior Load Carriage

Graphic results are shown in Figure 5.4a, 5.4b and 5.4c, with summary data in the Table 5.3. There were significant reductions in the flexor digitorum EMG activity across all percentile values ($p<0.05$) for the assisted posterior load carriage condition. A minimum of a 56% reduction ($p=0.02$) in EMG amplitude occurred when using the device during assisted posterior load carriage.

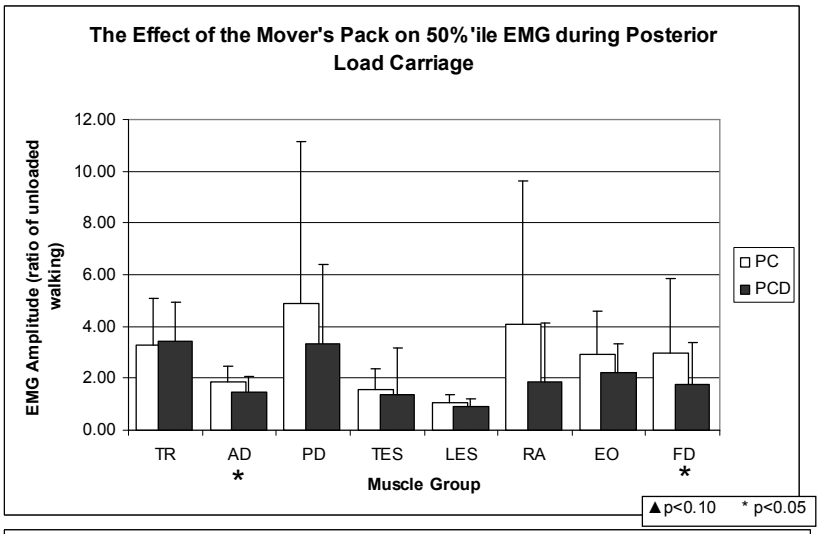
During posterior load carriage, the assistive device had a significant effect on the anterior deltoid. It produced a minimum 19% reduction ($p<0.05$) in EMG activity at the 10^{th} and 50^{th} percentiles and near-significant reduction ($p=0.06$) at the 90^{th} percentile. There were no significant effects of the assistive device on the trapezius or the posterior deltoid.

The assistive device produced no significant decreases in TES or LES EMG activity during posterior load carriage. There was a difference of means in the rectus abdominus (minimum 39% reduction at 10^{th} percentile, $p=0.29$) and external oblique (average 29% reduction at 10^{th} percentile, $p=0.16$); however, the differences were not statistically significant.

a)



b)



c)

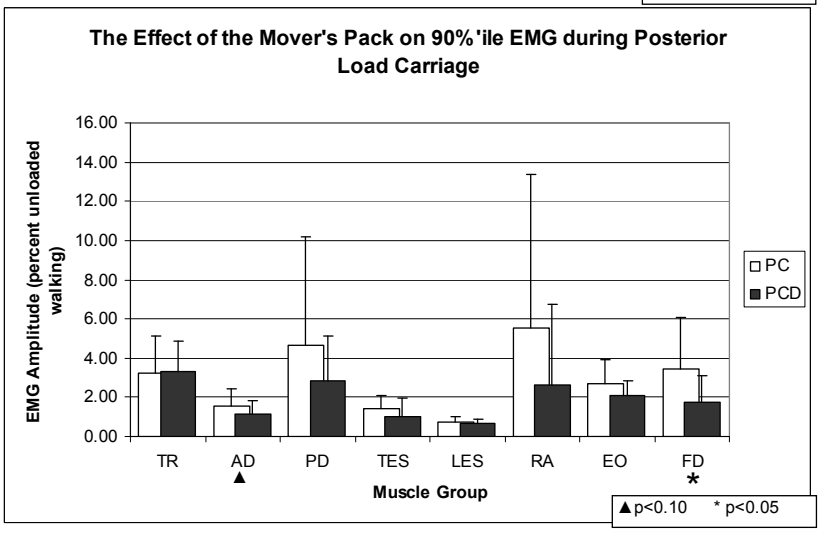


Figure 5.4 - a) A comparison between PC and PCD carriage methods at the a) 10th, b) 50th and c) 90th percentile EMG amplitudes. [1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Table 5.3 - The effect of the assistive moving device on the EMG APDF values during posterior load carriage. Significant values are $p<0.05$.

EMG APDF percentile means for unassisted posterior and assisted posterior load carriage (n=10)

	TR		AD		PD		TES		LES		RA		EO		FD	
	PC	PCD	PC	PCD	PC	PCD	PC	PCD	PC	PCD	PC	PCD	PC	PCD	PC	PCD
10th Percentile																
Mean	**3.62**	**3.95**	**1.77**	**1.44**	**5.73**	**3.94**	**1.43**	**1.18**	**1.25**	**1.11**	**2.01**	**1.22**	**2.91**	**2.24**	**26.40**	**15.30**
SD(+/-)	±1.74	±1.66	±0.40	±0.35	±8.23	±4.10	±0.49	±0.68	±0.33	±0.29	±1.57	±0.49	±1.74	±1.38	±18.9	±13.0
p-value	**1.000**		**0.001**		**1.000**		**1.000**		**0.697**		**0.298**		**0.165**		**0.009**	
50th Percentile																
Mean	**3.29**	**3.45**	**1.88**	**1.48**	**4.88**	**3.33**	**1.55**	**1.38**	**1.04**	**0.91**	**4.06**	**1.87**	**2.92**	**2.23**	**29.50**	**17.40**
SD(+/-)	±1.78	±1.51	±0.61	±0.57	±6.28	±3.10	±0.86	±1.82	±0.31	±0.30	±5.54	±2.27	±1.68	±1.11	±29.0	±16.0
p-value	**1.000**		**0.011**		**1.000**		**1.000**		**0.702**		**0.410**		**0.277**		**0.022**	
90th Percentile																
Mean	**3.23**	**3.33**	**1.59**	**1.14**	**4.65**	**2.87**	**1.40**	**1.01**	**0.76**	**0.65**	**5.52**	**2.64**	**2.70**	**2.07**	**34.29**	**17.60**
SD(+/-)	±1.91	±1.50	±0.84	±0.68	±5.56	±2.27	±0.73	±0.97	±0.29	±0.24	±7.87	±4.15	±1.24	±0.79	±26.1	±13.9
p-value	**1.000**		**0.068**		**0.940**		**0.898**		**0.923**		**0.250**		**0.532**		**0.029**	

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

Results of Subjective Survey

In response to question 1: "Which posture would you use next time you move?", 46.67% of subjects reported that they would use the unassisted posterior load carriage posture next time they moved. In response to question 2: "Did you find the posterior carriage method to be awkward?", 66.67% reported that the unassisted posterior load carriage method felt awkward and foreign. In response to question 3: "Did the assistive device make anterior load carriage easier?", all subjects (100%) found that the assistive load carriage device made the anterior load carriage easier compared to unassisted anterior load carriage. The most common reasoning behind this answer was that little grip force was required to secure the load compared to the unassisted anterior load carriage condition. In response to question 4: "Did the assistive device make posterior load carriage easier?", all but one subject (93.33%), found that the assistive load carriage device made posterior load carriage easier. The most common reasoning for this response was that they "did not have to hold the load up" but rather just focused their muscular effort on "holding the box against their backs".

Outlier Analysis

Statistical outliers were detected in the PC, ACD, and PCD test conditions for subjects 4, 6, and 7. Subject #4 was classified as a statistical outlier (z-score cutoff = 2.29, n=10) in the rectus abdominus and posterior deltoid in the PC and PCD test conditions. Subject #7 was classified as a statistical outlier in the thoracic erector spinae in the PC and PCD conditions and the anterior deltoid in the ACD condition. Lastly,

subject #6 was classified as a statistical outlier in the trapezius in the ACD condition. Refer to Table 5.4 for a summary of outlier results.

Table 5.4 – A summary of the outliers detected in the 50th percentile APDF. Values presented are EMG amplitudes normalized to unloaded gait. Results are grouped by test condition (PC, PCD, ACD) and by muscle group. Outliers are indicated by the shaded squares.

	PC		
Subject	PD	TES	RA
1	**5.15**	**1.01**	**2.04**
2	**3.37**	**0.96**	**2.69**
3	**2.08**	**1.97**	**1.50**
4	**21.87**	**1.01**	**19.37**
5	**0.54**	**1.20**	**4.90**
6	**5.94**	**1.63**	**1.79**
7	**5.47**	**3.52**	**1.20**
8	**1.31**	**1.10**	**1.57**
9	**1.57**	**2.15**	**4.54**
10	**1.48**	**0.99**	**1.03**

	PCD		
Subject	PD	TES	RA
1	**5.87**	**0.88**	**1.27**
2	**2.52**	**0.83**	**1.47**
3	**1.86**	**1.03**	**1.11**
4	**10.51**	**0.85**	**8.29**
5	**1.47**	**0.44**	**1.57**
6	**1.58**	**0.88**	**0.91**
7	**5.67**	**6.53**	**1.00**
8	**1.51**	**0.52**	**1.02**
9	**0.54**	**0.87**	**1.09**
10	**1.76**	**0.99**	**0.95**

	ACD	
Subject	TR	AD
1	**4.01**	**1.07**
2	**1.01**	**1.17**
3	**3.64**	**0.58**
4	**0.62**	**1.08**
5	**3.38**	**1.16**
6	**10.82**	**0.99**
7	**2.53**	**9.87**
8	**3.74**	**1.55**
9	**2.36**	**1.23**
10	**5.69**	**1.87**

Muscle Group Abbreviations

TR = trapezius	AD = anterior deltoid	PD = posterior deltoid
RA = rectus abdominus	EO = external oblique	FD = flexor digitorum
TES = thoracic erector spinae	LES = lumbar erector spinae	

Subject #7 was not only a statistical outlier, but also displayed trends that responded in the opposite direction of other subjects between test conditions. When monitoring the response of the TES muscle between the PC and PCD conditions, subject #7 experienced large increases in TES activity when using the device. For a graphical description of how subject seven responded to the use of the device during PC (Figure 5.5).

Furthermore, subjects #4 and #7 responded in opposite manners to the same test condition while being statistical outliers. During PCD, subject #4 displayed larger proportions of RA activity in comparison to TES activity. In contrast, during PCD, subject #7 displayed larger proportions of TES activity in comparison to RA activity. Refer to Figure 5.6 for a graphical representation of this phenomenon.

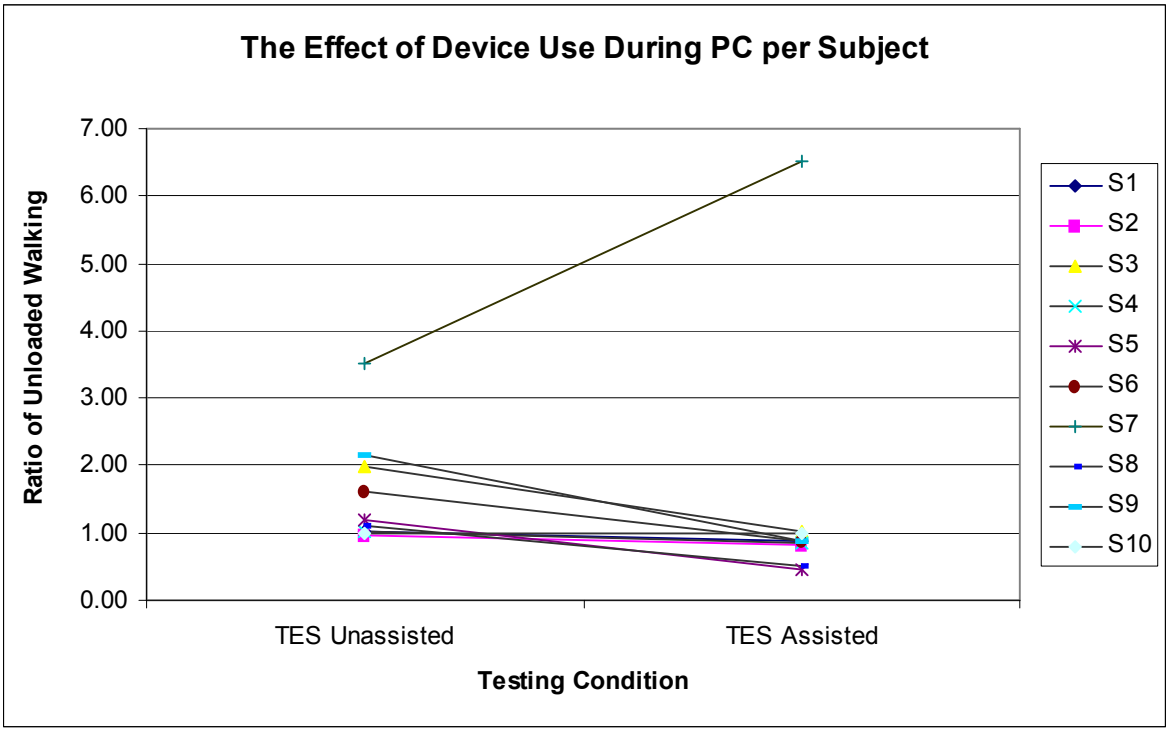


Figure 5.5 - Descriptive plot displaying the effect of the assistive device on median thoracic erector spinae (TES) activity during PC gait. It is evident that there is inter-subject variability regarding the effect of the device.

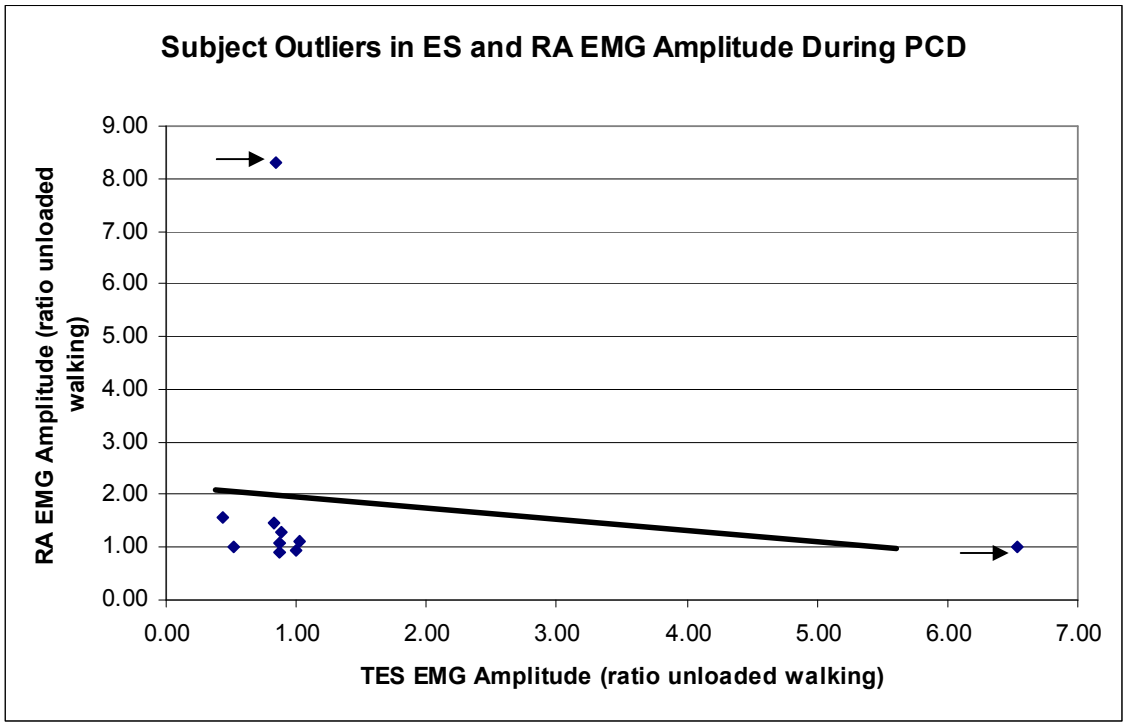


Figure 5.6 - A plot of each subject's 50th percentile rectus abdominus (RA) activity versus thoracic erector spinae (TES) activity in the PCD condition. Statistical outliers, subjects #4 and #7, are indicated by arrows, and a linear trend was line added

5.4 Discussion

The primary objective of the study was to investigate the effect of an assistive device on muscle effort during ACD and PCD conditions, using EMG and subjective surveys. It was also possible to examine the AC and PC conditions with a different EMG normalization method and changes in load parameters and carriage technique. However, before such analysis is discussed, consideration must be given to inter-subject variability.

Inter-subject Variability

Many significant differences were found between AC/PC, AC/ACD and PC/PCD comparisons. However, the EMG responses to the PC method and the assistive device were not consistent between all subjects. This was best exemplified through the thoracic erector spinae and rectus abdominus muscles (figures 5.5 and 5.6). The occurrence of inter-subject variability has been noted in other studies of ergonomic devices (Burgess-Limerick et al., 1999; Tepper et al., 2003). The authors suggest the source of variability may be due to anthropometric differences of body segments or strength. Additionally, due to a lack of experience, some subjects may not have used the most mechanically-efficient motor behaviour due to differences in motor learning rates while carrying the load, which would have resulted in altered recruitment of certain muscle groups in comparison to other subjects (Flanagan et al., 2003; Witney et al., 2000; Gagnon, 1997; Authier et al., 1996; Authier et al., 1995).

In Figure 5.6, it can be seen that eight of ten subjects recruit similar proportions of the muscle groups RA and TES compared to unloaded gait. However, subject #4 disproportionately recruited the RA and subject #7 disproportionately recruited the TES.

Each subject may have balanced the external load in such a manner that the disproportionate muscle recruitment could be maintained without disturbing the L5-S1 moment equilibrium during *loaded* gait. This proves that different subject may perform the same through different biomechanical methods. Therefore, further study is required that would involve detailed anthropometric measurements of multiple body segments and provide the subjects with detailed instruction and sufficient time to practice each test condition. Furthermore, sampling the subjects over a period of hours or days, rather than minutes, would also allow researchers to study the effect of motor learning and how it may reduce mechanically inefficient motor activity (Witney et al., 2000; Flanagan et al., 2003).

It was decided not to exclude the outliers from the statistical analysis as the findings may not be due to a known exceptional circumstance within that particular subject. It is argued that outliers should only be removed when they are statistically identified and the physical nature of their outcome is understood (Lewis, 1999). In many cases, understanding the physical nature behind the outlying result will effectively determine the proper course of action to manage the outlier (Lewis, 1999). If outliers are removed without this understanding, statistical significance will be improved; however, clinical significance of the results may be diminished. With possible mechanisms hypothesized to explain the outlier phenomenon, further investigation is required to identify the source of biomechanical variability between the subjects before they can be effectively removed from this study.

Unassisted Anterior and Posterior Load Carriage

The normalization method used in this study allowed for an interesting observation in that the peak APDF value for the LES during unassisted PC was actually below that of normal unloaded gait (ratio = 0.76) and the median LES APDF value was comparable to normal unloaded gait (ratio = 1.04). Thus, when subjects were carrying 20% of their own body weight, the PC method maintained similar or lower levels of erector spinae activity to that of unloaded gait. These findings are similar to other studies that compared mean EMG amplitudes between posteriorly loaded to unloaded conditions (Cook & Neumann, 1987; Motmans et al., 2006; Devroey et al., 2007). This study was also similar to Motmans et al. (2006) and Cook & Neumann (1987), who found that erector spinae EMG activity during PC was less than 50% of EMG activity during anterior load placement. Comparatively, the results of this current study are less dramatic than Motmans et al. (2006) and Cook & Neumann et al. (1987): only the peak (90th) LES EMG activity was below that of unloaded conditions and static and median levels were similar to unloaded gait (refer to Table 5.1, values <1.00 are below that of unloaded condition). However, differences in percent bodyweight and load parameters may have lead to the difference in reported erector spinae activity between these studies. Therefore, further investigation is required to determine the effect of load mass and load dimension on erector spinae activity.

The Effect of the Assistive Device on Posterior and Anterior Load Carriage

Both studies have demonstrated that the unassisted posterior load carriage method (PC) creates significant reductions in erector spinae activity and thus may significantly benefit the lumbar spine through reductions in compressive force. However, as discussed in the introduction, some novice movers do not use the PC method because of the difficulty in learning the technique and the lack of perceived load security. Therefore, the authors thought it would be ideal to design an assistive load carriage device that would make PC easier to perform by novice movers. One primary objective of this study was to determine if the assistive device could reduce the necessary muscular activity needed to perform the PC technique. However, when testing prototype devices in the field, it became apparent that many professional movers may use the device for AC as well. Thus the secondary objective was to study the effects of the assistive device on AC. Such data would provide information regarding whether ACD would provide any benefit over unassisted AC conditions. Below is a discussion of the effects of the device on the musculoskeletal system in both AC and PC conditions.

The Effect of the Device on the Distal Extremities

The most noticeable effect of the assistive device is the significant reduction in flexor digitorum EMG across all percentiles. In the mover survey (Section 3.0) it was found that movers experience high static forces and awkward grip postures over long work durations. During the survey (n=30), 34% reported having significant wrist pain and stiffness in the wrist and fingers in the morning.

The data suggests that the device is effective at reducing grip forces in both ACD and PCD conditions. When regarding Tables 5.2 and 5.3, it can be seen that the greatest reduction in flexor digitorum activity occurred with device usage in ACD (>50% reduction, $p<0.03$). During PCD, significant reductions in flexor digitorum activity also occurred across all percentile ranges (>40% reduction, $p<0.03$). The difference in the percent reductions between the ACD and PCD conditions may be caused by differences in wrist postures and angles during force application. However, the assistive device was highly effective in reducing grip forces compared to its unassisted postures in both AC and PC conditions. Therefore, device use may reduce the incidence of force-dependent wrist pathologies (Silverstein, 1987; Moore et al., 1991).

The Effect of the Mover's Pack on the Erector Spinae

Posterior Load Carriage

The use of the assistive device during PCD appeared to have no significant effect on the activity of the TES and LES. Such an outcome was not unexpected, as the device did not bypass the use of the erector spinae to offset the external moment created by the load. Indeed, the mean values of the LES were below that of unloaded gait for both the PC and PCD conditions. However, this outcome is due mainly to the posture adopted while being posteriorly loaded, with or without the device. However, when referring to Table 5.4, all subjects except for subject #7 experienced a reduction in rectus abdominus activity when using the device in PC/PCD conditions. Therefore further investigation is required to determine why subject #7's back musculature may have responded differently to device usage during PCD. However, the results suggest that the use of the device

during PC does not appear to provide any reductions in TES or LES muscular activity or muscular compression of the spine.

Anterior Load Carriage

The use of the assistive device during ACD appeared to have no significant effect on the activity of the TES and LES. Such an outcome was not unexpected, as the device did not bypass the use of the erector spinae to offset the external moment created by the load. The ACD condition did display increasing significance values when lower percentiles were approached (i.e., 10^{th} percentile LES = 0.14). Power analysis indicated that an increase in subject sample size to n=15, would effectively determine whether or not the static EMG results for the LES during AC could be statistically significant.

The Effect of the Device on the Abdominal Muscles

The abdominal musculature (RA and EO) responded differently to the use of the assistive device during AC and PC methods. During manual material handling, the abdominal muscles serve dual roles in balancing the system moment equilibrium and participating in co-contraction with the back musculature to generate stability in the lumbar vertebrae. The external oblique and rectus abdominus muscle groups are an active contributor to trunk flexion (McGill, 1996) and spinal stability (Cholewicki et al., 1997; Gardner-Morse & Stokes, 1998; Cholewicki et al., 2000; Granata & Orishimo, 2001). Therefore, changes in abdominal EMG may indicate changes in trunk posture or changes in the system stability.

Posterior Load Carriage

Although the means for the rectus abdominus and external obliques appear less when the device was used during PC, the results are not significant. Thus the device does not induce any reactive muscle contractions of the abdominal musculature as seen with weight-lifting belt usage (Miyamoto et al., 1999). This suggests that the device does not create changes in motor behaviour of the abdominal muscles during PC.

Anterior Load Carriage

The external obliques experienced a 25% increase in static ($p=0.03$) and median ($p=0.07$) EMG activity when the device was used. Of the four paraspinal muscles measured (TES, LES, RA, EO), the external obliques were the only muscle to show significant increases with device usage during ACD. It is not likely that the increased activation of the external oblique will significantly increase spinal compressive forces, as shown in a stability modeling study by Gardner-Morse & Stokes (1998). However, it is possible that the increased external oblique recruitment is not a result of a stabilizing response since a stabilizing response would have also increased antagonistic TES and LES muscle groups (Cholewicki et al., 1997; Granata & Orishimo, 2001). A more appropriate explanation is that the increased EO may be a result of a change in carrying posture. Due to the fit of the device, the box was typically held lower on the anterior side of the pelvis during ACD compared to PCD. This may result in greater hip-hiking to overcome the added resistance of pelvic motion during gait. Further kinematic investigation is needed to determine whether the device lowered the load to the point where it obstructed normal gait patterns of the legs and pelvis.

The Effect of the Assistive Device on the Shoulder Musculature

Literature has shown that cumulative static loading of the trapezius can lead to increased reporting of shoulder and neck injury and myalgia (Westgaard et al., 1986; Veiersted et al., 1993; Veiersted, 1994). Furthermore, an industrial study indicated that peak shoulder forces also predict incidence of reported shoulder pain (Fethke et al., 2007). When both AC and PC conditions were considered, the assistive device did not create any significant increases in shoulder EMG amplitudes. Therefore, it is not believed that the assistive device would increase the incidence of force-dependant injury to the shoulder musculature.

However, there was a presence of an outlier in the anterior deltoid activity. Therefore, further analysis must be conducted to determine if sample size, task learning/familiarization, or device fit are the causes of this variability. Identifying such factors would allow for the more effective use of the assistive device.

Posterior Load Carriage

The device produced significant reductions in EMG activity (18%-28% reduction, $p<0.05$) for the anterior deltoid. This may possibly be due to the subjects having to apply less shoulder force to hold the box up against their back. Additionally, due to greater load stability, there may have been less co-contraction occurring in the shoulder musculature in reaction to increased load stability when using the assistive device (van der Helm & Rozendaal, 2000; van Dieen et al., 2003; Milner, 2004). The greatest significance in the anterior deltoid occurred in the 10^{th} and 50^{th} percentiles ($p<0.02$) and the least significant effect occurred in the 90^{th} percentile ($p=0.068$). This suggests that

the assistive device is most effective at reducing anterior deltoid activity due to potential changes in postural forces and/or increased stability during the PCD condition.

During PC, the trapezius appeared to remain unaffected by the assistive device, with nearly equal mean values and non-statistical significance ($p>0.93$) across all percentiles. Therefore, it is not likely that the assistive device would induce static level contraction trapezius myalgia over the unassisted PC condition (Westgaard et al., 1986; Veiersted et al., 1993; Veiersted, 1994).

Use of the device during PC did not significantly affect posterior deltoid activity. Further investigation is required to determine why some subjects experienced reductions in posterior deltoid activity and others experienced increases in activity during PCD (Table 5.4). When comparing individual subject heights to posterior deltoid activity, no significant correlation was found ($r=0.11$, $df=8$, $p>0.85$); furthermore, the subjects were all males with similar height and body weight. However, some individuals may learn motor skills more quickly than others. Thus, by the third trial of PC, one subject may have learned the most mechanically efficient motor pattern while another subject still performed PC with the same skill as seen in the first trial. These potential sources of variability require further specific investigation into each possibility.

Anterior Load Carriage

The most noticeable effect occurred in the anterior deltoid, in which means were reduced by 78-83%; however, significance was not achieved due to inter-subject variability (10th, $p=0.51$; 50th, $p=0.51$; 90th, $p=0.75$). Table 5.4 displays how subject #7's anterior deltoid activity was over seven times higher than the other subjects. As

stated in the PC condition, further study is required to understand the physical nature of this outlier.

The trapezius also showed a reduction in means when using the assistive device during AC. However, a trend ($p=0.08$) occurred only in the peak (90^{th}) EMG percentiles, suggesting that the device may be effective at reducing *peak* trapezius activity during AC. A reduction in peak trapezius force may reduce the incidence of reported shoulder and neck pain (Fethke et al., 2007). However, further study is required on a greater quantity of subjects to determine if this effect is truly significant ($p<0.05$)

Limitations

The load carriage data were collected in a lab setting and thus possessed methodological limitations. First, gait was simulated on a treadmill at a controlled speed. However, in the field, the gait speed may not be so linear depending on inclination or obstacles. Additionally, it has been shown that force patterns while walking on a treadmill have small, yet significant differences compared to over-ground walking (White et al., 1998). This limitation may have altered the gait motor behaviour in the lab.

This study involved no more than 3 hours of subject participation per collection period and thus would not have produced any noticeable fatigue. Subjects were not exposed to heat, sun, humidity or other environmental factors that would alter fatigue. During the field study (Chapter 3) it was observed that many movers operate for 12 hour shifts and are exposed to fatiguing environmental factors such as heat, sun and humidity. Therefore, such factors may alter the motor behaviour between the laboratory and field settings and thus alter the performance of the PC and AC techniques.

Previous literature has shown that the motor behaviour between novice and expert MMH subjects is significantly different. Their different handling techniques can alter the biomechanical properties of certain tasks (Authier et al., 1995; Authier et al., 1996; Gagnon, 1997). Furthermore, it has been shown that excessive muscle force may be generated when learning new motor behaviours, and such excessive force will decrease with greater experience (Witney et al., 2000; Flanagan et al., 2003). Therefore, it is possible that the results of this study may have been different had the subjects been professional movers with greater amounts of experience. Future study with an experienced subject pool may elucidate differences between inexperienced and experienced manual material handlers.

Trial data was not normalized to isometric MVEs, but rather the respective percentiles of unloaded gait. Therefore, smaller increments in true signal amplitude can produce relatively large increases in the EMG ratios. It is possible that the source of inter-subject variability in this study maybe due to the increased sensitivity of the normalization procedure. Furthermore, some muscles have less involvement in unloaded gait, such as the flexor digitorum, therefore when a load is carried the ratios appear much larger. Hence, caution should be exercised when reading an interpreting the EMG results in this study.

5.5 Conclusions

This study has confirmed the main findings of the previous unassisted load carriage study conducted the by author of this paper (Section 4.0), in that PC reduced erector spinae activity and increased posterior deltoid activity compared to AC. With

use of the new normalization method, it was also found that PC can reduce levels of LES activity below those of unloaded gait.

The most noticeable benefit of the assistive device was the reduction in flexor digitorum activity. It is believed that use of the assistive device will reduce the incidence of force-dependent wrist injuries involved in professional moving. However, further research is required to determine if any deleterious postures are created with device use. Another benefit is that the anterior deltoid also received reductions in EMG activity when the device was used in both AC and PC conditions. The combined reductions in flexor digitorum and anterior deltoid activity may have been responsible for the nearly unanimous perception by subjects that the assistive device made both AC and PC methods easier to perform. While the assistive device did not significantly alter erector spinae activity in the AC or PC conditions, it maintained the reduction in erector spinae activity found in unassisted PC. Thus, by maintaining the reductions in erector spinae activity and further reducing flexor digitorum activity, it is believed that the device is truly assistive to both AC and PC methods of load carriage. Furthermore, by reducing shoulder and grip effort, it is also believed that the device will make the PC method more secure and viable for less-experienced professional movers.

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Chapter 6

General Discussion and Conclusions

The original impetus for this study was to understand why some professional movers carried boxes using a posterior carry rather than an anterior carry. Based on subjective interviews and focus groups with professional movers, they stated that: it was easier on their backs during the posterior carry and their main aches and pains occurred in their backs, shoulders, and wrists. However, lack of research into hand-held posterior carrying techniques, concern about musculoskeletal injuries, and the absence of an ergonomic aid to assist movers were the rational for further investigation into the advantages and disadvantages of the posteriorly-placed and anteriorly-placed loads used by professional movers.

This section provides a rational for changes to the protocols between Studies 1 and 2 as well as findings for the main muscle groups affected by the two load carriage techniques. This comparison will be made by examining the effect that anteriorly-placed and posteriorly-placed loads have on various muscle groups. Direction is also provided for future research.

Changes to Protocol between Study 1 and 2

There were three differences between the first laboratory study (Section 4.0) and second laboratory study (Section 5.0) study: i) the method of gripping the box, ii) the changes in box dimensions, and iii) the normalization method. The first two differences in protocols were based on further field analysis. It was determined that the majority of

professional movers used an asymmetrical grip on the boxes during posterior load carriage. This involved placing one hand on the bottom corner of the box and the other hand along the vertical wall of the box. This asymmetrical grip was reported to be less difficult when initially grasping the load. Additionally, the investigators found that the most common box dimension was 2 cubic feet (61cm x 61cm x 61cm) and not the smaller document box used in the initial study.

The normalization strategy was also changed between the first and second studies. The first study involved collecting isometric maximum voluntary efforts (iMVE) at an optimal static joint angle for each muscle. The normalization approach used in the second study was based on using eight consecutive cycles of unloaded gait and determining the 10^{th}, 50^{th}, and 90^{th} percentiles; these percentile values were then divided into their relative test condition numerators.

The use of either peak, mean or static EMG amplitudes from dynamic activity to normalize data has been published previously in literature (Yang & Winter, 1984; Yack & Winter, 1987; Kadaba et al., 1989; Finch et al., 1991; Allison et al., 1993; Neumann et al., 1992; Neumann, 1999). However iMVEs remain the most common method of EMG normalization (Yang and Winter, 1984). Despite the method's common use, Yang and Winter (1984) described iMVEs as being prone to intersubject variability such as muscle fibre composition, thickness of subcutaneous fat, electrode position and neurological states. Their study compared four normalization methods; 1) %MVC, 2) EMG/joint moment, 3) the mean value over a stride period and 4) the peak value over a stride period. Yang and Winter (1984) found that normalizing to the mean and peak values obtained during a stride ensemble drastically decreased the coefficient of variability (CV) between

subjects. In contrast, the %MVC and joint moment methods made no difference and in some trials even increased the coefficient of variability (Yang and Winter, 1984). Such methods and findings have also been confirmed in another controlled study of the upper extremity, in which reductions in the CV lead reductions in inter-subject variability and increased statistical power (Allison et al., 1993).

Soderberg and Knutson proposed that the prominent limitations of isometric MVE normalization method is that great variation can exist between the muscles activated during an isometric MVE, the lack of subject training in performing the MVE and lack of subject motivation to effectively recruit a maximum amount of motor units (2000). Therefore, when dividing these variances into the trial data, the overall variance of the data increases multiplicatively.

Mirka (1991) challenged the use of isometric MVE normalization for dynamic activity because it does not represent the true EMG behaviour in dynamic activity such as force length characteristics, the changing moment arm about the joint centre and the dynamic properties of the tissues. Mirka stated that data from dynamic activity that are normalized to a single isometric MVE are simply a scaled down versions of the raw data (1991).

In the second laboratory study; the method of separating peak, median and static values and normalizing trial APDF data by their respective percentiles reduces the "scaling" effect caused by normalization of a MVC value (Mirka, 1991). Furthermore, changes in a specific percentile range are relative to their own percentile amplitude. For example, static EMG amplitudes during a loaded trial a directly compared to static values present during normal unloaded walking.

When considering the changes in methodology between study 1 and study 2; box dimension, grip technique and normalization method do not obscure the main trends and significant findings when comparing AC and PC techniques.

Repeatability Results between Study 1 and Study 2

The Erector Spinae

Despite the different normalization methodology and physical characteristics, the main findings from Study 1 were confirmed in Study 2. The TES and LES both experienced significant reductions in static, median, and peak EMG ($p<0.05$) (Table 5).

Table 6.1 - A comparison between Study 1 and Study 2 of TES and LES percent reduction when using the PC method. The percent reduction is very similar between the two studies, regardless of the analytical and physical differences.

Percent Reduction Using PC Study 1 (n=10)		
Percentile	**TES**	**LES**
10th	61.6%	88.1%
50th	64.3%	82.8%
90th	54.5%	65.2%

Percent Reduction Using PC Study 2 (n=10)		
Percentile	**TES**	**LES**
10th	57.9%	78.2%
50th	66.3%	80.5%
90th	54.2%	74.3%

It is interesting to observe that, regardless of the differences in normalization, box dimensions, and grip technique, the relative findings in the erector spinae muscle group are still consistent between the first and second laboratory studies. This repeatability demonstrates that changes in load dimensions and grip technique during PC do not alter the reductions in erector spinae activity. This result supports the conclusion made in the first laboratory study that the method of securing the load has no significant effect on reduction of erector spinae activity during the PC method. This also implies that the

benefits may be far reaching to fields of manual material handling other than professional moving (e.g., construction, warehousing, agriculture), where loads may vary greatly in dimension and coupling factors.

Shoulder Activity Distribution

In both laboratory studies, the PC method focused shoulder activity on the posterior deltoid. However, in the second laboratory study, the relative activity of the posterior deltoid was much higher (Table 6.2).

Table 6.2 - A comparison of percent increases in posterior deltoid activity across static, median and peak APDF ranges when using PC compared to AC.

	Percent Increase Using PC Posterior Deltoid	
	Study 1	**Study 2**
10th	268%	321%
50th	200%	310%
90th	152%	318%

This larger increase in EMG activity in Study 2 was probably due to the much larger box dimensions in combination with the different grip technique. This combination of factors made subjects hold their vertical grip arm at a much greater posterior flexion angle, thus eliciting greater activity from the posterior deltoid. These results also showed that the posterior deltoid was less affected by load dimensions in the AC method than in the PC method. Therefore, unlike the erector spinae, the shoulder musculature was affected by the change in physical characteristics between the two studies. This implies that, in real-world settings, some larger load dimensions might increase musculoskeletal risk of injury

to the shoulder region when the PC method was being used. Further investigation of this premise is warranted.

Most literature about the musculoskeletal implications of shoulder loading indicate that increased static activity of the trapezius may be related to myalgia in the upper extremities (Westgaard et al., 1986; Veiersted et al., 1993; Veiersted, 1994). However, a new industrial study reported that high peak loading of the trapezius was also indicative of general shoulder pain (Fethke et al., 2007). Additionally, increases in trapezius forces have been correlated to decreased blood flow in the forearm (Visser et al., 2006). No studies were found that would imply a causal relationship between shoulder loading onto the posterior deltoid and myalgia, injury, or decreased blood flow to the upper extremities. Both the first and second laboratory studies have shown that the AC method significantly increases peak trapezius activity compared to the PC method. Based on current literature, it is not clear as to whether the focused shoulder activity in the posterior deltoid creates an increased risk of shoulder injury while using the PC method. However, literature has proven there is concern that the increased loading of the trapezius in the AC method may increase the risk for shoulder myalgia and injury more so than the PC method.

External Obliques

Another disparity between the first and second laboratory studies is that in the second study, the relative normalized percent increase in external oblique activity was significantly higher during the PC method compared the AC method. This may be due to the physical changes in the second study in which the larger box dimensions caused the

load's center of gravity to be further away from the body. In order to maintain equilibrium, this longer moment arm must be counterbalanced with a longer moment arm of the upper body's center of gravity, resulting in greater forward flexion at the hip and lower back while carrying the same mass. The external oblique muscle group is an active contributor to trunk flexion (McGill, 1996), spinal stability (Cholewicki et al., 1997; Gardner-Morse & Stokes, 1998; Cholewicki et al., 2000; Granata & Orishimo, 2001), and ipsilateral support for the weight-bearing leg during gait (Murray et al., 1984). Thus, the flexed posture induced by the larger load in Study 2 coupled with the need for ipsilateral leg support may have elicited a larger muscle activity in comparison to the first study. It is doubtful that the increased EO activity would cause a significant increase spinal compression based on a study by Gardner-Morse & Stokes (1998) in which a spine model revealed that the external oblique generated the greatest stability with the least increase in spinal compressive force.

Summary of Gained Information from Repeatability Analysis

From the similarities and differences presented between the two studies, it becomes apparent that the benefit of the PC method on the erector spinae may be independent of load dimensions and grip technique. The key finding is that loads placed posterior to the spine reduce erector spinae activity more than loads placed anteriorly and in some cases, the erector spinae activity is reduced below that of normal unloaded gait.

Comparison between the two studies revealed that changes in load dimensions and grip technique could affect the shoulder activity distribution and alter external oblique activity. It is believed the increases in external oblique activity would

significantly increase spinal compression force. However, there was not enough evidence in the literature to conclude that the focused shoulder loading of the PC method presented a higher risk of injury than that of the AC method.

Conclusions from Studies 1 and 2

The purpose of the EMG component of this thesis was two-fold. The first goal was to assess the biomechanical differences between AC and PC conditions; the second goal was to determine if an assistive load carriage device could reduce muscle effort during both AC and PC conditions. It was hypothesized that the PC method would reduce back EMG activity compared to AC, and that the assistive device would further reduce muscle loading in both AC and PC methods of load carriage.

The first hypothesis regarding muscle loading during unassisted load carriage was partially correct. It was found that PC significantly reduces back muscle effort while reducing the shoulder activity in the trapezius and anterior deltoid and focusing it onto the posterior deltoid. The second hypothesis regarding the assistive device was also partially true. Large and significant reductions in flexor digitorum and anterior deltoid activity occurred in both PC and AC conditions, while almost all remaining muscle groups maintained similar EMG amplitudes compared to their unassisted test conditions. The only muscle to experience increases in EMG when using the assistive device was the external oblique, which displayed small yet statistically significant increases in activity during ACD. The device may have held the box lower than in unassisted carriage and thus interfered with flexion at the hip. This hip flexion interference can increase hip-hiking and increase external oblique activity.

From these two studies, general conclusions can be made regarding unassisted and assisted load carriage. First, the PC method may offer an effective alternative to traditional AC methods, especially for occupations with higher tendencies for low back pain. It is understood that movers typically perceive this technique to be awkward and cumbersome; however, field observations have shown that many professional movers perfect this technique and use it as easily as AC. Therefore, it may be beneficial for professional moving companies to consider encouraging the use of the PC technique and even instruct novice movers when and how to use the technique.

The second conclusion is that the assistive load carriage device used in this study can be an effective ergonomic tool to alleviate grip forces and shoulder forces in both AC and PC conditions. Furthermore, based on EMG data and subjective surveys, the assistive device decreased the awkwardness and difficulty in performing the PC technique. One additional ergonomic aid that may create an even higher acceptance of the PC technique among movers is the use of a rope with grips slung around the box. This type of aid would allow the arms to be held in front of the body rather than hyper-extended to grip the box with the hands. If the device by itself, or with a rope-assist, can help more professional movers utilize the PC technique in everyday work, this may help reduce work-related musculoskeletal disorders.

Future Research

The main goal of this work is to disseminate the information gained from these studies and begin to apply them to real-world manual material handling settings. It would be ideal to produce multiple assistive devices, similar to the one used in this study, and have them used consistently in professional moving applications. It is hypothesized that

the workers would benefit noticeably from the reduced grip and shoulder activities that occur with use of the assistive device. It is also hypothesized that use of the assistive device would result in greater numbers of novice movers utilizing the PC technique.

The long-term research goal is to have the assistive moving device used consistently in an occupational setting over one to two years duration. Such device use would allow tracking of various health outcomes, such as musculoskeletal pain and prevalence of reported musculoskeletal injuries. A case-control study could then be used to compare statistically the effectiveness of prolonged use of the assistive moving device. Such statistical information would also allow the authors to determine if the significant findings in the laboratory studies actually produced significant effects in real occupational settings. Such a comparison would also validate the efficacy of EMG use in the investigation of occupational biomechanics studies.

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Appendix

Appendix A – Tabled EMG APDF Data Across All Testing Conditions

EMG amplitude probability distribution function percentile means for all test conditions

10th Percentile EMG Values (ratio of unloaded walking)

	TR		AD		PD		TES		LES		RA		EO		FD	
AC	5.39	±2.11	7.09	±9.21	1.36	±0.80	3.41	±2.32**(a)**	5.72	±3.61**(a,b)**	1.15	±0.15	1.18	±0.22**(a)**	18.60	±13.0**(a)**
PC	3.62	±1.74	1.77	±0.40**(a)**	5.73	±8.23	1.43	±0.49	1.25	±0.33**(a,c)**	2.01	±1.57	2.91	±1.74	26.40	±18.9**(b,c)**
ACD	3.31	±2.09	1.57	±1.29	1.24	±1.08	2.20	±1.37**(b)**	4.50	±2.35**(c,d)**	1.16	±0.17	1.44	±0.30**(a)**	7.70	±5.3**(a,b)**
PCD	3.95	±1.66	1.44	±0.35**(a)**	3.94	±4.10	1.18	±0.68**(a,b)**	1.11	±0.29**(b,d)**	1.22	±0.49	2.24	±1.38	15.30	±13.0**(c)**

50th Percentile EMG Values (ratio of unloaded walking)

	TR		AD		PD		TES		LES		RA		EO		FD	
AC	5.30	±2.33	9.43	±12.41	1.19	±0.67	4.61	±2.28**(a,b)**	5.32	±2.63**(a,b)**	1.17	±0.20	1.16	±0.31	23.20	±16.1**(a)**
PC	3.29	±1.78	1.88	±0.61**(a)**	4.88	±6.28	1.55	±0.82**(a,c)**	1.04	±0.31**(a,c)**	4.06	±5.54	2.92	±1.68	29.50	±29.0
ACD	3.78	±2.88	2.06	±2.77	1.18	±1.05	4.06	±2.17**(c,d)**	4.91	±2.32**(c,d)**	1.16	±0.21	1.46	±0.36	10.10	±8.1**(a)**
PCD	3.45	±1.51	1.48	±0.57**(a)**	3.33	±3.10	1.38	±1.82**(b,d)**	0.91	±0.30**(b,d)**	1.87	±2.27	2.23	±1.11	17.60	±16.0

90th Percentile EMG Values (ratio of unloaded walking)

	TR		AD		PD		TES		LES		RA		EO		FD	
AC	5.45	±2.08**(a)**	7.11	±10.97	1.11	±0.60	3.05	±0.85**(a,b)**	2.96	±1.09**(a,b)**	1.16	±0.26	1.26	±0.42**(a)**	27.57	±18.8**(a)**
PC	3.23	±1.91**(a)**	1.59	±0.84	4.65	±5.56	1.40	±0.73**(a,c)**	0.76	±0.29**(a,c)**	5.52	±7.87	2.70	±1.24**(a)**	34.29	±26.1**(b,c)**
ACD	3.96	±2.87	1.24	±0.84	1.13	±0.87	2.89	±0.66**(c,d)**	2.89	±1.17**(c,d)**	1.19	±0.32	1.52	±0.57	10.58	±7.6**(a,b)**
PCD	3.33	±1.50	1.14	±0.68	2.87	±2.27	1.01	±0.97**(b,d)**	0.65	±0.24**(b,d)**	2.64	±4.15	2.07	±0.79	17.40	±13.9**(c)**

Note: Values sharing the same letter designation are statistically different means ($p<0.05$).

Table A.1 - The mean EMG APDF values obtained across all subjects and each load carriage condition.

Appendix B – Graphed EMG APDF Data Across all Test Conditions

Figure B.1 – 10th Percentile EMG Data across all Test Conditions

Figure B.2 – 50th Percentile EMG Data across all Test Conditions

Figure B.3 – 90th Percentile EMG Data across all Test Conditions

Figure B.1 – 10th Percentile EMG Data across all Test Conditions

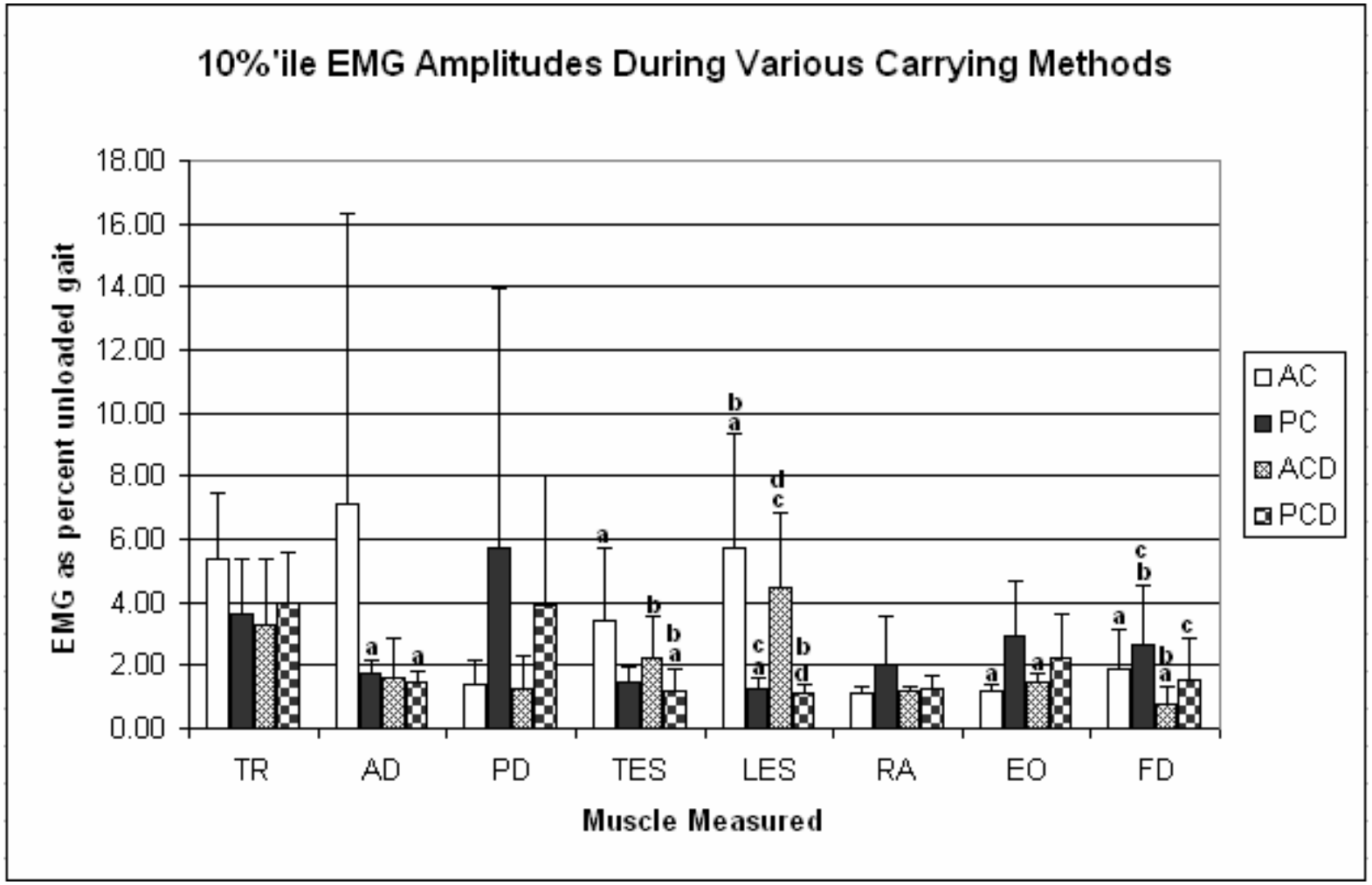


Figure B.1. The EMG amplitudes at the 10th percentile for all load carriage conditions in Study #2.

[1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Figure B.2 – 50th Percentile EMG Data across all Test Conditions

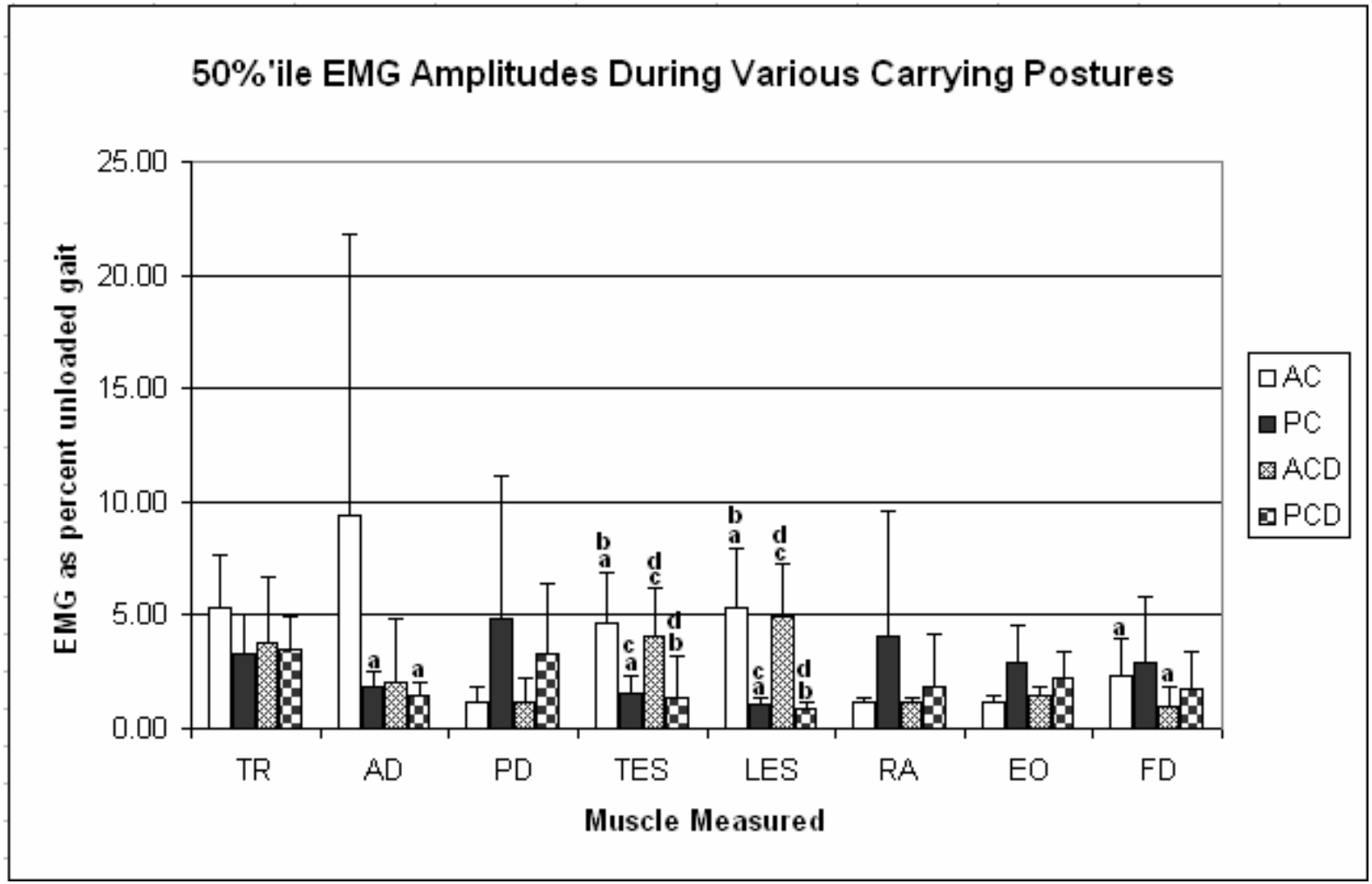


Figure B.2. The EMG amplitudes at the 50th percentile for all load carriage conditions in Study #2.

[1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Figure B.3 – 90th Percentile EMG Data across all Test Conditions

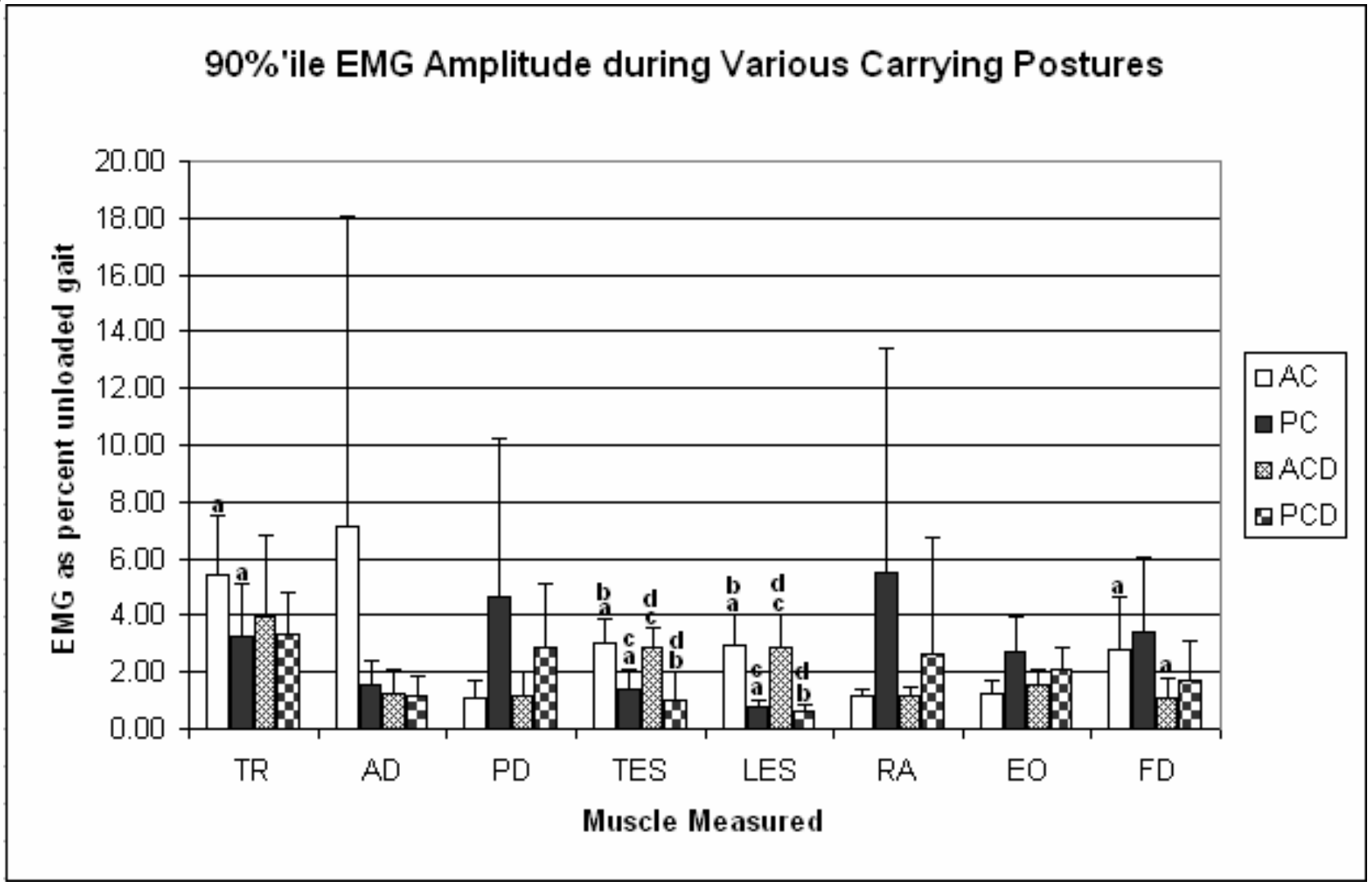


Figure B.3. The EMG amplitudes at the 90th percentile for all load carriage conditions in Study #2.

[1]**Note:** All amplitudes and standard deviations listed for the "FD" are divided by a factor of 10.

Appendix C – Ethics Approval Document

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD

Queen's University

Queen's University, in accordance with the "Tri-Council Policy Statement, 1998" prepared by the Medical Research Council, Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of Canada requires that research projects involving human subjects be reviewed annually to determine their acceptability on ethical grounds.

A Research Ethics Board composed of:

Dr. A.F. Clark	**Emeritus Professor, Department of Biochemistry, Faculty of Health Sciences, Queen's University (Chair)**
Dr. S. Burke	**Emeritus Professor, School of Nursing, Queen's University**
Rev. T. Deline	**Community Member**
Dr. M. Evans	**Community Member**
Dr. M. Green	**Assistant Professor, Department of Family Medicine, Queen's University**
Mr. C. Kenny	**Community Member**
Ms. T.C. Knott	**Research & Evaluation, Southeastern Regional Geriatric Program, Providence Continuing Care Centre – St. Mary's of the Lake Hospital Site**
Dr. J. Low	**Emeritus Professor, Department of Obstetrics and Gynaecology, Queen's University and Kingston General Hospital**
Dr. H. Murray	**Assistant Professor, Department of Emergency Medicine, Queen's University**
Dr. W. Racz	**Emeritus Professor, Department of Pharmacology & Toxicology, Queen's**
Dr. H. Richardson	**Assistant Professor, Department of Community Health & Epidemiology Project Coordinator, NCIC CTG, Queen's University**
Dr. B. Simchison	**Assistant Professor, Department of Anesthesiology, Queen's University**
Dr. A.N. Singh	**WHO Professor in Psychosomatic Medicine and Psychopharmacology Professor of Psychiatry and Pharmacology Chair and Head, Division of Psychopharmacology, Queen's University**
Dr. S. Taylor	**Director, Office of Bioethics, Queen's University and Kingston General Hospital; Associate Professor, Department of Medicine, Queen's University**
Ms. K. Weisbaum	**LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)**

has examined the protocol and consent form for the project entitled "**Development of a Mover's Pack: a specialized backpack for the moving industry**" as proposed by Dr. Joan Stevenson and Mr. Ian Kudryk of the School of Physical and Health Education and Dr. Tim Bryant, Department of Mechanical Engineering at Queen's University and considers it to be ethically acceptable. This approval is valid for one year. If there are any amendments or changes to the protocol affecting the subjects in this study, it is the responsibility of the principal investigator to notify the Research Ethics Board. Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information."

Albert Clark
Chair, Research Ethics Board

April 7, 2006
Date

ORIGINAL TO INVESTIGATOR - COPY TO DEPARTMENT HEAD- COPY TO HOSPITAL(S) - P&T - FILE COPY

PHE-066-06
EX

Appendix D – Informed Consent Document for Field Data

Letter of Information & Consent Form

Development of an Ergonomic Aid for the Moving Industry.

Dear Mover,

I would like to invite you to participate in a research study run by Dr. Joan Stevenson and her graduate student Ian Kudryk of Queen's University. There is no requirement to volunteer and you may stop the study at any time without coercion or pressure. I will describe the study in detail so that you may decide if you wish to participate. If you do, then I will ask you to sign two copies of a consent form so you can keep this information. This complete study will occur over a six month period and will require your involvement on four specific days. Please feel free to ask questions at any time.

Purpose of the Study:

The Queen's researchers have been awarded a Workplace Safety and Insurance Board (WSIB) grant to develop a "Mover's Assist Device". The goal of the study is to develop an assistive device that movers would use to save wear and tear on their backs while moving boxes. However, we hope this ergonomic aid will not only help you, but many other industries that also move numerous boxes on a daily basis.

Overview of the Study:

We recognize that you understand your job very well and we want to incorporate your knowledge into the design of an ergonomic assist device. Hence, we are asking you to join a Design Team which will be comprised of: 1) our manufacturer, Bill Ostrom, 2) two researchers from Queen's University, 3) a representative from the Transportation Health and Safety Association of Ontario (TSHAO), 4) six to eight movers from your company, and 5) six to eight movers from two other local companies. We hope that the Design Team will work together for the whole study but this is not a requirement, as you may withdraw your participation at any moment. The steps we wish to follow in this project are:

1) **Initial Design Team Meeting.** We wish to host a Design Team meeting with other volunteers from your company to discuss the main difficulties of the job, why you carry boxes the way you do and what are the functional requirements you want built into any assistive device that we build for you. We will seek your advice on future steps to follow that will allow others to participate if they wish.

2) **Collecting Quantitative Data from a Typical Day.** We wish to send two researchers out on the trucks with you to observe both loading and unloading tasks.

We would like your permission to videotape you on a typical moving day. Without getting in your way, we would like to weigh you while carrying your loads, To do this, we will ask you to pause for a moment overtop a force platform that will be placed on your path between the truck and the house. To measure the distances and terrain you travel and types of loads you carry, we will ask you to wear a heart rate monitor and a step counter. Periodically we will acquire data from these devices. At the end of the day, we would like to ask you some questions about your discomfort and aspects of the job you find difficult.

3) **Design of Two Prototypes.** We are working with a designer, Bill Ostrom of Ostrum Outdoors, who plans to provide us with two distinct prototype designs of an Ergonomic Lifting Aid. We would like to ask you to assist us two ways. First, we would like you to try out each style for half of your day. We will ask you some questions about your comfort as well as whether you feel this ergonomic aid was quick, easy to use, efficient and effective. At the end of the day, we will ask you which one you liked best and why. We would also like to videotape some of your lifts. After we have allowed everyone to test the Ergonomic Aid, we will have a group meeting with Ostrum Design to discuss your input and what you would like to see changed in the next design.

4) **Design of Semi-final Prototype.** Based on your feedback, the Ergonomic Aid will be re-designed and brought back to you for final testing. Similar to the previous set of tests, we will ask you to use the Ergonomic Aid for half of your work day. We will ask only some of you to also wear a portable heart rate monitor, step counter and muscle signal electrodes over your back muscles. Similar to the previous testing, we would like to videotape and measure the forces during some of the tasks. At the end of the testing, we will provide the same questionnaire to help us understand any discomfort or design issues that concern you. Again, once everyone has worn the Ergonomic Aid, we will have a group meeting to gather everyone's feedback for the designer.

5) **Final Design Evaluation.** The designer, Bill Ostrum will take your previous concerns into account when he builds the final Ergonomic Aid design. We intend to have one last Design Team meeting to see and test the final version in a casual way. We plan to give one Ergonomic Aid to each company president/manager and we look forward to receiving your feedback. We will celebrate with a final party for everyone who participated.

Risks of Participation

Heavy manual materials handling does increase the risks for low back pain. However, we will not be asking you to do more work than you normally would do in your job. At no time will we ask you to lift more boxes or loads than your normal daily routine. When using the Ergonomic Aid, because it is new, there may be some muscular soreness. If any soreness persists for more than a day, we want you to call us so we can help you recover. Another potential risk relates to placing athletic tape and electrodes on your skin. If skin irritation persists overnight, we would like you to contact us for assistance.

Benefits of Participation:

In terms of benefits, you will be part of a research project that is developing a new Ergonomic Aid for the benefit of the whole industry. The intention is that this Ergonomic Aid will help movers use less force and reduce the risks of low back pain. Another benefit is an appreciation for scientific approaches in reducing risks of low back pain. This knowledge may help to reduce the future risk of low back pain in the moving industry.

Exclusion Criteria:

To minimize the risk of injury during this study, we do not want any mover to participate in this study if you have had low back pain in the last six months.

Confidentiality:

Any information you provide will be kept confidential within the research team at Queen's University. All of your data will be coded using numbers and archived with no trace to your identity. While studying the videotape of your loads carried as well as your loading and unloading activities, no individual outside the research team will view these tapes without your written permission. Also note, your moving company and fellow movers will be aware of your participation. We will ask your team members to respect your confidentiality and privacy in regard to revealing information about this study. However, please be aware that it will be difficult for us to completely protect your confidentiality because of the number of people who are aware of your participation. However, all reports and publications from the researchers will respect your confidentiality and anonymity.

Voluntary Nature of the Study:

Your participation in this study is completely voluntary. You may withdraw from this study at any time without penalty or coercion. Your data will be removed if you wish it withdrawn.

Liability:

By signing the consent form, you do NOT waive your legal rights nor release the investigator(s) from their legal and professional responsibilities.

Subject Statement and Signature:

As a volunteer participant, I have read and understand the consent form for this study. The purposes and procedures have been explained to me. I have had the opportunity to ask questions that have been answered to my satisfaction. I have been given sufficient time to consider the above information and withdraw if I choose to do so. I understand that my participation is in confidence and that my data and videotape will be viewed by the researchers only. I am voluntarily signing this consent form below. I will receive a copy of this consent form for future reference.

If I am dissatisfied with any aspect of the study, or have questions, concerns or adverse events, I have been encouraged to contact the principal investigators, Dr Joan Stevenson (stevensj@post.queensu.ca) at 533-6288 or Ian Kudryk at 533-2658 (4iak@qulink.queens.ca) or Janice Deakin, Director of the School of Physical and Health

Education at 533-6601 (deakinj@post.queensu.ca) or Dr Albert Clark, Chair of the Queen's University Health Sciences and Affiliated Hospitals Research Ethics Board at 533-6081. (clarkaf@post.Queensu.ca).

By signing this consent form, I am indicating that I agree to participate in this Professional Movers Ergonomic Aid study.

_____ X _____

Signature of Subject Date

By signing this consent form, I confirm that I have carefully explained the nature of the above research study to the subject. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and the demands, benefits, and risks involved to participants in this study.

_____ _____

Signature of Witness Date

Request for Permission to use Photograph for Scientific Purposes

The video data is part of the acquired materials for analysis of the Movers Ergonomic Aid study and these data will be kept confidential. However, this request is to ask permission for use of your video data to be shown during research presentations or possible research reports or papers. This video footage is NOT a required part of the project. However, if you are willing to waive your right to confidentiality of your video data for the above uses, please sign below.

_____ X _____

Signature of Subject Date

Appendix E – Informed Consent Document for Lab Data

Letter of Information
& Consent Form

Professional Mover's Load Carriage Study: Investigative Pilot Work Regarding Potential Benefits of Posterior Load Carriage.

Dear _____

You are being invited to participate in a research study on lifting strategies for professional movers as part of the PHED857 Electromyography course. There is no pressure to be a volunteer subject and you may stop the study at any time without coercion or pressure. I will review this consent form with you and describe the procedures in detail. Please feel free to ask questions at any time.

Purpose and Aims of the Study:

The PHED857 Electromyography (EMG) course is run by Professors Joan Stevenson and Linda McLean. This research project is a course assignment and a master's thesis pilot study intended to investigate the differences of posterior and anterior carrying methods used by professional movers. It has been reported by a number of professional movers in the Kingston area that carrying boxes behind their back is perceived to be easier than carrying boxes in front of their abdomen. The purposes of this experiment are to: 1) measure the electromyographical activity from muscles in the axial and appendicular regions of the body (i.e., rectus abdominus, external oblique, L_3-erector spinae, T_9-erector spinae, trapezius, anterior deltoid, posterior deltoid, flexor digitorum), and 2) compare kinematic and kinetic differences between the two postures, while carrying the load during treadmill walking.

Objectives:

The objectives of this experiment will be:

a. To determine the EMG activity and estimate muscular effort in anterior and posterior carrying postures while carrying a __ kg box during treadmill walking.
b. To determine the kinematics (posture angles) and kinetics (compressive/shear forces and moments) acting about the $L_{4/5.}$
c. To combine information from EMG, kinematics and kinetics to determine any possible biomechanical advantages (if any advantages exist) that occur during posterior load carrying.
d. To determine if the combined information and knowledge from steps a, b and c of this pilot study are important to continue collecting in the development of a specialized mover's lifting pack .

Procedures during Testing

If you accept this invitation to participate in the movers study, you will be asked to be weighed, and then warm-up with back and hamstring flexibility exercises as well as practice treadmill walking to mimic test conditions with an empty box and then a partially weighted box

of 10 kg. Then, eight surface electrodes will be placed over your right rectus abdominus, external oblique, L_3-erector spinae, T_9-erector spinae, trapezius, anterior deltoid, posterior deltoid and flexor digitorum. You will be asked to perform four data tests to acquire EMG data: resting baselines, maximum contractions, anterior load carrying and posterior load carrying. The treadmill walking trials will require you to carry a box weighing 20% of your body weight for approximately 1 minute. During that time, a digital video camera will be running to capture your load carrying postures. The test procedure is expected to take about 60 minutes.

Your EMG data will be saved in a spread sheet under a subject code, not your name. The video data will be digitized and converted to stick figures and graphic data and stored under your subject code.

Risks of Participation

There are risks associated with this study in that you will be carrying a load while walking on a treadmill at a top speed of 2km/hr. In order to safeguard subjects, a slow increase by increments of 0.1km/h will be used by the subjects signal for speed increase, until 2km/h is be reached. During your short 1 minute walk on the treadmill, I will have a research assistant act as a safety spotter in case you lose your balance. If this occurs, please justdrop the box rather than risk hurting yourself.

You will asked to carry 20% of your total bodyweight during the walking test. Therefore, as a precaution, I will ask you to have practice trials of treadmill walking as part of your warm-up in addition to your stretches prior to experimental testing.

You may experience stiff muscles the day after testing due mild fatigue. This stiffness should disappear within two days. If you have stiffness or pain that does not disappear, please contact me or the professors right away.

Benefits of Participation:

There are no direct benefits from participation in this study other than having e a chance to participate in a novel load carriage study and helping to provide data for in-depth analysis. After the study, upon your request, you may have access to the information regarding conclusions made from the study and understand your specific contribution to the development of new biomechanical knowledge.

Exclusion Criteria:

To minimize the risks of injury during this study, we are excluding anyone who currently has back pain, shoulder pain or wrist pain within the last six months. We also request that you complete "PAR-Q and You" questionnaire in case exercise is contraindicated.

Confidentiality:

Complete confidentiality of all information taken during this study is guaranteed. You will be identified by a subject number on all data files. After analysis, your data will be stored and archived with no trace to your identity.

Voluntary Nature of the Study:

Your participation in this study is completely voluntary. Please be aware that investigators will be providing encouragement for you to give a maximal effort on strength tests. However, stopping the testing protocol is still under your control. You may withdraw from this

study at any time without penalty or coercion. Your data will be removed if you wish it withdrawn.

Liability:

By signing the consent form, you do NOT waive your legal rights nor release the investigator(s) from their legal and professional responsibilities.

Subject Statement and Signature:

As a volunteer participant, I have read and understand the consent form for this study. The purposes, procedures and technical language have been explained to me. I have been given sufficient time to consider the above information and withdraw if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I understand that I can withdraw at any time. I understand that my participation is in confidence and that my data will be provided to the primary investigators of this project. I am voluntarily signing this consent form below. I will receive a copy of this consent form for future reference.

If I am dissatisfied with any aspect of the study, or have questions, concerns or adverse events, I have been encouraged to contact the principal investigators, Ian Kudryk at 533-2658 (4iak@qulink.queens.ca), Dr Joan Stevenson at 533-6288 (stevensj@post.queensu.ca) or Linda McLean at 533-6101 (mcleanl@post.queensu.ca); or Janice Deakin, Director of PHED at 533-6601 (deakinj@post.queensu.ca) or the General Research Ethics Board at 533-6081. (fridl@post.queensu.ca).

By signing this consent form, I am indicating that I agree to participate in this Professional Mover's Load Carriage study.

_____ _____

Signature of Subject Date

Request for Permission to use Photograph for Scientific Purposes

Video data are being acquired for analysis of posture and back forces and these data will kept confidential. However, this request is to ask permission for your video data to be shown during class, research presentations or possible research reports or papers. The research project does NOT require this permission; however, if you are willing to waive your right to confidentiality of your video data for the above uses, please sign below.

_____ _____

Signature of Subject Date

By signing this consent form, I confirm that I have carefully explained the nature of the above research study to the subject. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and the demands, benefits, and risks involved to participants in this study.

_____ _____

Signature of Witness Date

Appendix F – Professional Mover Survey for Field Study

All questions contained in this questionnaire are strictly confidential.

CODE NUMBER: DATE:				
Primary Occupation:			***% of total work time:***	
Secondary Occupation:			***% of total work time:***	
Total Months Employed:				
Hrs./Wk.:	**Hrs./Shift:**		**Shifts/Wk.:**	
Percent of 8 hr. day actually spent manually transporting materials:				
Typical Footwear:		***Typical Handwear:***		
List material handling assist devices from most commonly used to least commonly used:	**1.**		**3.**	
	2.		**4.**	

Approx. Body Height:		**Approx Body Weight:**	
☐ M ☐ F **Age:**	**Yrs.**		
Any disease that may interfere with moving (respiratory, diabetes, stroke, etc.):			
Any general Physical Disabilities (CP, etc. :			
Any general musculoskeletal disorders (fibromyalgia, back spasms, etc.):			
Exercise regularly (3 X per week @ 30min per session):	☐ Y ☐ N		
Most common hobbies:	**1.**	**2.**	
Recuperative strategies used during and after work:	**1.**	**2.**	
Most Difficult Task:			
Least Difficult Task:			
Task Most Liked:			
Task Least Liked:			
What climatic factors affect you the most:			
Sufficient Lighting Present:	☐ Y ☐ N	Explain:	
Recommend Work Change			

Organization (management issues):	
Recommendation on Engineering of work (lifting devices, truck devices, etc.):	
List Common Accidents while working:	
Other Comments about Work:	

SECTION C- SURVEY OF MUSCULOSKELETAL REGIONS AND INJURIES

SUBSECTION C1- NECK

Experienced Pain in Neck?	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you commonly experience fatigued in the neck:	☐ Y ☐ N
If YES, what action causes this fatigue:	

From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always
From 1 – 5 how often is your neck in an awkward posture?	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always

Have you sought medical attention for this pain:	☐ Y ☐ N		
Has this pain prevented you from working:	☐ Y ☐ N		
SUBSECTION C2- SHOULDER			
Experienced Pain in Shoulder ?:	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N		
If YES, what was the cause:			
At the end of the day, do you commonly experience fatigued in the shoulder:	☐ Y ☐ N		
If YES, what action causes this fatigue:			
From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always		
From 1 – 5 how often are your shoulders in an awkward posture?	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 □□□□□□□□□□□□□□□□□□□□		
Have you sought medical attention for this pain:	☐ Y ☐ N		
Has this pain prevented you from working:	☐ Y ☐ N		

SUBSECTION C3- ELBOW		
Experienced Pain in Elbow :	Ever ☐ Y ☐ N	Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:		
At the end of the day, do you commonly experience fatigued in the elbow:	☐ Y ☐ N	
If YES, what action causes this fatigue:		
From 1 – 5, How often do you perform this action:	○ ○ ○ ○ ○ 1 2 3 4 5 Never Sometimes Always	
From 1 – 5 how often are your elbows in an awkward posture?	○ ○ ○ ○ ○ 1 2 3 4 5 □□□□□□□□□□□□□□□□□□□□	
Have you sought medical attention for this pain:	☐ Y ☐ N	
Has this pain prevented you from working:	☐ Y ☐ N	
SUBSECTION C4- WRIST		
Experienced Pain in Wrist?:	Ever ☐ Y ☐ N	Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:		
At the end of the day, do you	☐ Y ☐ N	

commonly experience fatigued in the wrist:	
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always
From 1 – 5 how often are your wrists in an awkward posture?	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N
SUBSECTION C5- BACK	
Experienced Pain in Back?:	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you commonly experience fatigued in the back:	☐ Y ☐ N
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always

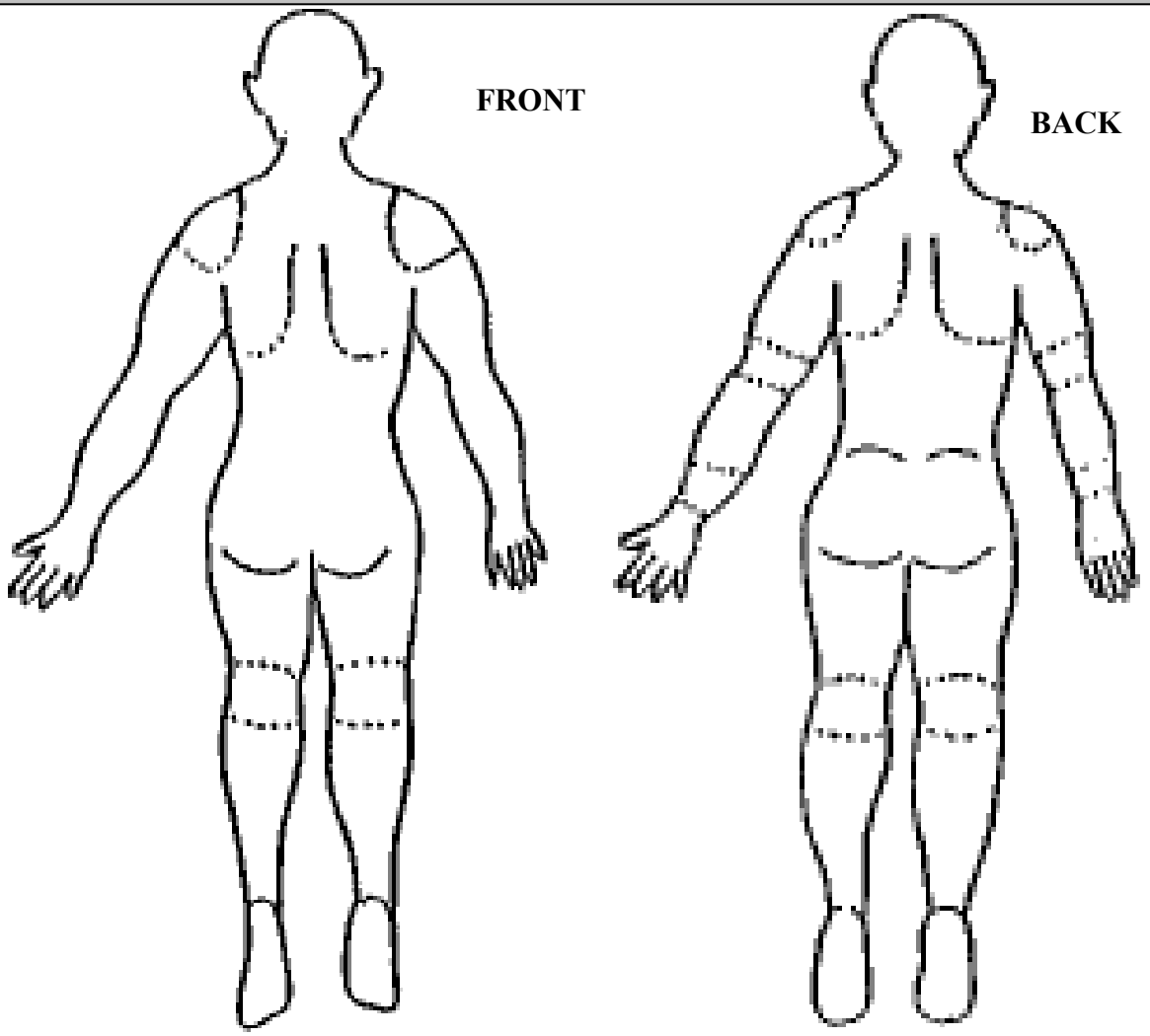
From 1 – 5 how often is your back in an awkward posture?	○ ○ ○ ○ ○ 1 2 3 4 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N
SUBSECTION C6- HIPS	
Experienced Pain in Hips?:	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you commonly experience fatigued in the hips:	☐ Y ☐ N
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ ○ ○ ○ ○ 1 2 3 4 5 Never Sometimes Always
From 1 – 5 how often are your hips in an awkward posture?	○ ○ ○ ○ ○ 1 2 3 4 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N

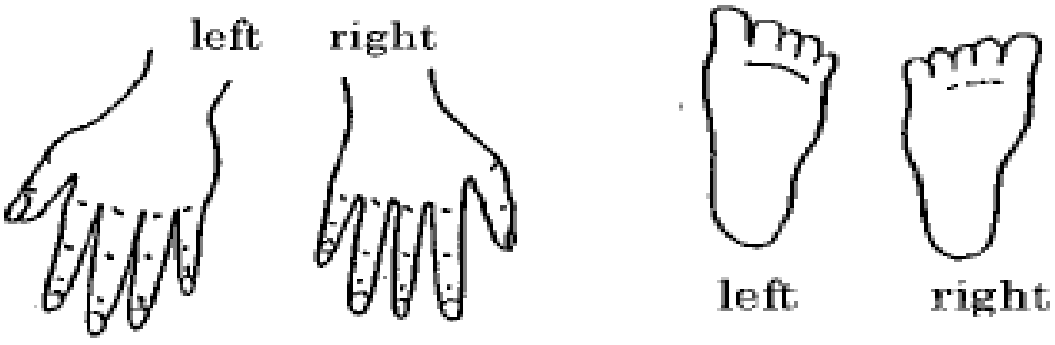
SUBSECTION C7- KNEES	
Experienced Pain in Knees?	☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you commonly experience fatigued in the knees:	☐ Y ☐ N
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ ○ ○ ○ ○ 1 2 3 4 5 Never Sometimes Always
From 1 – 5 how often are your knees in an wkward posture?	○ ○ ○ ○ ○ 1 2 3 4 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N
SUBSECTION C8- ANKLES	
Experienced Pain in Ankles?	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you	☐ Y ☐ N

commonly experience fatigued in the ankles:	
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always
From 1 – 5 how often are your ankles in an awkward posture?	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N
SUBSECTION C9- HANDS	
Experienced Pain in Hands?	Ever ☐ Y ☐ N Last 12 Months ☐ Y ☐ N Last Week ☐ Y ☐ N
If YES, what was the cause:	
At the end of the day, do you commonly experience fatigued in the hands:	☐ Y ☐ N
If YES, what action causes this fatigue:	
From 1 – 5, How often do you perform this action:	○ 1 Never ○ 2 ○ 3 Sometimes ○ 4 ○ 5 Always

From 1 – 5 how often are your hands in an awkward posture?	○ ○ ○ ○ ○ 1 2 3 4 5 □□□□□□□□□□□□□□□□□□□□
Have you sought medical attention for this pain:	☐ Y ☐ N
Has this pain prevented you from working:	☐ Y ☐ N
Rank your regions of pain from Worst Pain to Least Pain:	1. 2. 3. 4. 5.
List any problems we might have missed:	

Section D - Visual Identification of Pain





Appendix G

Needs Assessment Session #1

The purpose of this day will be to introduce the volunteers to the study. A five minute introduction is given according to the script developed for session #1. Following the introduction another 5 minutes is spent reviewing and signing the ethics documents. For the remaining time, the investigator poses the first main question for session #1.

Introductory Script

"Hi everyone, my name is Ian Kudryk, I'm a masters student from Queen's University. As some may already know, I am here to study professional moving, and more specifically you. I am hoping that around 7 of you will consider participating for the duration of the project."

"With the support of three Kingston companies, we have been given a grant by the provincial government to investigate the nature of your occupation. We were awarded the grant to build an ergonomic aid (such as a lift assist) that might be helpful for single person tasks."

"It is my goal to conduct some groundbreaking research in which you all can be part of. I aim to study the demands of professional moving and hopefully create ways in which to make your job easier, because everyone would agree that this is very difficult job."

"However, I can only do this if I have your help. You see, your experience in this business, either brief or long, is very important to me and success of this study. What you experience day in and day out, is something that 'science' could never replace. Therefore, I need your expert ideas to help improve the business in which you already work."

"Now is the chance to voice your opinions and ideas, because they will be heard and seriously considered. And not only may you change your worksite, but worksites all across Ontario and Canada."

"So I ask you be involved, be part of an exciting project. Please know, that if you volunteer to help, you may quit the study at any point in time. Furthermore, anything you say or write will remain anonymous from supervisors and even the government and its insurance agencies."

"If you wish to participate please sign this informed consent form."

- Distribute consent forms and pens.
- Collect consent forms.

Question 1a:

"What are the limits you encounter while lifting and carrying loads during the moving process? Feel free to mention anything that may hurt or strain your body, anything that frustrates you or annoys you while you are trying to work."

- Let members answer freely.
- Record answers.
- Carry on until the 20minute time limit.

Just before the subjects are about to leave the discussion, one last question is posed to them.

Question 1b:

"Now that all these limits are on your mind, I would like you to consider how to solve these problems with ergonomic solutions. Think of ergonomic equipment that you can design or equipment that you believe should be modified. Keep this in mind as you work this week, and I will look forward to hearing your great ideas."

<u>Needs Assessment Session #2</u>

Less time is spent on the introduction for the second session.

- Seat members in an appropriate area.
- Gain attention

Introductory Script

"High everyone. It's good to see you all here. I really appreciate you help. I want you to remember, that every idea and statement you make today is very important to this study, so don't be afraid to speak up, no matter how ridiculous it may sound."

Question 2:

"You may now have come up with some great ideas for ergonomic solutions in your job setting. They may be completely new ideas or changes made to old ideas. Now is the time to present them and discuss them with your colleagues."

- Let members answer freely.
- Record answers.
- Carry on until the 20minute time limit.

Closing Script

"Thanks everyone, you have all made great suggestions and I and the rest of the team in the lab will seriously consider what you have said today. If you have more ideas, please let me know, here is my card."

"I hope to see you all soon and have a chance to perform a brief survey on each of you in the next few weeks. I hope you haven't got sick of me already, because you will still be seeing a lot more of me in the future. So remember to keep thinking, because now is your chance to make a difference."