# An Assessment of the Interplay between the Shoulders and the Low Back in Occupational Tasks: A Manual Patient Handling Example

by

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## Author's Declaration

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

I understand that my thesis may be made electronically available to the public.

## Abstract

Redundancy and variation are characteristics of humans. Many muscles contribute to producing a movement at a joint, allowing different strategies for task performance. Further, the shoulders and back are involved in many tasks, including manual materials handling, but flexibility as to their relative roles in performing a task exists. In nursing, where manual patient handling (MPH) occurs daily, a risk of injury exists resulting from interactions with patients that may require awkward postures or sudden shifts in hand forces. Although some recommended MPH techniques have been advocated, many focus on lowering the risk of low back injury, without considering the effect of these techniques on other body regions. This study aimed to identify differences in shoulder and back physical exposures between performing self-selected and recommended patient handling techniques designed to reduce low back exposures. Twenty female participants performed three repetitions of five manual patient handling tasks using a self selected technique, followed by three repetitions of the same tasks using techniques learned in an interposed training session. Peak, mean and cumulative muscle activity, peak resultant moment, and ratings of perceived exertion were compared for each of the tasks before and after training, as well as identifying meaningful changes between the joints in mean population strength using a static strength prediction program. Significant decreases occurred at both the left and right shoulders and the low back for most measures, generally supporting the recommended techniques. Important exceptions existed, however, for the Sit-to-Chair tasks and Turn Toward tasks, where increases in several individual shoulder muscle activities, along with peak resultant moment, existed. Future recommendations for patient handling techniques should take into account potential negative exposures at the shoulders that may result from a back-centric injury avoidance paradigm.

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# Dedication

To Sandra Davis: a talented and loving nurse, friend and mother
who, along with the other nurses in my life, inspired the content of this research.
You are greatly missed.

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# I. Introduction

## 1.1 The Importance of Ergonomic Interventions to Preventing Injury

Manual materials handling (MMH) is a well documented and heavily researched area, especially when involving low back pain (LBP). In industry, many tasks involve MMH such as working on an assembly line, lifting and moving boxes in a warehouse, loading goods on and off a truck, and lifting and maneuvering patients. In 2007 in the United States there were 335,390 musculoskeletal disorders (MSD) reported that required days away from work; most of these resulting from overexertion and repetitive motion. Back pain was associated with 70.4% of these claims (Bureau of Labour Services, 2008). In Ontario in 2009, nearly 47% of all lost time claims were due to overexertion, bodily reaction and repetitive motion (WSIB, 2010). Upper extremity MSDs are also attributable to occupational exposures; nearly 40% of these injuries are work-related (Punnett & Wegman, 2004). The cost of these injuries justifies research for preventing them, as, for example, low back pain cost a reported $8.8 billion dollars in 1995 alone (Murphy & Volinn, 1999).

Epidemiological, laboratory, and field studies have all contributed to the growing knowledge regarding the risk of injury associated with MMH. Outcomes of this research are analysis tools that focus on posture analysis, strength predictions, safe lifting guidelines and fatigue analysis. Training and education programs for workers as well as managers on proper lifting strategies to limit overexposure to the lower back are often implemented prior to manually handling materials. However, many studies have found them to be effective only when combined with other ergonomic interventions, such as the introduction of mechanical aids or ergonomic changes to the workplace (Snook, 1978; Daynard et al., 2001). While many tools and intervention techniques ostensibly depend on a whole body analysis, few offer specific insight into strategies to prevent injury at the shoulder.

## 1.2 Nursing as an example of Manual Materials Handling

While manual material handlers are traditionally associated with lifting and moving boxes and assembly line parts, those involved in the nursing profession interact with substantially more complicated objects that must be lifted and repositioned. While some patients are unable to assist in their transfer, other patients may be combative or uncooperative, which may change typical nursing tasks into awkward and dangerous exertions (Garg et al., 1991a; Owen et al., 2002; Nelson & Baptiste, 2006). In Ontario in 2009, health care and social services accounted for 13% of total lost time claims due to injury, second behind manufacturing with 15.5% of total claims (WSIB, 2010). In the United States in 2007, nurses and nursing aides accounted for the third highest occupation requiring days away from work and 465 injuries per 10,000 workers. MSDs were the cause of nearly 50% of the injuries in this occupational group, which is nine times the national MSD rate in the United States and the highest among all professions in that country (Bureau of Labour Services, 2008).

Many tasks performed daily by nurses consistently produce greater than recommended spinal compression forces (Garg et al., 1991a; Daynard et al., 2001; Schibye et al., 2003; Yassi, 2005). These obvious dangers associated with manual patient handling (MPH) have led many health units and governments to consider or adopt a safe lifting policy, while banning patient handling tasks that are considered dangerous (Nelson & Baptiste, 2006). Mechanical lifting devices and recommended lifting techniques have effectively reduced low back injury among nurses and improved ratings of perceived exertion (RPE) scores and lowered days away from work (Owen et al., 2002; Schibye et al., 2003; Fujishiro et al., 2005). The direct influence of these devices on the shoulder, however, is unknown. Translation and turning of a patient is reported to be most stressful on the shoulder (Gagnon & Smyth, 1987) and even after implementing an ergonomic intervention that included adding mechanical assistive devices and additional MPH training, the RPE scores reported by nurses after completing these tasks did not decrease as much at the shoulder than reported RPE scores did at the back (Owen et al., 2002). Even with many dangerous lifts banned and mechanical lifting devices available to workers, manual patient handling continues to be completed by nurses who cite a lack of time, unfamiliarity with the manual devices and not enough devices available to use as reasons for favouring manual transfers (Garg et al., 1992a; Engst et al., 2003; Evanoff et al., 2005).

### 1.3 The Potential Specificity of Ergonomic Recommendations and Analysis Tools

While many obvious redundancies exist throughout the human body, less defined ones exist within the musculoskeletal system. Many muscles contribute to producing movement or stability at a joint, but are mathematically capable of generating the required moment with a variety of combinations of actions. It thus follows that each person is capable of performing a given task, but with unique muscular and kinematic strategies. The shoulder and back muscle groups are primary contributors in movements associated with MMH and MPH (Kronberg et al., 1990). In reaching movements, the hand must eventually reach the endpoint or target, but the muscles acting at the shoulder must guide the arm and stabilize it once the hand reaches the target (Kronberg et al., 1990). In squatting and stooping postures, which are quite common in MMH and MPH tasks, the muscles acting on the hip and torso are also quite active, providing most of the movement and stabilization. In addition, the shoulder muscles are also important contributors in the stoop posture while performing a MMH task (Park et al., 2005).

Despite evidence that the large muscle groups acting on the shoulders and back are important in lifting and movement, many ergonomic interventions focus solely on minimizing lower back injuries, and may neglect their consequences on other muscle groups or joints in the body. In some MPH studies, authors have cautioned about the potential transfer of problems from one joint to another because of specific interventions (Gagnon & Smyth, 1987; Menzel et al., 2004; Yassi, 2005). In other research, where intended ergonomic interventions reduced RPE at the lower back, they concomitantly increased perception of effort at the shoulder (Owen et al., 2002; Fujishiro et al., 2005). Since shoulder injuries in MMH and MPH are still common among manual material handlers and nurses, there is a need for a stronger focus on their specific exposures following interventions that target back injury prevention.

## 1.4 Purposes

The purpose of this research was to determine whether safe patient handling strategies designed to prevent low back injury were increasing physical and biomechanical exposures at the shoulder, while decreasing the same measures at the low back. The following objectives helped guide the research to determine if such changes were taking place:

- To determine whether or not there were any differences in shoulder and low back peak and mean physical exposures between performing self-selected novice manual patient handling techniques and recommended manual patient handling task techniques following a training session.
- To determine whether there were any differences between cumulative, peak, and mean shoulder and back biomechanical exposures across different manual patient handling tasks.

- To identify a possible transfer of demand from one joint to another when using recommended MPH techniques by quantifying changes in shoulder and back normalized muscle activity and moment loading

These objectives ultimately helped to address whether or not an intervention that focuses on one joint (such as the lower back) created meaningful differences at another joint (such as the shoulder), as well as whether these differences were detrimental or protective of both joints. Electromyographical data allowed identification of specific muscle demand changes, while joint moment data allowed identification of changes at all three joints (two shoulder and low back) studied. Collecting Ratings of Perceived Exertion (RPE) also gave insight into changing levels of exertion at both shoulders and the lower back between the freestyle and post-training trials.

## 1.5 Hypotheses

This study examined the influence of performing recommended MPH techniques on indicators of physical exposure at the shoulders and the low back. Specific hypotheses were:

(1) Ratings of perceived exertion will decrease at both the shoulders and the low back when MPH tasks are performed following a training session on recommended techniques.

(2) Peak external joint moment magnitudes will be reduced after the MPH technique training session for both shoulders and the low back.

(3) Normalized mean, peak and cumulative muscle activity will be reduced at both the shoulders and the low back when MPH tasks are performed using recommended techniques.

(4) A transfer of proportional joint strength demands from the low back to the shoulders will occur after recommended techniques aimed at limiting exposures to the low back are implemented.

# II. Literature Review

## 2.1 Redundancy in Movement

The human body is full of redundancies across all major body systems, including the excretory, digestive, respiratory, lymphatic, reproductive and musculoskeletal systems. The most obvious macroscopic evidence is the possession of multiple organs or body parts; two arms, two legs, two kidneys, two lungs, two ovaries, two ears and many other examples. Less obvious functional redundancies also exist throughout the musculoskeletal system. A prime example for biomechanists is the joint muscular load sharing problem, where many muscles contribute to moments at a single joint, but can generate a required moment with a nearly infinite combination of actions. This creates many possibilities for muscle activation and how the movement is completed, as well as uncertainty in estimating how specific muscles contribute physiologically to body actions. Additionally, each person has unique muscular and kinematic strategies for performing tasks. When studying stoop versus squat type lifting using motion capture data, Park et al. (2005) discovered that different strategies exist for each type of lift and also vary greatly between each participant, yet the end result remained the same. While the overall movements showed similar major muscle groups involved in movement, there were also moderate knee flexions, large torso flexions and lateral torso bending that varied between the lifting groups. Park et al. (2005) postulated that trade-offs may be taking place because of the different strategies taken by the participants for each type of lift. Cost functions and movement selection may exist for each individual that help determine a specific movement strategy.

Motion at a joint is caused by muscle moments, which are a function of the moment arm and force of specific muscles, and rotate about particular axes of motion (Kronberg et al., 1990). In load manipulation the lower back and shoulder are primary contributors, due to their relatively large size (Kaminski et al., 1995), and need to stabilize distal joints during manual activities (Kronberg et al., 1990), particularly if the manual activity places high demand on the musculoskeletal system (Herberts et al., 1984). Further, the back and shoulder are known to interact to enable the performance of complex lifts, such as stoop lifting (Park et al., 2005). This points towards a systematic functional redundancy that is relatively poorly defined.

## 2.2 Manual Materials Handling

Manual materials handling involves a complex interplay between the worker, the task, and the environment (Ayoub & Mital, 1989). In an industrial context, tasks involve MMH include working on an assembly line, lifting and moving boxes or automobile parts, lifting and maneuvering patients, loading parts on and off a truck and countless others. Personal worker characteristics including gender, age, strength, anthropometry and experience all influence the ability of the individual to lift, push, pull or carry objects of various weight and dimensions. The geometry and configuration of the workplace environment also affects the ability to skillfully and safely lift and move materials (Ayoub & Mital, 1989; Chaffin et al., 2006).

In 2008, the U.S. Bureau of Labour Services (BLS) indicated the pervasiveness of occupational musculoskeletal disorders associated with MMH. Even though the number of MSDs resulting from MMH, which include risk factors such as repetitive motion and overexertion in lifting, has decreased over the last few decades, the numbers and associated injuries remain astounding (Table 1). In Ontario in 2009, the Worker Safety and Insurance Board (WSIB) reported approximately 47% of total injuries claimed were caused by bodily exertion reactions (a total of 30,236). Of these injuries, 23% were caused by overexertion and 5% were caused by repetitive motion (WSIB, 2010). The costs associated with these injuries are a major concern to businesses, governments, and families. The Ministry of Labour of Ontario reported that for the period from 1996 to 2003, estimated MSD lost time costs were more than $3 billion dollars (Ministry of Labour, 2005). It has also been reported that low back pain (LBP) alone cost the United States nearly nine billion dollars in 1995 (Murphy & Volinn, 1999).

**Table 1.** Number of injuries reported in 2007 caused from overexertion or repetitive motion requiring a minimum 9 days away from work (Bureau of Labor Services, 2008).

| Industry | Number of Injuries caused by overexertion and repetitive motion |
|---|---|
| **Private** | 264,930 |
| **Goods Producing** (such as construction and manufacturing) | 66,760 |
| **Service Producing** (such as trade finance and healthcare) | 198,170 |
| **Total** | 335,390 |

Historically, most MMH joint-based research has focused on the lower back, but this is not the site of all associated problems. A Scopus search for ‘manual materials handling’ and ‘low back’ yields 250 results, while ‘manual materials handling’ and ‘spine’ yields 165 results, compared to just 76 for ‘manual materials handling’ and ‘shoulder’. Indeed, while many reported MMH injuries are in the low back (Bernard, 1997; Murphy & Volinn, 1999; Burgess-Limerick, 2003), other parts of the body are also affected by repetitive lifting, pushing, pulling and overexertion, and not mutually exclusively. Yeung et al. (2002) reported that 85% of lower back symptoms are associated with disorders in other body regions. While LBP was the most common region of complaint, participants also had symptoms in the shoulder, upper back, hips, upper legs and neck. Nearly 40% of all upper extremity MSDs in the US population can be attributed to occupational exposures, including MMH (Punnet & Wegman, 2004).

Discovering which movements may put a worker at risk has been a main focus of many researchers. Both laboratory and field studies have been conducted to isolate the exact causes of injury to both the upper and lower extremity during MMH. Bernard (1997) included over 600 studies on occupational MSD and risk factors, all of which evaluated exposures to gain insight into repetition, force, extreme joint position, static loading or vibration, and lifting tasks. Resultant risk seemed to depend on a variety of factors, as outlined in Table 2. Along with these occupational biomechanical risk factors, non-physical factors are also thought to influence the risk of MSD due to MMH. Factors such as worker environment, high job demand, low social support, high perceived stress and low job satisfaction may also contribute to occupational back and upper extremity disorders (Punnet & Wegman, 2004). Specific risk factors affecting the back and shoulder will be described in detail in sections 2.2 and 2.3.

**Table 2.** Risk factors as determined by a critical review of epidemiological work related MSD studies (Bernard 1997). Evidence of these factors was based on meeting selected criteria for causality (strength of association, consistency, specificity of effect, temporality, exposure-response relationship and coherence of evidence).

| **Body part**<br>*Risk Factor* | **Strong evidence**<br>(+++) | **Evidence**<br>(++) | **Insufficient Evidence**<br>(+/0) | **Evidence of no effect**<br>(-) |
|---|---|---|---|---|
| **Neck and Neck/Shoulder** | | | | |
| *Repetition* | | * | | |
| *Force* | | * | | |
| *Posture* | * | | | |
| *Vibration* | | | * | |
| **Shoulder** | | | | |
| *Posture* | | * | | |
| *Force* | | | * | |
| *Repetition* | | * | | |
| *Vibration* | | | * | |
| **Elbow** | | | | |
| *Repetition* | | | * | |
| *Force* | | * | | |
| *Posture* | | | * | |
| *Combination* | * | | | |
| **Hand/wrist** | | | | |
| Carpal Tunnel Syndrome | | | | |
| *Repetition* | | * | | |
| *Force* | | * | | |
| *Posture* | | | * | |
| *Vibration* | | * | | |
| *Combination* | * | | | |
| Tendinitis | | | | |
| *Repetition* | | * | | |
| *Force* | | * | | |
| *Posture* | | * | | |
| *Combination* | * | | | |
| Hand-arm Vibration Syndrome | | | | |
| *Vibration* | * | | | |
| **Back** | | | | |
| *Lifting/forceful movement* | * | | | |
| *Awkward posture* | | * | | |
| *Heavy physical work* | | * | | |
| *Whole body vibration* | * | | | |
| *Static work posture* | | | * | |

*2.2.1 MMH + Low Back Injury*

Back injuries associated with MMH have been a persistent occupational health problem. Even with a recent increase in ergonomic interventions such as mechanical handling aids, many occupations are still considered high risk for developing low back pain such as construction, mechanical repair of vehicles and equipment, baggage and package handling, police, military, fire fighting plus many others (Chaffin et al., 2006; Kerr et al., 1997). Injuries to people working in these types of sectors are common, and in 2009 in Ontario, the WSIB reported that back injuries accounted for nearly 30% of lost time claims (WSIB, 2010). In the United States, the BLS reported that in 2008, nearly 25 out of 10,000 workers were required to take time off due to injury or illness to the back. Service industries had the highest percentage of injuries to the back (22%), while private industry (20.4%) and goods producing (16.6%) closely followed (BLS, 2009).

Numerous research studies have examined potential risk factors for injuries to the lower back. Studies in both the field and laboratory have focused on a combination of biomechanical, psychophysical and environmental factors (Keyserling, 2000). Biomechanical factors include the magnitude and direction of a force exerted while working, location the force acts on the body, postures required to perform the job and movement dynamics; psychophysical factors focus on worker discomfort and stress or fatigue that may arise from performing a job. A review of over 40 articles by Bernard in 1997 found very strong evidence to link LBP with lifting and forceful movements as well as whole body vibration. Evidence was also found for a positive relationship with heavy physical work and awkward postures. Biomechanical risk factors that have been agreed upon by many researchers include increased trunk forward flexion and trunk rotation, one handed lifting, awkward and restricted postures, heavily weighted objects and the shifting of center of gravity out from under the feet (Kerr et al., 1997; Bernard 1997;Marras et al., 1993;McGill, 2007; Keyserling 2009). Task duration, shift length, repetition and increased distance of object displacement have also been noted as environmental risk factors (Ayoub and Mital, 1984; Kerr et al., 1997, Keyserling 2000). Table 3 outlines risk factors that have been found to be related to LBP. Any one of these factors can influence the risk of an acute or cumulative MMH injury.

**Table 3.** Job and task factors significantly related to biomechanical and/or psychophysical measures of strain (Keyserling, 2000).

| Job or Task Factor | Biomechanical Strain | Psychophysical Strain |
|---|---|---|
| Weight lifted | X | X(Dependant Variable) |
| Horizontal reach distance | X | X(Box size) |
| Posture: trunk flexion | X | |
| Posture: trunk twisting/bending | X | X |
| Posture: lift above shoulder | | X |
| Lift frequency | X | X |
| Lift dynamics | X | |
| Displacement distance | | X |
| Presence of handles | | X |
| Shift duration | | X |
| Population variability | X | X |

Although an understanding of acute overexertion in MMH is well established, cumulative injuries also demand attention (Norman et al., 1998), and there remains a need for more reliable ways to predict risk of low back disorders due to MMH (Waters et al., 2006) Compressive and shear forces generated from MMH tasks act on the spine over days and months at work. Specifically, large extensor moments are required at the joints of the vertebral column, particularly in the lower back to balance the large flexor moments caused by the weight of the upper body and the additional demand caused by the lifting and/or repositioning of the object (Burgess-Limerick, 2003). Though there is a large variation of population size within the workplace, gender is thought by some to have considerable effect on LBP as well, even though females are capable of producing static strength values similar to that of men (Chaffin et al., 1973). When comparing spine loading between men and women who are exposed to similar demands, like that in the workplace, Marras et al., (2003) discovered that men tended to have significantly greater compression forces and gender effects were larger when lift origin height was normalized to subject anthropometry. Since men tend to have higher compression tolerance forces, women's compression values were compared against suggested tolerance values, and the authors found them to be 25% closer to their limits. While Marras concluded that gender has a smaller impact on spinal loading than postural asymmetry and load weight, the need to account for gender when designing a workplace remains. All of these factors contribute to a variety of reasons why workers continue to injure their low back while at work. The large variety of LBP research has provided ways to avoid these types of injuries, but the exact causes remain attributable to a variety of factors.

*2.2.2 Historical Ergonomic Strategies that Focus on Minimizing Low Back MMH Injury Risk*

Lifting is a prevalent task in industry and is known to cause injury, therefore numerous suggested weight limits have been put in place in order to reduce these injuries by limiting the amount of stress put on the back (and low back especially). In 1962, the International Labour Organization (ILO) published safe weight limits for men and women, but seemed to have little impact on reducing the incidence of MSD in the industrial workplace (NIOSH, 1981). Some important lift-related factors that researchers and ergonomist agree are important were missing from the ILO standards, some of which include the size of the object and the frequency of lifting. To update the available ergonomic strategies for lowering low back pain the workplace, the NIOSH lifting equation was produced in 1981 which included known epidemiology of musculoskeletal injury as well as biomechanical concepts, physiological principals, and psychophysical (subjective estimates of maximum weight of lift) (Waters et al., 1993). Figure 1 is an illustration describing the interplay between these key factors of MMH. The higher the frequency of lifts per minute, the more the physiological criterion would dictate recommendations for over eight hours of lifting. If the frequency of lifts per minute is lower than three, biomechanical limits will determine the weight to be lifted. Otherwise, psychophysical criterion will dictate how much to lift per minute over an eight hour shift (Chaffin et al., 2006).

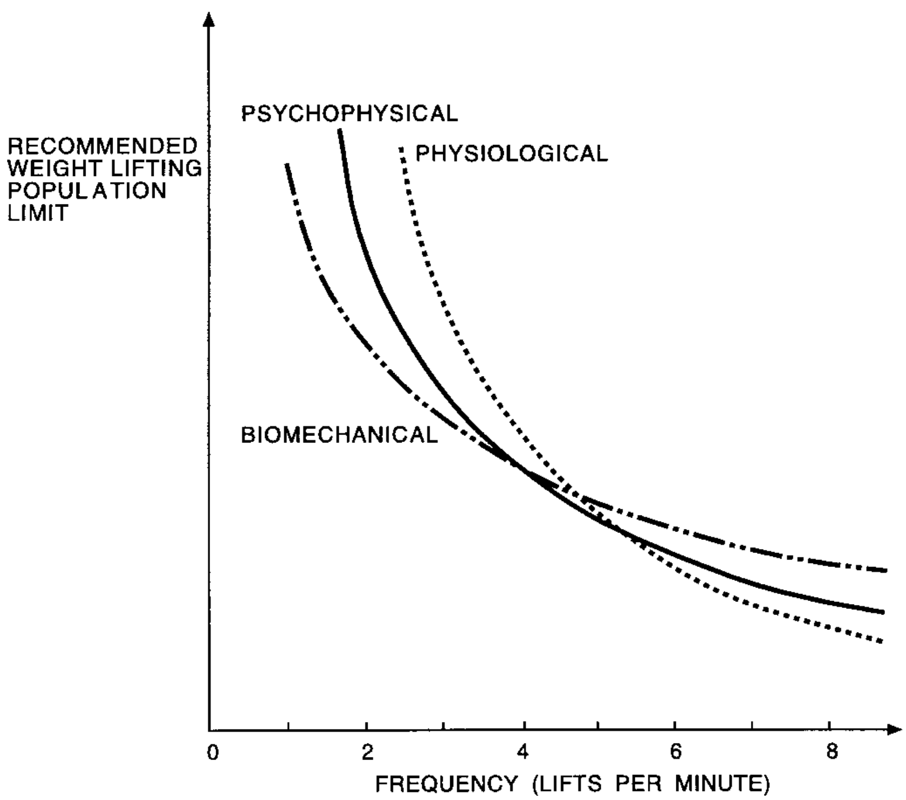


**Figure 1.** Interplay between biomechanical, physiological and psychophysical risk factors (Ayoub, 1992)

Using NIOSH guidelines, manual material handlers were instructed to maintain straight backs while lifting, use leg muscles to lower the body then lift the load, keep load as close to the body as possible, lift with a smooth body motion and turn with the feet rather than the trunk in order to avoid lateral flexion and axial twisting (NIOSH, 1981). This early lift equation calculated a recommended weight (spinal compression) at L4/L5 for two-hand symmetrical lifting tasks only, and the resultant term to control injury was the Action Limit (AL). This equation takes into account injury variables (horizontal location of the load and the vertical location of the load at the beginning of the lift) as well as fatigue variables (the vertical distance travelled as well as the frequency of lifting in lifts per minute). The maximum permissible limit (MPL) was considered three times the found AL and represents an increased risk of injury for most workers (acceptable for only 1% of women and 25% of men) (NIOSH, 1981). While these early guidelines provided insight to specific risk factors within MMH, many aspects of lifting were overlooked. The lifting equation was revised, then, in 1993, adding psychophysical data to generate a recommended weight limit (RWL) that incorporates 90% of a mixed gender population of workers. The psychophysical data helped to provide information to contribute to the RWL in terms of asymmetric lifts, gripping and modifying a weight constant. This new RWL is used towards generating a lifting index, which is not to exceed 3.0 (Waters et al., 1993). The resulting lifting index recognizes that not all workers are at an equal risk and provides a more realistic and even safer RWL. While experts appreciate the newer comprehensive method (which includes incorporating axial twisting into the equations), there is some concern over the lack of definition of hazards when the lifting index is greater than the recommended 1.0 (Chaffin et al, 2006). The 1993 guide is also still lacking information regarding one handed lifting which can happen often in a work setting, and questions remain regarding its level of conservative estimates. Lifting limits based on NIOSH equations have been suggested in order to reduce the amount of injuries from MMH. Numerous cadaver studies have revealed a wide variety of tolerance of the low back to compressive force (Jager, 1987), with some of the variance being explained by age, gender and population percentile (Genaidy et al., 1993). Even with the large amount of variance in values, NIOSH concluded that the AL should be set at 3400N limit, with the MPL typically set at 6400N. Some guidelines have tried to factor age into the AL and MPL limits, taking more of the found variance in tolerance limits into account (Chaffin et al., 2006). Industrial engineers and biomechanists have been implanting numerous other strategies to minimize occupational injuries to the low back in the past few decades, however best practice principles for ergonomic design remains elusive. Job rotation strategies have been suggested in order to limit the type of exposure one worker may get throughout the day. Questionnaires handed to refuse collectors (Kuijer et al., 2005) determined that while rotating between driving a truck and collecting containers, after one year there was a reduced need for recovery but was associated with an increased risk of low back complaints. Of concern is the fact that in some cases the rotation could potentially injure both workers because now all workers are exposed to the riskier jobs. While analyzing the effect of job rotation on predicting the risk of low back pain, Frazer et al. (2003) found that while using a time weighted average approach, the increase in risk for reporting low back pain was greater for those rotating into the demanding job than the reduction experienced by the workers who rotated out of that job. Various lift technique recommendations such as squat lifting instead of stoop lifting have commonly been used in industry, but stoop type lifting may be less fatiguing than the traditional squat mechanism, leading to a semi-stoop compromise position (Straker, 2001; Burgess-Limerick, 2003). Mechanical lifting aids have been provided for many industries, including scissor lifts in many industrial workplaces and ceiling or floor patient transfer lifts in hospital settings. Introducing these types of interventions may not be as cost effective as training, but the outcome has a far greater impact on total health (if they are used and implemented properly), especially in more developed countries (Lahiri et al., 2005). On body personal lift assists have been introduced as an alternative to mechanical lifting aids and back belts (Abdoli-E et al., 2006). While supporting the back muscles during repetitive lifting by becoming external muscle force generators, these non-motorized devices successfully lower muscle activity during any type of lifting style or load, however the effect they have on de-conditioning the muscles remains to be seen. It is obviously the long term effect of these aides still require plenty of investigation. Lifting teams were created with the knowledge that capacity is greater than one individual (Barrett & Dennis, 2005). By 'splitting' the lifting load evenly between two people, the stress can be reduced successfully to the low back; however the unexpected interactions (such as slips, trips and losing grip) can make team lifting quite dangerous. The advantages of this intervention is still not clear cut, therefore it remains to be seen whether hiring a lifting team is worthwhile for MMH industries.

Training and education has been a mainstay in industry, however there is still no consensus on the efficacy of these programs. Generally, the objectives are to prevent MMH injuries as well as rehabilitate or accommodate previous injuries in return to work programs. They tend to emphasize training in safe lifting, training to increase overall strength, and methods to reduce existing back pain (Ayoub & Mital, 1989). Research has found that when comparing those workers who had a lifting program to those who did not, there was no difference in injury rates or injury time off work (Snook, 1978; Daltroy et al., 1997). In fact, after a literature review of 19 studies focusing on the quality of methodology (only six of these trials were considered high-quality), Heymans et al. (2005) found only moderate evidence to suggest that 'back schools' to prevent or rehabilitate LBP are effective. While training may also be very cost effective, the impact on total health outcome remains limited (Lahiri et al, 2005). Many agree that while education and training programs combined with proper body mechanics while lifting are effective, they cannot be preventative without the inclusion of targeted ergonomic intervention (Daynard et al 2001; Owen et al., 2002; Garg & Owen, 1994)

*2.2.3 MMH + Shoulder Injuries*

Despite having had substantially less research and recognition than MMH-related low back consequences, the shoulder is the second most affected part of the body in MMH tasks (Yeung et al., 2002). Nussbaum et al. (2001) noted that shoulder injuries are quite prevalent in industrial work, especially MMH tasks that involve work at or above the shoulder level. In 2009, compensable shoulder injuries reported in Ontario totaled 6.6% of all claims, an increase from 5.8% in 1998 (WSIB, 2010), while in the United States, shoulder injuries required approximately 18 days time off work, more than any other part of the body (BLS, 2008). BLS also reported that eight out of 10,000 workers had shoulder injuries in 2007, with half of the reported injuries being caused by overexertion (occurring in nearly even numbers for private, service producing and goods producing industries).

Similar to the low back, a multitude of factors make the shoulder at risk for injury while performing MMH tasks. A review by Bernard (1997), included 20 epidemiological papers and found a positive association between highly repetitive work and shoulder MSDs, but did not find enough evidence to show an interaction between forces exerted at the shoulder and shoulder injuries. Static loads, lack of rest and non-neutral postures have also been found to be associated with an injury at the shoulder, and these are quite prevalent in industrial work, especially with MMH tasks that involve work at or above the shoulder level (Nussbaum et al., 2001). In fact, it has become widely accepted that the main risk for shoulder injuries remains where workers are performing MMH tasks that are sustained at or above the head level, about 60 degrees of flexion and abduction (Bjelle et al., 1979; Kilbom, 1994; Bernard, 1997; Nussbaum et al., 2001).

Postural discomfort is also known to occur when arms are required to work overhead (Wiker et al., 1989), which contributes to the positive relationship known between increased discomfort and muscle fatigue (Oberg et al., 1994). Specific postures known to contribute to higher amounts of muscular demand are pulling in a backward direction, especially at angles of -15° and 0° compared to pushing down or forward, which require considerably less muscular demand (Chopp et al., 2010).

While physical analyses focusing on biomechanical risks provide much insight into overall workplace risk, psychosocial and psychophysical factors are also important when discerning risk factors that may lead to MSD of the shoulder. Psychosocial factors like work organization and job demands (work pace) can influence a worker's job satisfaction; low job satisfaction may also represent the outcome of physical strain at work and lead to the experience of MSD pain at work (Punnet & Wegman, 2004). Punnet and Wegman (2004) also found that psychosocial factors were just as attributable to MSD exposure as physical factors, and included high job demand, low decision latitude, low social support and little rest break opportunities; for the shoulder especially, eliminating these risk factors would improve the chance of not having a MSD by nearly 70% in some cases. The occurrence of psychophysical factors in MMH tasks mean the worker must use his or her perception about the task in order to avoid over-exertion or fatigue (Ayoub & Mital, 1989). These findings regarding psychophysical factors point to an importance in their inclusion in current and future tools to limit shoulder exposures.

While investigations regarding shoulder injuries are revealing more reasons as to why these types of injuries are so prevalent among MMH workers (often second to low back injuries), the information available to designers and ergonomists still falls short of that available for low back pain and injuries. Reasons as to why the injuries are happening to the shoulder joint remain unclear in many types of situations.

*2.2.4 Historical Ergonomic Strategies that focus on Minimizing Shoulder MMH Injury Risk*

Safe lifting strategies involving the shoulder generally do not exist beyond simple postural guidelines. Various researchers have shown that loads cannot be supported for sustained times, especially if the arm or forearm is elevated at or above shoulder level in a forward or lateral reach posture (Chaffin et al, 2006, Nussbaum et al., 2001). It has also recently been found that in jobs that demand overhead postures, improvements to working conditions may be made by requiring hand force to be directed either forwards or downwards and moving the task closer to the individual (Chopp et al., 2010). In attempt to add to current knowledge regarding guidelines for overhead work, work/rest cycles of 20 seconds of work to 40 seconds of rest were introduced by Nussbaum et al. in 2001, in order to determine endurance and fatigue limits while performing an overhead assembly task commonly performed dynamically and intermittently. These suggested guidelines are based on compiled subjective rating of perceived exertion (RPE) that were taken after each type of work/rest cycle as well as muscular activity and the onset of fatigue for selected muscles of the forearm. While these results are aimed for simple repetitive tasks and may not be reliable for more complex intermittent dynamic MMH tasks, the knowledge that duty/rest cycles are key factors in avoiding injury and fatigue in workers is extremely useful for future design and analysis of overhead work tasks (Nussbaum et al., 2001). Many other ergonomic tools exist that may be whole-body analyses in concept but can be applied to the upper extremity and the shoulder specifically. These include tools such as postural analysis, strength limits and fatigue analysis. Postural approaches to task analysis exist where no instrumentation may be available, and can provide information on the occurrence and amount of non-neutral postures throughout the task. Missing from these approaches, however, is the ability to assess risk and provide action recommendations. Postural analysis techniques include postural targeting methods developed by Corlett et al., (1979) which requires an analyst to observe a worker at random times throughout the day, and record the angular configuration of desired body segments on a diagram. The Ovaco Working Posture Analysis System (OWAS) also helps identify unsuitable working postures by observing and recording percentages of working time devoted to a certain posture and describing associated action categories (Karhu et al., 1981). Keyserling (1986) developed a standard posture classification system incorporating computer technologies to assist in evaluating a variety of postures. Michigan's 3D Static Strength Prediction Program (3DSSPP) can also be used in assessing upper extremity joint strength requirements for MMH tasks. By inputting known hand loads and worker characteristics, and positioning the onscreen mannequin in certain positions, the analyst is provided with a multitude of outputs. While the current program is still limited (static tasks, sparse strength data), it is constantly being improved to include a greater variety of outputs and to be able to include more work-like situations. Muscle fatigue guidelines can also be applied to the shoulder, and they include Rohmert's (1973) endurance time curve as well as Jonsson's (1978) amplitude probability distribution function (APDF). Rohmert (1973) predicts that contractions below 15 % of maximal voluntary contraction (MVC) can be sustained indefinitely without fatigue, where Jonsson (1978) suggests that in cases of continuous work, static exertions should not exceed two to five % MVC and dynamic exertions should not exceed 10 to 14 % MVC. Other more recent developments, as well, have shown Rohmert's suggestion to also be unrealistic (Chaffin et al., 2006). McAtamney and Corlett (1993) have also developed an assessment specifically for the upper limb called the Rapid Upper Limb Assessment (RULA). Using this approach, an analyst can gain a sense of muscular effort and body posture through a tabular analysis that generates an overall score for each arm. This type of analysis, however, entails subjectivity in rating and may oversimplify MMH task requirements by only including broad categories of work situations and potential musculoskeletal risk.

### 2.3 Exclusivity of Ergonomic Recommendations and Analysis Tools

Many current analysis tools may take into account lower and upper limbs, but most do not consider them together (i.e. can analyze certain parts). Recommendations do not take into account what is happening at one joint compared to another. Mostly, tools and recommendations are centered on lowering or eliminating suspected injury risk factors (i.e. less overhead work, less awkward postures) without taking into consideration what may be happening at another joint when this "fix" is accomplished. While the NIOSH lifting equation gives insight into loads that put the low back at risk (Waters et al., 1993), once these loads are changed, there is no way to know how they may affect the shoulder (negatively or positively). Computerized models and analysis tools such as Michigan's 3DSSPP, however, are starting to allow ergonomists to analyze multiple areas of the body at one time and see the impact changing the position of the back may have on other areas of the body (Chaffin et al., 2006). These types of tools are effective in designing new workplace set-ups, but may not get used as often to analyze current jobs, where quicker field methods may be applied, such as RULA or the NIOSH RWL; in many cases those analyzing a particular job lack the expertise necessary to run and understand the output coming from complex computerized models. Until these methods incorporate full body analysis and consideration of the effect changing a posture may have on another joint, the risk for injury being transferred exists.

## 2.4 Nursing as an example of MMH

While most people involved in MMH industry move boxes or parts on an assembly line, nurses instead interact with and move, transfer, push and pull living people. Physical loading of the nurses associated with these tasks results in many occupational MSDs and days off work. Due to reporting standards, it remains difficult to determine the full extent to which nurses develop MSDs. Even with a reported 83% higher MSD rate among nurses than the regular workforce (Obrien-Pallas et al.,  2004), nurses continue to under-report their injuries and seem to accept daily pain as part of the their chosen profession. Warming et al., (2009) also found an increase amongst nurses from day one to day three over three consecutive work days in neck and shoulder pain, but following a day off the pain was reduced. This suggests that the pain is likely attributable to performing work place tasks and indeed at least 44% of nurses surveyed by Obrien-Pallas et al. (2004) had missed time in the past because of an MSD or pain related symptoms. The following sections will outline the extent of nursing injuries to the Ontario and US populations and the types of risk factors that make these nurses susceptible to increased amounts of injury. The types of proper lifting strategies that have been taught to nurses will be briefly explained as well as the effectiveness of common types of interventions (such as mechanical lift assists and no-lifting policies) given to avoid the low back pain commonly associated with manual patient handling (MPH).

### *2.4.1 Injuries Associated with MPH within the Nursing Profession*

All over the world, nursing and those involved in the nursing profession (including aides and orderlies) are being injured by manually handling patients throughout the day. In 2008, healthcare represented 11.2% of total lost time claims reported to the WSIB for the year, ranking third behind manufacturing (13.5%) and services (24.7%) where the industry once ranked far behind these same services in 1999. A total of 29,716 injuries by both large and small businesses in health care were reported in 2008, moving the industry behind manufacturing, construction, and services in injuries per year (WSIB, 2009). In the United States, statistics that are more comprehensive are available regarding nursing injuries, and MSDs that are specific to injury site on the body are readily available. It is also important to note that in the US, nursing aides or orderlies do most of the patient handling, while in Canada, nurses alone do these jobs. For 2007, the BLS reported that with 44,390 days away from work, nursing is the third highest occupation for lost work days, behind only general labourers (including most manual material handlers) and tractor trailer drivers (Figure 2). With 465 injuries per 10,000 workers, nursing aides have the highest recorded injury rate of all occupational groups. Most striking, however, is the fact that the MSD rate for nursing aides and orderlies is seven times the national MSD rate, with 252 MSDs reported per 10,000 workers. Specifically, nursing aides reported that 249 per 10,000 injuries were to the trunk; 185.2/10,000 occurred in the back and 35.9/10,000 reported in the shoulder. Specific causes of these injuries overwhelmingly come from moving the health care patient, where 258 whole body injuries per 10,000 happen in this way.

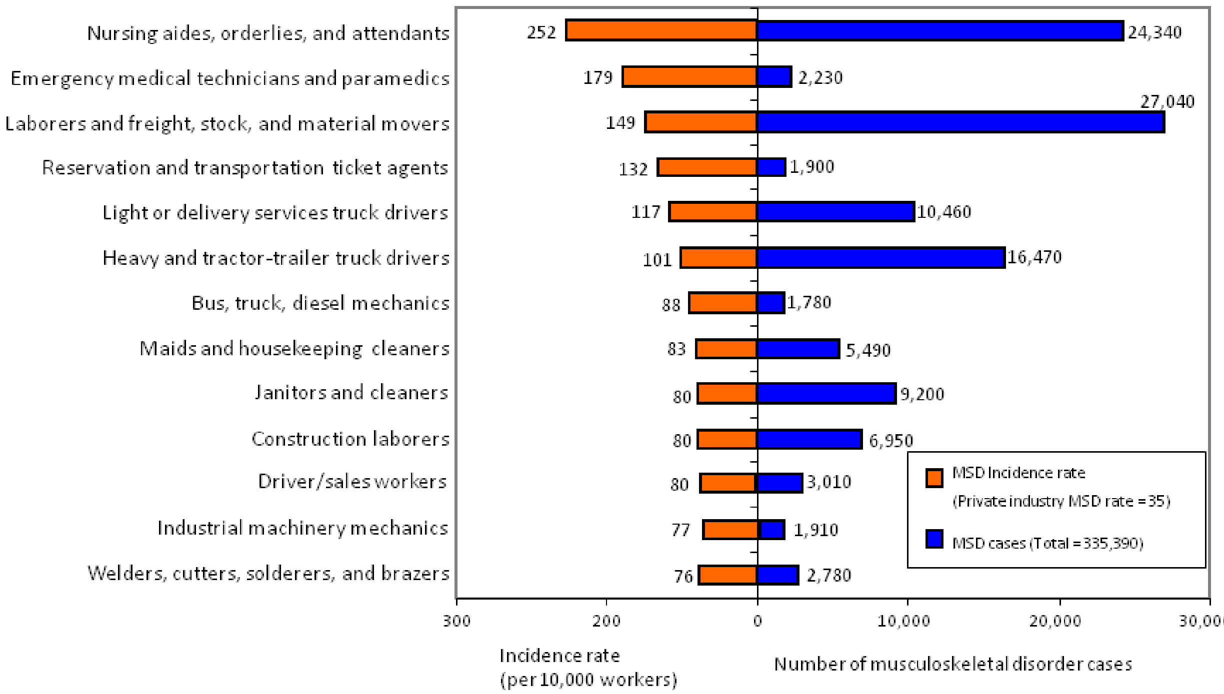


**Figure 2.** American MSD rate data from 2007. Note nursing aides, orderlies and attendants have the second most total MSDs and highest incident rate of all occupations listed (BLS, 2008).

### *2.4.2 Risk Factors Involved with MPH*

There are many underlying reasons why nurses and nursing aides have more MSDs than any other occupation in the United States, and rank third in Canada among industries. Many different factors come together to create risk factors for nurses including biomechanical, environmental and psychosocial factors. MPH is not the same as moving an inanimate object. A patient can be combative and uncooperative, and require special care of broken bones and surgery wounds (Garg et al., 1991a; Garg & Owen, 1992b; Owen et al., 2002). Patients lack handles that boxes or materials may have, and humans do not have an even distribution of weight, which can lead to unexpected and awkward posture loads (Nelson & Baptiste, 2006). The nurse may need to assume a position where awkward postures are necessary, leading to forceful exertions and twisting movements. Tuohy-Main (1997) reported that nurses may handle over 1.8 tonnes during a normal eight hour shift. Cramped workspaces, usually involving patient transfers from the bed to a chair to the bathroom, can also make it challenging to achieve optimum body posture (Garg et al., 1991a). Task, technique, weight of a patient and the ability of a patient to assist all play a key role in the safety of nurses (Skotte & Fallentin, 2008).

Typical daily nursing tasks include types that involve direct patient care, indirect care (such as interacting with family members), documentation, administration and housekeeping activities (Wong, et al., 2003). While investigating various postures assumed by nurses throughout an eight hour work shift at a long term nursing home, Hodder et al. (2010a) discovered that only 1.4% of the eight hour shift was spent performing manual lifts, while 2.5% of the same shift was spent using mechanical aids to lift. Most of these lifts and transfers occurred at the beginning of the work shift, which may be a concern because of muscle stiffness (Hodder et al., 2010a). Walking accounts for much of a nurses activity in a day (nearly 80%), and while transfers and tasks have high peak loads, other daily tasks can contribute to the amount of cumulative loading a nurse experiences throughout a shift, such as changing linens and assisting with activities of daily living of patients (Holmes et al., 2010).

Even though nurses do not lift and transfer patients continuously throughout an eight or twelve hour shift, the time at which they perform these tasks combined with the unique risks of lifting and transferring a person compared to a box may increase the risk of acute injury. The risk of cumulative injury also exists for a nurse working in an acute or long term setting, as the time spent walking to and from patient rooms, as well as the tasks they perform on these patients add to the muscular stress of transferring those patients.

*2.4.3 MPH Tasks Typically Performed in Nursing*

There are many different types of patient lifting techniques used in a variety of situations, from repositioning a patient on the bed to lifting a fallen patient off the floor and back into a wheelchair. A variety have been analyzed by researchers for their effectiveness and safety, with many researchers focusing on moving a patient from the bed to a wheelchair or toileting device; a maneuver that happens frequently throughout the day (Garg et al., 1991a,b; Skotte et al., 2002; Schibye et al., 2003). Typical lift types for this kind of maneuver include one person hug, two person hook, or standing pivot, while repositioning a patient requires similar techniques (Silvia et al., 2002). Examples of some of these techniques are shown in Figure 3. Specific techniques used in this study are described in detail in section 3.3.

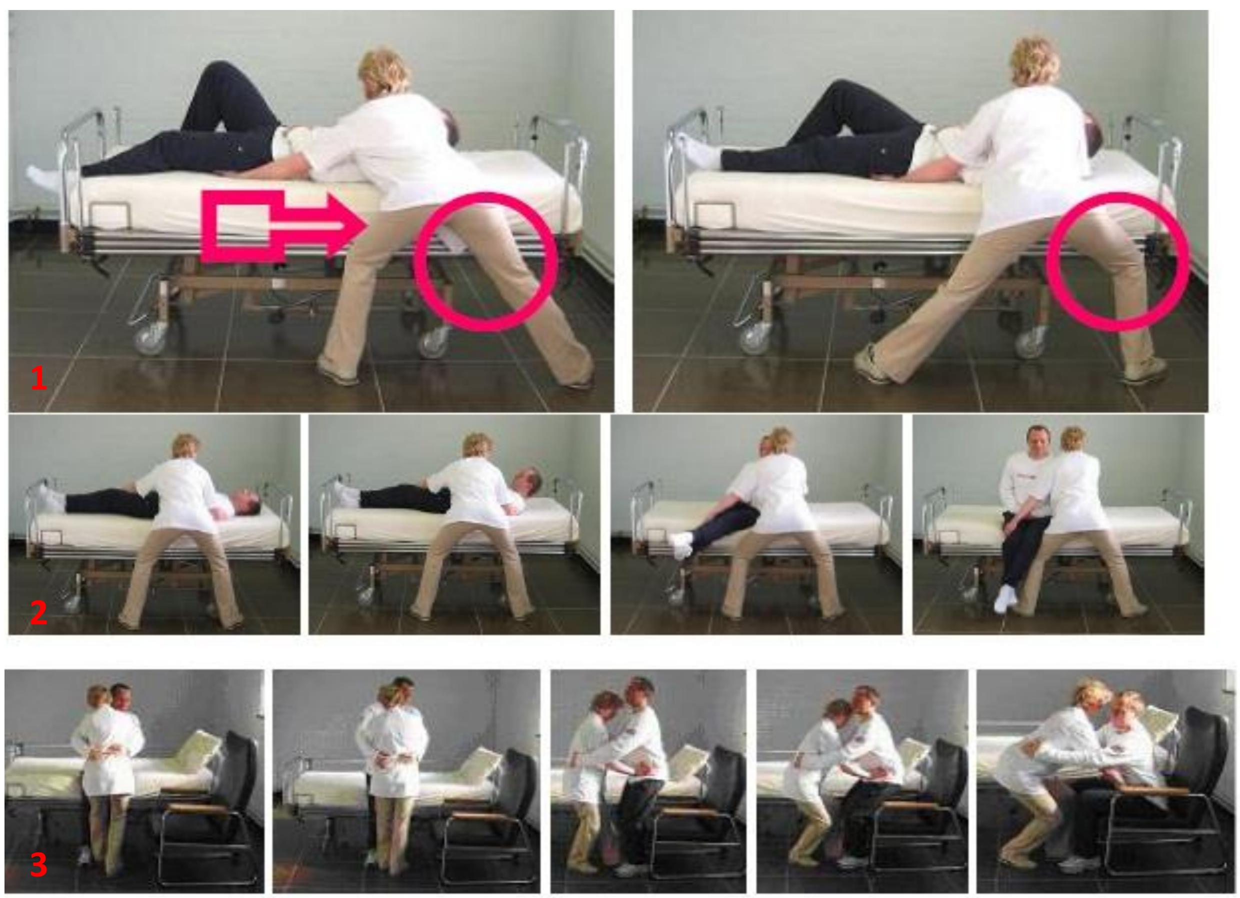


**Figure 3.** One person MPH transfers: (1) reposition, (2) Lie to Sit, and (3) standing pivot (E-Facts, 2008).

*2.4.4 MPH Tasks and their Relationship to Low Back Injuries*

Specific manual lifts have been classified by researchers as being worse than others for causing injuries to a worker. In some cases, they are even banned by governing bodies (examples in Figure 4). In Canada, a one person low pivot manual transfer as well as a two person side by side transfer are banned, while in the UK, the drag lift, cradle lift and shoulder lifts are banned. While high risk tasks vary by clinical setting, many researchers agree on a set of dangerous tasks that include vertical transfers, repositioning a patient on a hospital bed or in a chair, moving a patient from bed to toilet, bed to chair, toilet to bed and chair to bed, and turning a patient toward or away to apply a sling for a mechanical lift device(Garg & Owen, 1994; Marras et al., 1999; Schibye et al., 2003; Daynard et al., 2001; Yassi et al., 2001; Owen et al., 2002; Hanson et al., 2003; Keir & Macdonell, 2004; Nelson & Baptiste, 2006).


**Figure 4.** MPH techniques that have been banned from many hospitals; (1) Orthodox (two person cradle) Lift, (2) Shoulder Lift, (3) Modified Shoulder Lift (Stevenson, 1998).

Many biomechanical studies have been performed on these common MPH tasks to see how they influence low back stress. Based on intra-abdominal pressure (IAP), Pheasant and Stubbs (1992) listed types of MPH tasks in order of risk (Table 4), where risk level represents how often (percentage) known tolerable limits of IAP were violated. In many cases, MPH tasks exceed recommended tolerance levels set by NIOSH in 1981 (and revised version in 1993). Risk level percentages over 50% were considered ‘high’ risk, 25-50% ‘moderate’ risk, and under 25% were thought to be ‘low’ risk (Pheasant and Stubbs, 1992). Skotte and Fallentin (2008) analyzed six different tasks that involved repositioning, turning and lifting patients that represented various levels of paralysis. Low back net moment, compression and shear forces at the L4/L5, and muscle activity of the erector spinae muscles and ratings of perceived exertion (RPE) were collected and inputted into a 3D biomechanical seven-segment model. The NIOSH AL was exceeded in 25% of the trials, with the highest peak compression values measuring at 4132N and 4433N for lifting a patient into a wheelchair and repositioning them in the wheelchair; shear also exceeded the recommended value of 500N in 52% of the trials. Lifting tasks by one person were found to have nearly 6717N of compression force by Marras et al., (1999) while one person repositioning tasks measured a maximum lateral shear force of 676.6N. Marras et al. (1999) suggested that none of the current manual patient tasks for either one or two people should be considered safe to use in a hospital setting. Garg and colleagues studied MPH in the early 1990’s using nursing students and different manual techniques. Manual two person lifting compression reached 4800N while shear nearly doubled the recommended limits at 926N (Garg et al., 1991a). A pre-intervention biomechanical evaluation in 1992 also showed how dangerous MPH can be, with the most stressful lifts producing 4751N of compression on L5/S1 (Garg et al., 1992). Sliding sheet usage and bed to wheelchair transfers also produce compression values over the AL (Daynard et al, 2001; Yassi, 2005). Proper strategies for MPH techniques have decreased these metrics, with Schibye et al. (2003) finding that all loads were reduced below 3400N using recommended techniques. While these studies may provide insight into how low back injuries can be prevented with an ergonomic intervention such as mechanical lift assists and proper lifting strategies, they do not include information on the consequences of the interventions for other joints in the body, specifically the shoulder.

**Table 4.** Risk assessment of traditional MPH tasks that exceed known safe IAP levels; assessment level corresponds to how often tolerable limits were violated. High is >50%, Moderate is 25-50%, Low is < 25% (Pheasant & Stubbs, 1992).

| **Manoeuvres** | **Risk Assessment** |
|---|---|
| Cradle (orthodox) lift | High |
| Wheelchair to bed | High |
| Three-person lift | High |
| Desperate drag | Moderate/high |
| Bed to wheelchair | Moderate/high |
| Pivot turns: 180° elbow hold | Moderate/high |
| Pivot turns: 90° axillary hold | Moderate |
| Shoulder (Australian) lift | Low |
| Draw-sheet lift | Very low |

*2.4.5 MPH Tasks and their Relationships to Shoulder Injuries*

Scarce information exists regarding the loads and stresses occurring at the shoulder during transfer and repositioning tasks. Questionnaires analyzing any 12 month prevalence of MSD among Japanese nurses cited shoulders as the most commonly reported site for MSDs, while a similar study showed the same results for Korean nurses (Smith et al., 2006; Kee & Seo, 2007). Garg et al. (1991a), reported that after testing five manual techniques and three mechanical hoists, nurses reported the shoulder being the most stressed body part on post intervention RPE's, while in 1994, post intervention stress was higher in the shoulder than in the back as reported by a nine-point stress scale. Translating and turning a patient has also been reported to be extremely stressful on the shoulder (Gagnon & Smyth, 1987). In this study, bed height had a direct impact on shoulder comfort, as well as the ability to support the knee on the bedside. Most shoulder specific results are reported in papers that focus on low back exposures, which give limited insight into the reasons behind shoulder injuries associated with MPH.

*2.4.6 Ergonomic Interventions aimed at Lowering MPH Related Injury*

Nursing students and Registered Nurses (RN) are prepared with training and education courses on proper patient manipulation. This often takes the form of organizational interventions such as flow and decision charts or manuals. These are available for staff, helping them decide what lift to implement or what mechanical aid to use for different patient handling scenarios (Hignett, 2003). Local hospitals may be given pictures and explanations to help nurses decide when and how to use a lift, and may look similar to those in Figure 5, which are provided for nurses and staff at a rural Ontario hospital. Information on posture, strength exercises and stretching can also be given within the manual. The Health Care Health and Safety Association (HCHSA) Handle with Care program provides most of the information provided in these patient handling program guides. Also available for the nursing population are decision flow charts that describe a lifting or repositioning situation where a patient needs to be moved from one position to another (Figure 6). These flow charts are developed to allow for a certain procedure to be followed for each situation that may arise.

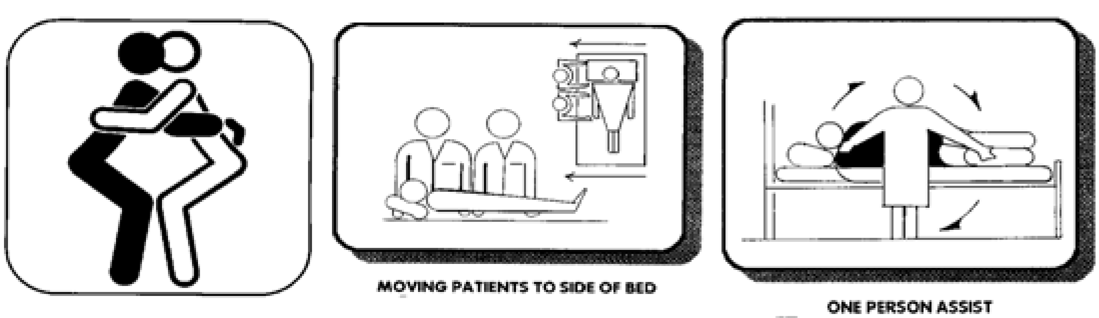


**Figure 5.** Visual guides for manual patient handling techniques (GBRHS, 2005).

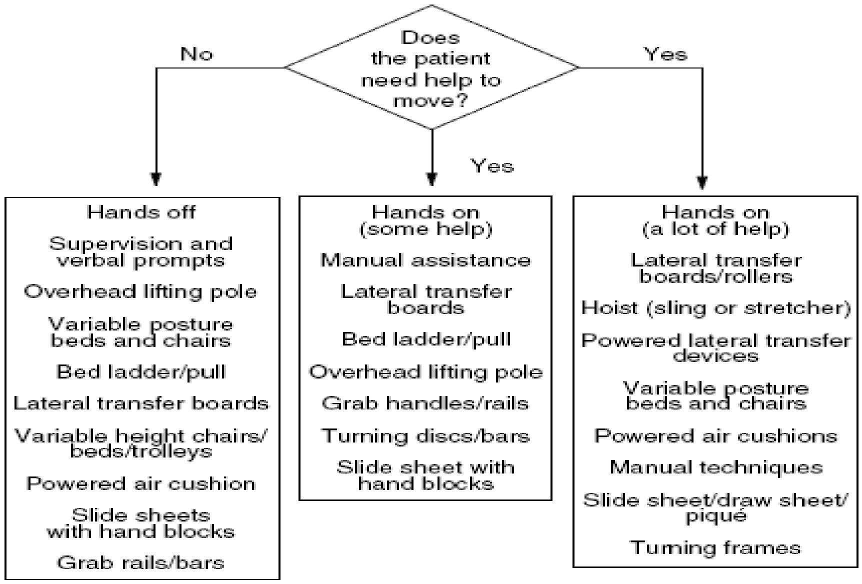


**Figure 6.** Recommendations for moving a patient in a lying position to supine (Hignett, 2003).

There is a general agreement, however, that training and education alone are not sufficient for a decrease in the musculoskeletal symptoms (Daltroy et al., 1997; Daynard et al., 2001; Bos et al., 2006). While Daynard et al. (2001) found that shear loads are reducible through compliance with proper lifting strategies, education and training programs must be combined with ergonomic assessments and interventions in order to be as effective as possible.

2.4.6.1 Ergonomic Interventions in MPH for Low Back Relief

Mechanical lifting aids (MLA) have been introduced over the last decade to hospitals and long-term care facilities in an effort to eliminate tradition manual patient handling tasks performed by nurses. Types of lifts generally seen on the hospital floor include vertical lifts, which help to lift and lower the patient into wheelchairs or onto toilets. Vertical lifts consist of mobile floor lifts as well as the more popular ceiling mounted lifts, both of which incorporate a sling into which the patient is seated during the lift. Lateral transfer devices help with repositioning movements or transferring from one bed to another, and they can include air flow systems, draw sheets, friction slip sheets, transfer boards and gait belts. Many companies provide MLA to hospitals, and a selection from ArjoHuntleigh and Liko patient lifts are shown in the Figures 7 and 8. Technological improvements have enhanced these aids over the past few decades, allowing for automation of hoist cranking that was usually incorporated with a vertical lift. Evidence also suggests that introducing MLA into the hospital setting has an economical benefit as well. In British Columbia, ceiling lifts were introduced during a three-year intervention study with an initial investment of $344,323. Post intervention, because of the decrease in MSD and days off work, an estimated $412,754 dollars were saved (Chokkar et al., 2005). Comparison studies done in the laboratory have showed that using a MLA lowers the amount of compression on the lower back, but precaution should still be taken when using the lifts provided on each hospital floor, as their effectiveness is variable (Garg  et al., 1991a&b; Garg et al., 1992a&b; Zhuang et al., 1999; Keir & MacDonell, 2004). In many of these studies, comparison were made between MLA and MPH techniques, and while most of the mechanical aids helped to reduce the amount of stress on the nurse, some did not help to lower the force exerted on the lower back (Garg et al., 1991a; Zhuang et al., 1999). Again, precautions must be taken in choosing a MLA, and patient weight can be an important factor in that decision (Zhuang et al., 1999).

**Figure 7.** ArjoHuntleight lift systems: MaxiSky 600 ceiling lift, Maxi Move sling lift, Sara Lite standing transfer.

**Figure 8.** Liko Patient transfer systems: Freespan straight rail free standing system, overhead mounted ceiling lifts. Mounted lifts allow for patients to be transferred room to room more easily.

Field studies have also proved to be beneficial for analyzing the effectiveness of MLA and other types of ergonomic interventions commonly used among the nursing profession. Many of these studies provide information on the effectiveness of training and education as well as an intervention's effect on injury incidence and days away from work (Owen et al., 2002; Evanoff et al., 2003; Chokkar et al., 2005; Engst et al., 2005; Fujishiro et al., 2005; Bos et al., 2006). Owen et al. (2002) found that control hospitals had a much higher RPE scores than the intervention hospitals after introducing several lift assists and training, while Fujishiro et al. (2005) was able to reduce the rate of MSD in 77 work units by adding an adjustable bed to each room and eliminating lifting patients manually. Training provided by Evanoff et al. (2003) included instruction courses plus ergonomic interventions and over a two-year period, was able to decrease the rate of MSD and lower the days off due to injury; those units that complied with the interventions similarly had reductions in lost day injury rates (Table 5). Evanoff et al. (2003) also noted that while the intervention seemed very effective in long-term care facilities, the large reductions were not seen within an acute care hospital setting; RN's working in a hospital reported fewer usage of MLA than in long term facilities.

**Table 5.** Annual Reduction in injury and lost time rates per 100 full-time equivalents (FTE); one FTE = 2,000 hours (Adapted from Evanoff et al., 2003)

| Facility | Injury Rates | | Lost time Rates (days) | |
|---|---|---|---|---|
| | *Pre* | *Post* | *Pre* | *Post* |
| *Long term care* | 6.9 | 4.9 | 3.13 | 0.89 |
| *Acute* | 6.59 | 5.7 | 32 | 14.9 |

A recurring factor in field studies concerns the compliance of nurses to use MLA. For many nurses, time is an important issue, especially on an acute care hospital floor. If hospitals do not have more than one type of lift on each floor (as suggested by Owen et al., 2002), the tendency of nurses is not to use them (Garg et al., 1992a; McGuire, 1996; Evanoff et al., 2003; Engst et al., 2005). Placement of the MLA within the hospital ward may also add to a reluctance of nurses using them, as noticed by McGuire (2006). Since the MLA are not readily available for each room, nurses have to take the time to find them and wheel them to the patient. Once there, the usually large hoist is awkward to move around a cramped hospital room. Nurses have cited lack of perceived need, lack of training and time as being factors in the decision to use MPH over the MLA, and intervention groups also felt more stressed and perceived greater workload with MLA (Evanoff et al., 2005; Engst et al., 2003). In 1992, Garg et al. found that nurses were using MPH 98% of the time, where in 18 seconds a MPH task could be completed, compared to 180 seconds for the same task using an MLA.

These types of non-compliance can negatively affect student nurses and new nurses on the work floor. While they may have been previously trained using a type of program mentioned previously in section 2.4.6., how they handle patients appears to depend on their senior coworkers (Goh & Watt, 2003; Swain et al., 2003; Cornish & Jones, 2007; Kneafsey 2007; Kneafsey & Haigh, 2007; Kovner et al., 2007; Cornish & Jones, 2010;). Even when new nurses felt confident that they knew how to properly transfer a patient and felt adequately trained to approach a lifting task, 94% of questionnaire respondents in a UK study by Swain et al., (2003) responded that they did not always use the techniques they knew were recommended. Nearly 40% of these respondents cited the influence and practices of other staff, while 32% cited lack of time or equipment. New nurses have to deal with rapid skills development, high anxiety and time management, but most importantly assimilation anxiety (Goh & Watt, 2003; Swain et al., 2003). The need to feel like they are fitting in with other nurses may lead to the newer nurses to not speak up when assisting with patient transfers or performing a MPH task (Goh & Watt, 2003). These emotional and physical demands on new nurses have been cited by other authors as a main reason for their taking on a poor practice approach to MPH (Duchschner 2008, Cornish & Jones, 2010). These new nurses, while months earlier expressing their confidence in knowing how to lift properly and planning on performing MPH tasks properly, are already citing lack of time, lack of space and lack of equipment for their reasons in not completing the task properly (Cornish & Jones, 2007). It is concerning, then, that more established workers have cited their affinity to continue to use manual patient transfers, as their choices greatly affect how the newer generation of nurses chooses to approach MPH tasks.

With the influx of these new recommended mechanical lift assists a growing concern among researchers is that when the duration of interacting with an MLA increases, so does the stress on the body, even if the peak stresses are being lowered (Yassi, 2005). Cumulative musculoskeletal exposures and associated disorders are still a risk for those consistently using these types of lift assists, especially those involving a sling, which are complicated to get on and off the patient and require a longer duration spent repositioning and moving the patient. Figure 9 helps to describe the differences between cumulative and acute trauma, where either a single overexertion event can cause injury or smaller over-exertions over an extended period of time can eventually cause failure, as may be happening with newer mechanical handling devices.

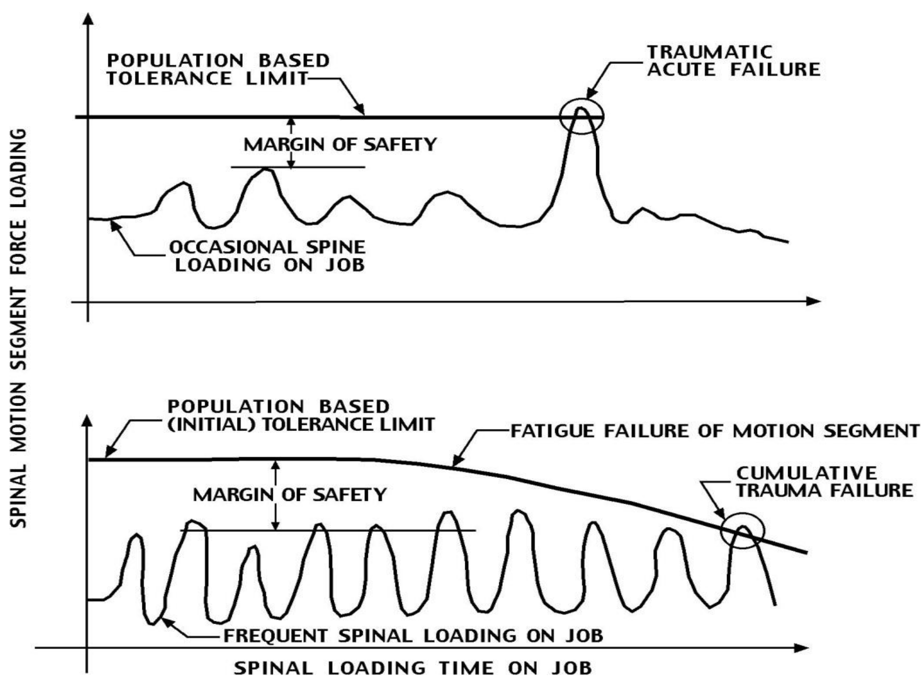


**Figure 9.** Cumulative versus acute injury mechanisms (Chaffin et al., 2006).

The creation of lifting teams represents another attempt to reduce patient handling injuries, and involve separate, trained workers to come onto a hospital floor and do the lifting for the nurses. A field study introduced by Charney & Hudson (2004) had 12 hospitals implementing lifting teams; some hospitals had separate teams on call seven days a week, 24 hours a day, while other hospitals had lifting teams available 12 hours a day. The teams were highly trained and educated in proper lifting strategies and had relatively good response times. All of the hospitals saw reductions in back injury rates for severity and frequency where the main cause was MPH, however lifting teams do not do repositioning or other job related tasks that are potentially as dangerous as lifts and transfers (Marras et al., 1999; Yassi, 2005). For many hospitals, additional costs associated with lifting teams make them infeasible; not only do they increase payroll, but they may also be injured performing the transfers and lifts.

A final solution to lowering injuries among nurses is to implement a 'no-lift' policy (often referred to a more correct term of 'safe-lifting' policies, as lifting is still allowed but only under certain conditions). Safe-lifting policies take into consideration organization structure, control over decision-making, equipment maintenance and storage, and the ability of patients to move themselves (Nelson & Baptiste, 2006). British Columbia has a memorandum of understanding between hospital unions and health employer's associations, whereby they establish a goal of eliminating unsafe manual lifts through the use of MLA (Charney & Hudson, 2004). Canadian safe-lift policies are similar to Australian policies, in that they promote the use of MLA and other equipment to ensure minimal force is exerted by the caregiver (Nelson & Baptiste, 2006). The United Kingdom Manual Handling Operations Regulations outlines the country's 'no-lift' policy and has been effect in hospitals there since 1992. The United States is looking to follow suit and is in the process of enabling an act that would limit MPH and mandate all hospitals use MLA (HR 2381 by D-MI John Conyers), and it was recently formed for passage in July of 2009. Similar acts brought forward by the same senator have gone unrealized up until now, not making it past passage in the United States Congress. The Nurse and Health Care Worker Protection Act of 2009 aims to have the use of mechanical devices used to the greatest degree possible by two years after initiation of the bill. Each health care employer would be required to develop a safe patient handling plan, purchase and maintain adequate number of MLA devices, track and analyze trends in injuries, and adequately train every employee to know how to use each MLA (Department of Labour, 2009). Considering the number of injuries associated with MPH in the United States as well as days required off work because of injuries, many are hoping this bill comes to pass quickly.

2.4.6.2 Ergonomic Interventions in MPH Focused on Lowering Shoulder Exposures

Interventions mentioned in the previous section have mainly been conducted by researchers to focus on pain and injury in the lower back and rarely give specific advice regarding safe lifting to protect the shoulder. This may be because of the limited knowledge regarding safe loading limits and tolerances of the shoulder, and the complex etiology of shoulder injuries. Manuals for nurses and textbooks may include small sections on how to lower the moment arm by keeping loads close to the body and to lift as light of weight as possible, but these are also simple lifting strategies that target lower back injury prevention as well. This lack of targeted shoulder MPH injury prevention cites an enormous need for more shoulder evaluations and recommendations.

## 2.5 Holistic Effects of Patient Handling Strategy (Multiple Joints Considered)

Some studies that analyzed muscle activation in multiple areas of the body have raised concerns that there may be a transfer of problems from a particular joint to other joints (Gagnon & Smyth, 1987) resulting from suggested patient handling techniques or ergonomic recommendations. Keir & MacDonell (2004) noted that experienced handlers tended to opt for a strategy that reduced erector spinae activity, while instead increasing the use of muscle surrounding the shoulder girdle. A rural hospital ergonomic intervention study produced results that show MLA and other devices lowering RPE in the shoulder and back at the intervention hospitals, however RPE for the shoulder was still reported to be higher than the RPE for the back following the intervention, indicating that it had variable regional effectiveness (Owen et al., 2002). Fujishiro et al. (2005) found a decrease in MSD rates at the back, however other parts of the body (which include the shoulder but were reported as “other”) saw an increase post intervention, causing skepticism regarding the effectiveness of interventions for lowering overall risk. Menzel et al. (2004) also expressed concern over the fact that where units contained MLA that were readily available, the musculoskeletal risk appears to shift to the knee or the upper extremities. There is also some evidence to suggest that MLA use may cause increases in moments at the shoulder, while at the same time decreasing moments acting on the lower back (Yassi, 2005). These studies offer some insight into the fact that there may be a transfer of problems from one joint to another; Gagnon & Smyth (1987) felt that such a problem was very likely to occur. Still, the unanswered questions regarding the transfer of demand in the body requires better answers.

# III. Methods

3.1 Participants

Twenty healthy female participants (aged 21.6±1.3 years) recruited from a university community participated in this study. The participant age range was chosen to mimic those entering the workforce working as nurses in Canada, while female participants were chosen because 94 % of Canadian nurses are female (Canadian Nurses Association, 2009). Participant weight was 62.5±9.4 kg while their height averaged 166.6±7.9 cm. Exclusion criteria consisted of any injury or pain in the last year to the upper extremity or back as well as any previous experience or training in manual patient handling techniques. Informed consent was obtained prior to experimental data collection and the study was reviewed and approved by the University of Waterloo Office of Research Ethics.

3.2 Instrumentation

*3.2.1 Surface Electromyography*

Muscle activity was recorded with two Bortec Octopus AMT 8 analog multiplexed telemetry systems (Calgary, Alberta) at a sampling rate of 1500 Hz. Muscle activity of 16 muscles on the trunk and upper limbs were monitored by placing b- polar Ag-AgCl dual surface electrodes two cm apart on the skin surface, parallel to the fibers of each muscle belly (Ambu Blue Sensor N, Malaysia). Table 6 details the exact electrode placement for bilateral placements on the following muscles: Erector spinae (thoracic and lumbar insertions), middle trapezius, middle deltoid, infraspinatus, pectoralis major (clavicular insertion), biceps brachii and triceps brachii. Raw EMG signal were band pass filtered from 10-1000Hz and differentially amplified (common-mode rejection ratio > 115dB @ 60Hz, input impedence 10 GΩ) to generate maximal signal amplification within the range of the analog-to-digital board.

**Table 6.** Electrode and MVC exertions for each monitored muscle site (*Cholewicki & McGill, 1996; Cram and Kasman 1998).

| Muscle | Location | Position for Collection |
|---|---|---|
| Biceps Brachii (BCP) | Above center of muscle, parallel to long axis | Elbow flexion (sitting) |
| Triceps Brachii (TRCP) | On posterior portion of upper arm, located medially | Supine, shoulder and elbow flexed to 90°; elbow extension against resistance (pushing up to ceiling). |
| Infraspinatus (INFRA) | Parallel to spine of scapula, approximately 4cm below it; over infrascapular fossa | Side-lying, elbow bent to 90. Subject externally rotates. |
| Middle Deltoid (MDEL) | Lateral aspect of the arm, approximately 3cm below the acromion, parallel to muscle fibres | While standing, abduct arm to 90° (elbow extended, thumb points forward). |
| Middle Trapezius (MTRP) | 2cm vertically above the trigonum spinae; T6 to T7 spinous process | Prone, abduct to 120° elbow extended and thumb pointing towards ceiling. Subject pushes up towards ceiling against resistance. |
| Pectoralis Major (PEC) | Between the scapular-clavicular joint and coracoidal process, 2cm below clavicle. Parallel when shoulder is abducted to 90°, else down and out | Sitting, shoulder flexed to 90, subject horizontally adducts and flexes shoulder (up punch). |
| *Erector Spinae Thoracic (TES) | 5cm lateral to T9 spinous process | Prone with torso extended over edge of table, extend back against resistance. |
| *Erector Spinae Lumbar (LES) | 3cm lateral to L3 spinous process | Same as above |

*3.2.2 Motion Capture*

A Vicon MX20+ motion tracking system was used to record 3-D body kinematics during the trials. Eight light emitting diode (LED) cameras (2.0MP) were strategically placed in order to capture the entire volume in which the participants moved, and 35 reflective markers were placed on the participant to capture upper limb and trunk movement (Table 7). Kinematic data was collected at a sampling rate of 60Hz and all data was processed using Vicon 1.5.2 software (Oxford, UK). Calibration of the collection space took place before participant arrival with the origin being placed in the center of the collection space. Each trial was then recorded in the positively defined space. During each trial, positive X was in the participant's frontal plane (leftward), positive Y in sagittal (backward), while positive Z was the participant's transverse plane (upward).

**Table 7.** Position of body markers for motion capture for both the left (L) and right (R) side.

| | |
|---|---|
| Hand Markers | 5th metacarpal phalangeal joint (L and R) |
| | 2nd metacarpal phalangeal joint (L and R) |
| | Ulnar Styloid (L and R) |
| | Radial Styloid (L and R) |
| Arm and Forearm Markers | Elbow lateral epicondyle (L and R) |
| | Elbow medial epicondyle (L and R) |
| | Acromion (L and R) |
| | Forearm cluster (three markers on L and R) |
| | Arm Cluster (three markers on L and R) |
| Upper Trunk Markers | Suprasternal Notch |
| | Xyphoid Process |
| | Back Plate just beneath C7 with four markers |
| Low Back Markers | L5/S1 |
| | Posterial inferior iliac spine (L and R) |

*3.2.3 Hand Force Estimation*

In order to quantify resultant joint moments at the shoulders and lower back, forces generated at the hand were estimated following each set of manual patient handling trials. Two ErgoFet 300™ uni-axial hand dynamometers (Hogan Health Industries, Utah) were used in order to record hand force estimates for each MPH task. Before collection, participants were calibrated with the dynamometers to determine left and right hand maximum push and pulls in similar postures as those they assumed for the MPH tasks. Marshall et al. (2004) found that accuracy and precision of estimations for upper extremity forceful exertions improve significantly when the participants are first exposed to a physical benchmark. The participants performed each push and pull twice, and the highest value was recorded as their maximum. The participants were then asked to perform a 50% exertion using the dynamometer, while they were not able to see the amount of force they were exerting throughout the trial. They repeated this until they accurately exerted 50% of their maximum three times consecutively. Exertions of 25% and 75% of max were also executed in the same way as the 50% exertion.  Figures 10 and 11 are examples of positions used for max push and pull calibrations.

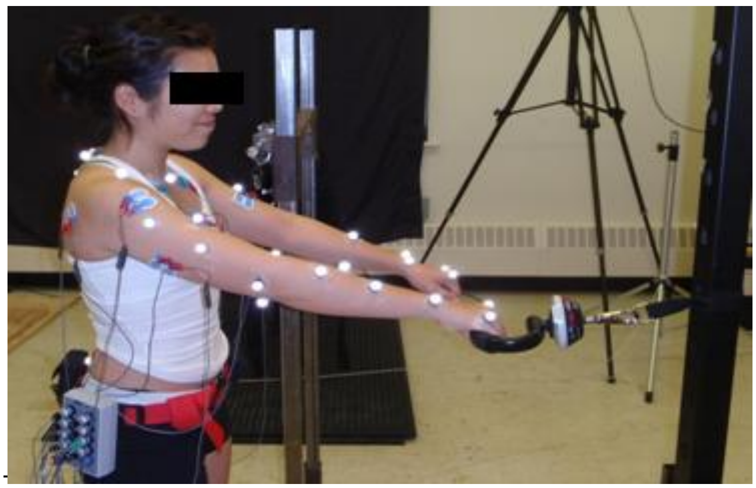

**Figure 10.** Position assumed by participant for calibration of a pull hand force using a hand dynamometer.

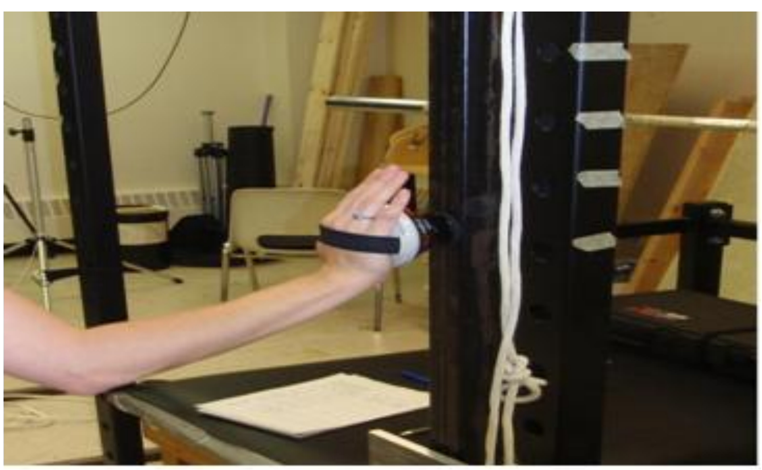

**Figure 11.** Position assumed by participant for estimating a push hand force using a hand dynamometer.

3.3 Manual Patient Handling Tasks

A total of five manual patient handling tasks that are commonly performed in a hospital setting were used for analysis in this study. They include moving the patient from a supine position to upright position (Lie-to-Sit), repositioning a patient from the foot of a bed to the head of a bed (Reposition), turning the patient away from the handler (Turn Away), turning the patient towards the handler (Turn Toward) and moving the patient from a sitting position on a bed to sitting in a chair (Sit-to-Chair). These techniques have been described by Schibye et al. (2003) as well as Skotte et al. (2002), and have also been explicitly described by the European Agency for Health and Safety at Work as part of an E-Facts supplement for European nurses (E-Facts 28, 2008). Verbal cues given to each participant during the training session are outlined in Table 8. Examples of some of the visual cues that were given to each participant during the training session are shown in Figure 12. For each task, the participant was instructed to 'countdown' to their movement. They were instructed to say "three – two – one" at the same time they rocked, moving their weight forward and backward while keeping their upright position. The purposes of this were two-fold; the counting would help to inform the patient of their upcoming movement, while it would help the participant to gain some momentum using this simultaneous rocking motion in their movement.

Each task took place on an electrically adjustable cushioned table (height range from 56 cm to 88cm) that had a surface similar to that of a slider sheet for a hospital bed. Bed dimensions were 70cm wide by 202 cm long. The sliding sheet used for proper technique in the post training state was obtained from a rural southwestern Ontario hospital.

**Table 8**. Description of recommended handling technique for each task for both patient and participant position.

| Task | Patient Position | Participant Position |
|---|---|---|
| Turn Away<br><br>(Schibye et al. 2003) | Lying supine, left leg flexed, left arm crossed over trunk, head turned to the right | Stand in walking position perpendicular to bed with right foot in front, left hand on knee and right hand on patient's left shoulder. Participant shifts weight from rear leg to front leg to push patient over to side. |
| Turn Toward<br><br>(Schibye et al. 2003) | Lying supine, right knee flexed, right arm crossed over the trunk, head turned to left | Stand in walking position perpendicular to the bed with left foot in front, left hand on knee and right hand on patient's right shoulder. Participant shifts weight from front leg to rear leg to pull patient over. |
| Reposition<br><br>(Back to Basics: towards head of bed) | On back, chin is tucked towards chest. Sliding sheet has been placed beneath patient. | With assistance from aide; approach bed and grab sliding sheet with two hands. Feet shoulder length apart, knees bent and back is upright. Slide patient up bed by shifting weight to forward (head of bed) foot. |
| Lie-to-Sit<br><br>(Schibye et al. 2003) | Turned to his left side but with both legs flexed | Stands in walking position beside the bed with feet in angle of 45° to the bedside with left foot in front. Left hand on upper hip/leg and right arm under neck and thorax of patient. Shift weight from rear leg to her front leg to push into sitting position |
| Sit-to-Chair<br><br>(E-Facts, 2008)<br>*Standing Pivot* | Start in sitting position, lean 'nose over toes'. Place hands on participant waist. | Using a folded sliding sheet, keep slight hollow in back, lean forward and place sheet so that it is snug around patient's lower back . Place knee farthest from chair between patient's knees and squeeze their leg. Lift with legs and pivot, bringing patient with you. Lower patient into chair. |

**Figure 12**. Example MPH pictures that would accompany detailed descriptions on how to properly perform techniques. A: Turn Toward, B: Turn Away, C:Turn Toward prep, D: Sit-to-Chair lift, E: Sit-to-Chair lower, F:Lie-to-Sit hand position, G:Lie-to-Sit foot position, H:Reposition hand position, I:Reposition Leg and Foot position (See Appendix B for example slides from the training presentation).

*3.3.1 The Patient*

A 92kg male was used as the patient for every participant throughout the data collection period. He had ample practice time before the collection started in order to ensure he simulated a partial weight bearing patient who requires physical assistance from a health care worker. He was instructed not to bear any weight in the torso and was not able to roll onto his side or lift any body part in order to move. The patient was able to sit unassisted once placed in an upright position and stand once moved to a standing position.

### *3.3.2 The Reposition Aide*

A female aide (62kg), who was previously trained by registered nurses who have received yearly MPH instruction for 15 years, was present for the training session as well as each of the post training Reposition collections. She provided assistance in sliding the patient up towards the head of the bed using the sliding sheet. Her performance was the same for each participant, and helped to verbally count down the participant in order to co-ordinate the transfer to be performed simultaneously.

## 3.4 Experimental Protocol

The protocol consisted of a calibration session (MVC, Vicon placement and hand force estimation), 15 pre-training trials and 15 post-training trials, with a 25 minute training period interposed. Approximate length of collection was two and a half hours. Figure 13 gives a detailed overview of the collection protocol along with approximate length of each collection.

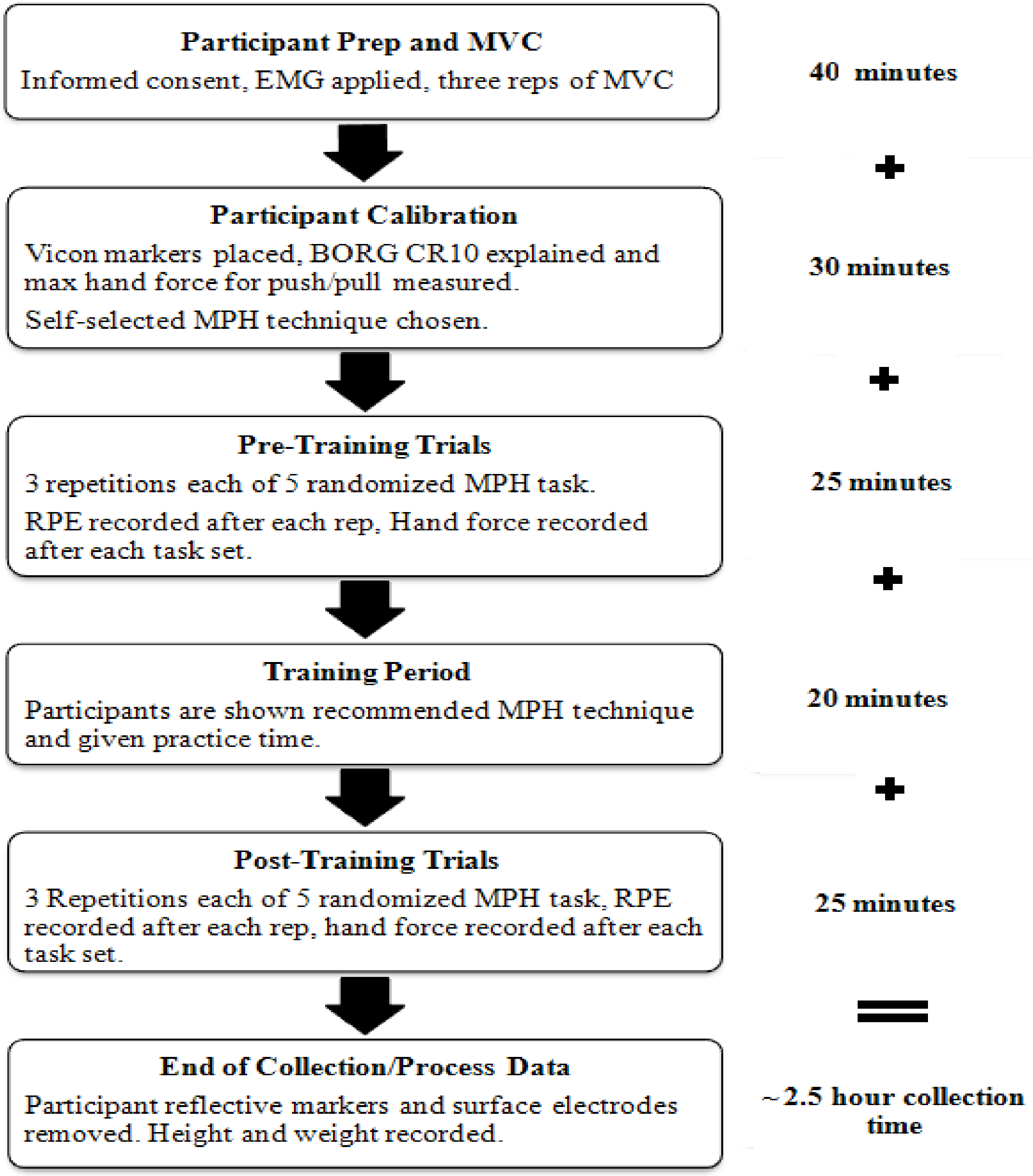


**Figure 13**. Brief description of collection protocol along with approximate length of each session.

### *3.4.1 Pre-Collection Protocol (Participant Calibration)*

Prior to performing the MPH tasks, participants performed maximal voluntary contractions (MVC) for each muscle (16 muscles with three repetitions of each; TES and LES were combined into one MVC). These were recorded for use in EMG data analysis. Two minutes of rest was provided between each set of MVC collections for each muscle to avoid fatigue. A peak was found using a 500ms moving window average of the individual MVC trials.

A total of 35 Vicon markers were then applied to the participant. They have been defined previously in Table 7, while Figure 14 shows placement on the trunk and upper extremities. A calibration trial of the participant in anatomical position to allow for all the markers to be visible to the cameras was taken before hand force calibration and MPH trials began.

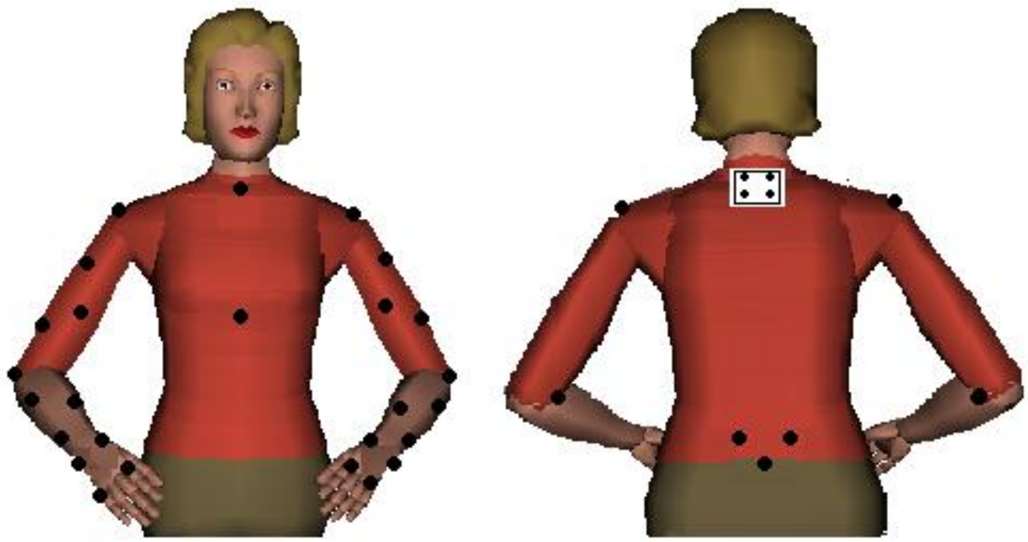

**Figure 14**. Placement of 35 Vicon reflective markers on participant

Following Vicon marker placement, hand force calibration and estimation (previously explained in section 3.2.3) took place. Following this calibration, the Borg CR10 scale was fully explained using the instructions provided by Borg (1998) to each participant to ensure complete understanding. This category ratio scale has an advantage over other tests such as visual analog scales (VAS) because of its ability to discriminate among extreme and maximal intensities as well as involving a communication between the researcher and participant. Perception categories are associated with specific numbers on the scale (Table 9), indicating appropriate numerical values associated with perceived exertions; i.e. a weak exertion would be a 2 where a very strong exertion is a 7.

**Table 9.** The Borg CR10 scale (Borg, 1998). An example explanation given to a participant for a level 7 exertion would be that it is “very hard” and very strenuous; a healthy person can still go on, but he or she has to push themselves and it may feel very heavy and tired (Borg, 1998).

| | | |
|---|---|---|
| 0 | Nothing at all | |
| 0.5 | Extremely Weak | (just noticeable) |
| 1 | Very Weak | |
| 2 | Weak | (light) |
| 3 | Moderate | |
| 4 | | |
| 5 | Strong | (heavy) |
| 6 | | |
| 7 | Very Strong | |
| 8 | | |
| 9 | | |
| 10 | Extremely Strong | (almost max) |
| • | Maximal | |

*3.4.2 Manual Patient Handling Trials*

The five MPH tasks were randomized separately for each training state (untrained and trained). Each participant performed three consecutive repetitions of each task before performing the next task. Figure 15 outlines the steps of each trial for each MPH task. Before each trial, the patient was in place on an adjustable table (representing a common adjustable hospital bed). The patient began in either a lying or sitting position, depending on the task.

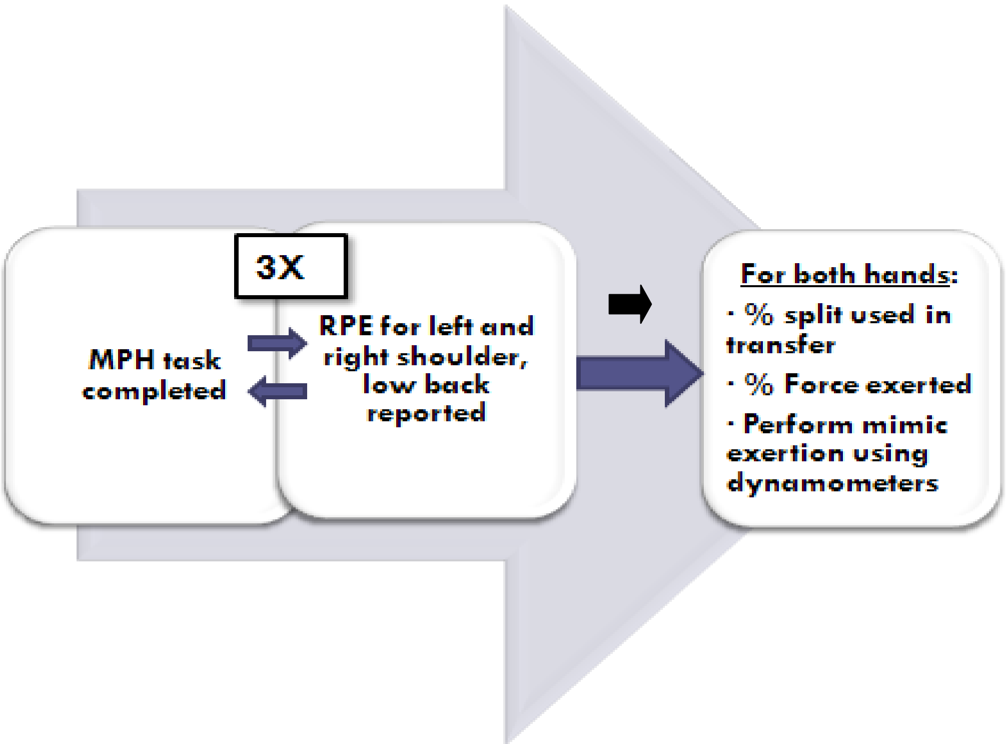


**Figure 15**. Procedure outline for untrained and trained MPH trials. One MPH trial is completed followed by immediate RPE reporting. After repeating this twice, hand force estimation took place using a dynamometer.

In the pre-training session, the participant was given time to decide on their self-selected technique for moving the patient in the given tasks. Along with being given the name of each task, the participant was shown the starting and ending patient positions for each task and given the opportunity to attempt a few transfers in order to decide on a preferred technique. The participant was also able to adjust the table height to their level of comfort for each task. Each was instructed they could not go around the head of the bed and must only approach the patient from one side of the bed. No helping aides were provided in the pre-training state. Once they had chosen their preferred technique for each task, they were told the order they would be performing the transfers which had been established prior to collection.

Each MPH trial commenced when the participant moves towards the patient after being given a ‘Go’ instruction. Trials involving Turn Away, Turn Toward and Reposition lasted for 15 seconds, while the participants had 25 seconds to complete the longer trials involving Lie-to-Sit and Sit-to-Chair. Trial lengths were determined earlier in pilot testing and provided ample time to perform each transfer without rushing. Three repetitions were completed for each task, with the participant immediately reporting their RPE for both the left and right shoulder and low back following each repetition. Video was also recorded of each participant’s pre-training trials from a lateral view (one video for each task). This was to provide additional information during the data analysis process by helping in determining when the lift took place during the trial collection time.

Hand force estimations were reported once the three repetitions of the MPH task and RPE reporting were completed. This was to ensure that the participant was confident in their ability to reproduce the force exerted. Before they recorded their hand force estimation trials by mimicking their chosen transfer position, participants were asked to verbally report how hard they were working as a percentage of their maximum, in addition to verbally reporting how their exertion was distributed between their hands (i.e. 70% left vs 30% right). They then performed the MPH task using the hand force dynamometers against a secured bar. Hand force direction relative to the hand, height of the performed task and orientation to the patient were taken into consideration. The mimicked exertion was done for both hands and the forces were recorded. This was repeated in the same way for each of the five self-selected techniques.

A formal training period followed the first set of trials, during which each participant completed a ten minute PowerPoint presentation that had written instructions along with visual cues (examples in Appendix B, Table 8, and Figure 14). Video instruction for each type of lift (with several viewing angles) was also provided to the participants following the power point presentation. Additional demonstrations (if the participant chose to view them) followed the presentation using the patient and adjustable bed. The participant was then allowed to practice these techniques until she was comfortable with performing them without reference to the visual or verbal cues (usually about 3-4 times per task). The aide was also available for assistance with the Reposition task during the training session.

Following the training session, participants completed the same five lifting trials, again three times each, in the random order determined prior to testing. Similar to the pre-training protocol, three repetitions of each task were completed with a reported RPE given after each repetition for the low back and both shoulders. Following all the three repetitions of one task, hand force estimation took place, repeating the process that took place in the pre-training state.

### 3.5 Data Analysis

#### *3.5.1 Electromyographical Analysis*

EMG signals were full wave rectified (FWR) and low pass filtered at 3Hz using a $2^{nd}$ order single pass Butterworth filter. Trial EMG was normalized to the maximal value obtained from individual muscle MVC trials using the peak 500 millisecond moving window average (Fischer et al., 2009). Heart rate contamination was removed using a 30Hz high pass filter (Drake and Callaghan, 2006). Mean muscle activity and maximum (peak) muscle activity for each muscle and each trial were extracted from the normalized data. Cumulative EMG was calculated using a trapezoidal integration method multiplied by the inverse of the sampling frequency (1500 Hz), to yield % MVC*second. Three repeated trials collected per task for each condition were averaged to negate any possible training effect, leaving a total of 10 trials analyzed for each participant.

Since each task had set time periods, there was risk that 'non-activity' time at the end of each trial would influence the results of the cumulative analysis and suppress differences. To remedy this, a program was created to implement a cutoff point using individual muscle activity levels and their changing values. First, a 0.2 second moving average was applied and its results rectified. The cutoff point was chosen as the point at which the last change in the rectified derivative exceeded 0.5, to establish that the entire task had been captured, but the inactive portion at the end of the trial had been removed. This method was applied to each muscle in all trials for each participant. Graphical output was used to confirm effectiveness of calculated cut-off point. This novel technique was used to eliminate potential subjectivity associated with a visually-based cutoff methodology.

*3.5.2 Biomechanical Analysis*

There were a total of 30 task trials plus one calibration trial captured for each participant. Any trials that had missing motion capture markers were gap-filled using the Vicon 2.1 system, and then exported to an 3-D static resultant moment analysis program similar to previous external dynamic shoulder moment models (Dickerson et al., 2006; Dickerson et al., 2007a). For the purpose of this study, one trial for each task type was analyzed for a total of 10 trials for each participant.

Participant weight, estimated hand force for both the left and right hand for each MPH task and the corresponding estimated direction of that force were used as input into a top down inverse quasi-static model to determine time series moment data for each trial and each task. Direction of force was estimated based on visual analysis of each task. Forces were identified as either push or a pull, and were applied perpendicular to the plane of the palm in the model. This model consists of seven segments: the trunk (with head), both upper arms, both forearms and both hands. Segment masses were calculated as percentages of body weight (Webb Associates, 1978) and joint centers of the low back (L5/S1), glenohumeral, elbow and wrist joints were estimated using published guidelines (Dempster, 1955). These locations were used to derive segmental locations of the centers of mass (COM) (Dickerson et al., 2007a). Calculation of the external joint forces (shown for the hand segment) is described by Equations 1-3:

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

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

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

where F, forces is equal to the force at the hand, H, plus the weight of the hand, W, plus the reaction force, R, at the wrist, Wr. Similar calculations were performed for the other body segments. Equation 4 is an example of the 3-dimensional moment (again, for the hand) calculation used for all segments to find the sum of the moment, M. The sum of the moments was assumed to equal zero (static equilibrium):

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

where M is equal to the distance, d, of the weight of the hand, WH, by the force, F, of the hand, plus the distance of the center of mass of the hand, $CM_H$, by WH, plus the moment of the wrist, Wr. The net joint moment for all joints was described (shown here by Equation 5) as a resultant moment calculated through quadrature:

(5)

where the resultant moment (m) is equal to a single value derived from the x, y and z coordinates of the net moment vector (Nm).

Since there is only one force is being inputted for each frame (for both hands) and each corresponding position in space, there is the risk of extracting a peak (the largest Nm produced throughout the entire task) when one may not exist. In order to prevent extraneous movement from being considered this possible ‘peak’, each trial for each task for each participant was analyzed visually using Vicon Nexus 2.1 software to record specific frame numbers that corresponded with the beginning and end of each transfer exertion. The peak resultant moment was then extracted for each joint from these selected exertion frames.

*Evaluation of Joint Transfer Demand using Mean Population Strength Predictions*

Michigan’s 3D static strength prediction program (3DSSPP) was used to compare mean population strength requirements between the untrained and trained conditions, allowing for more insight into the effect of using recommended techniques over self-selected techniques. This also enabled the evaluation of normalized strength demand transfers between the joints. Video analysis of the self-selected techniques revealed that a majority of the participants selected similar styles of moving the patient for each task. Two styles were chosen for self-selected Lie-to-Sit, Sit-to-Chair and Reposition postures, while one postural style was chosen for Turn Away and Turn Toward. The two styles for Lie-to-Sit and Reposition involved a push or a pull technique, while the Sit-to-Chair technique was done at two different bed heights. The posture in which peak force was applied was estimated based on these techniques, and this posture was modeled in 3DSSPP. The five recommended techniques were also modeled. Hand force was estimated as either a push or a pull force that acted perpendicular to the direction of the hands.

These forces at both the left and right hands were averaged across the 20 participants for each technique and used as input for 3DSSPP for each posture studied. Average height and weight of the 20 participants was used as anthropometric input for all techniques modeled. Figures of the chosen positions and 3DSSPP models can be found in Appendix C. Analysis of these positions consisted of dividing the given required moment by the population mean strengths for each type of rotation about each joint and then finding the resultant moment at that joint (Eq. 5) for both the untrained techniques and trained techniques. Percent change (Eq. 6) between the self selected and recommended techniques for each task at each joint were compared to analyze possible transfers of demand between the joints, as well as the demand on the joints themselves.

*3.5.3 Statistical Analysis*

All statistical analyses were performed using JMP 8.0 software (SAS Institute, North Carolina, USA). A p-value of 0.05 was used to determine significance for all scenarios. Each task was analyzed separately using training state as an independent factor. Ratings of perceived exertion analysis consisted of the right shoulder, left shoulder and low back as dependant variables. Three 1-Way ANOVAs were considered using training state as an independent variable for each task. Peak resultant moment was considered for the right shoulder, left shoulder and low back. Three 1-Way Anovas were used for each of the five tasks considering training state as an independent factor. EMG analysis considered mean, peak and cumulative measures of normalized muscle activity. Dependant factors included all 16 muscles as well as total overall muscle activity, total activity of muscles acting on the left shoulder, total activity of muscles acting on the right shoulder, and total activity of muscles acting on the low back. In total, 285 1-Way ANOVAs were used.

\

*3.5.4 Percent Change Analysis*

An additional analysis considered the magnitude of change between pre and post training states on the right shoulder, left shoulder and low back for each task among all three measures (EMG, peak resultant moment and RPE). The average percent mean, peak and cumulative normalized muscle activity change (Eq. 6) for the individual muscles acting on each specific joint was compared to those percent changes of the resultant moment and RPE for the same joints (Eq. 6).

$$\frac{\quad - \quad}{\quad} \qquad (6)$$

## IV. Results

Analyzing specific models that investigated the influence of training state for individual tasks showed that a majority of the muscles measured decreased in normalized muscle activity significantly following a training period, while some muscles that act on the shoulder as well as the low back are consistently increased. Resultant moment at both shoulders and low back varied, with all joints experiencing an increase for select tasks. Ratings of perceived exertion (RPE) consistently decreased for most tasks at the right shoulder, left shoulder and low back. Figures and tables describing the data use short forms described in Table 10, while asterisks denote significance and standard deviation bars are shown in each figure.

**Table 10.** Muscles measured and associated short forms referred to in figures and tables.

| Muscle | Short form | Muscle | Short Form |
|---|---|---|---|
| Right Biceps Brachii | **RBCP** | Left Bicep Brachii | **LBCP** |
| Right Triceps Brachii | **RTRCP** | Left Tricep Brachii | **LTRCP** |
| Right Infraspinatus | **RINFRA** | Left Infraspinatus | **LINFRA** |
| Right Middle Deltoid | **RMDEL** | Left Middle Deltoid | **LMDEL** |
| Right Middle Trapezius | **RMTRP** | Left Middle Trapezius | **LMTRP** |
| Right Pectoralis Major (sternal insertion) | **RPEC** | Left Pectoralis Major (sterna insertion) | **LPEC** |
| Right Thoracic Erector Spinae | **RTES** | Left Thoracic Erector Spinae | **LTES** |
| Right Lumbar Erector Spinae | **RLES** | Left Lumbar Erector Spinae | **LLES** |

### 4.1 Task Specific Analysis using Training State as Independent Factor

The intention of this 'by-task' analysis was to ascertain the effectiveness of using recommended patient handling techniques on five separate and unique tasks.

#### *4.1.1. Lie-to-Sit*

While a few muscles experienced significant increases post training, and some low back muscles did not decrease in muscle activity while using recommended techniques, the majority had significant decreases from the untrained to trained condition (Table 11). RPE significantly decreased for the right shoulder and low back, while peak resultant moment decreased significantly for the left shoulder and low back, but not the right shoulder.

**Table 11.** Summary of findings for Lie-to-Sit task, where arrows represent a significant increase or decrease in normalized muscle activity between the trained and untrained state. P-values are given for each measure.

| OUTPUT | MEAN | PEAK | CUMULATIVE |
|---|---|---|---|
| **MUSCLE ACTIVITY** | | | |
| **TOTAL MUSCLE** | | | |
| Total | ↓0.0001 | ↓ 0.0001 | ↓ 0.0019 |
| Right Shoulder | ↓0.0001 | ↓ 0.0001 | ↓ 0.0002 |
| Left Shoulder | ↓0.0002 | -- 0.1101 | ↓ 0.0317 |
| Low Back | ↓0.0001 | ↓ 0.005 | ↓ 0.035 |
| **INDIVIDUAL MUSCLE** | | | |
| Left Biceps Brachii | ↓ 0.0014 | -- 0.1081 | -- 0.0691 |
| Left Triceps Brachii | ↓ 0.0003 | ↓0.0338 | ↓ 0.0058 |
| Left Infraspinatus | -- 0.1274 | -- 0.736 | -- 0.2571 |
| Left Middle Deltoid | -- 0.4281 | ↓0.0068 | -- 0.0872 |
| Left Middle Trapezius | ↓0.0003 | -- 0.1551 | ↓ 0.0033 |
| Left Pectoralis Major | -- 0.1483 | -- 0.7379 | -- 0.7588 |
| Right Bicep Brachii | ↓ 0.001 | ↓ 0.0001 | ↓ 0.0001 |
| Right Tricep Brachii | -- 0.1507 | -- 0.0531 | -- 0.9522 |
| Right Infraspinatus | ↓ 0.0002 | ↓0.0001 | ↓ 0.0028 |
| Right Middle Deltoid | ↓ 0.0018 | -- 0.1243 | ↓0.0439 |
| Right Middle Trapezius | ↓ 0.0028 | ↓0.0146 | -- 0.0879 |
| Right Pectoralis Major | ↓ 0.0052 | ↓ 0.0021 | ↓ 0.0046 |
| Left Thoracic ES | ↓ 0.0001 | ↓ 0.0002 | ↓ 0.0001 |
| Left Lumbar ES | ↓ 0.0001 | ↓0.002 | ↓ 0.0407 |
| Right Thoracic ES | ↓ 0.0005 | -- 0.667 | -- 0.1865 |
| Right Lumbar ES | ↓ 0.0304 | -- 0.1296 | -- 0.4915 |
| **PEAK RESULTANT MOMENT** | | | |
| Right Shoulder | -- 0.9637 | | |
| Left Shoulder | ↓0.0058 | | |
| Low Back | ↓ 0.0001 | | |
| **RATING OF PERCEIVED EXERTION** | | | |
| Right Shoulder | ↓ 0.0425 | | |
| Left Shoulder | -- 0.2875 | | |
| Low Back | ↓ 0.0134 | | |

4.1.1.1 RPE

The analysis of training state on RPE revealed significant decreases at the right shoulder (p=0.04) and the low back (0.01), but there was no change at the left shoulder (Figure 16). Highest rated RPE was the left shoulder in both training states, and it also experienced the smallest decrease in RPE (0.5 decrease in RPE), whereas the low back had the largest decrease when using the recommended technique (a 1.15 RPE decrease).

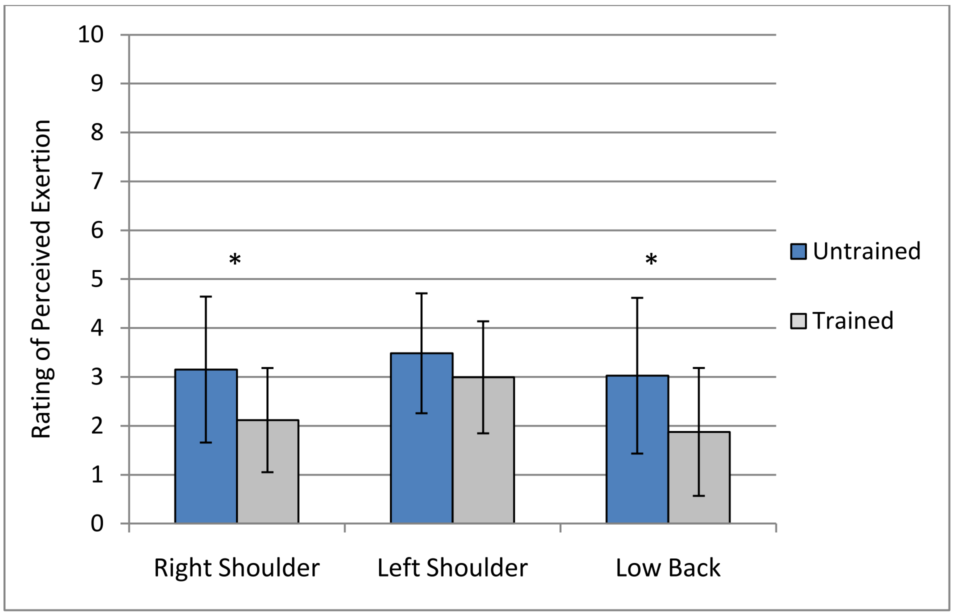


**Figure 16.** Joint specific RPE for Lie-to-Sit when considering training state as an independent factor.

4.2.1.2 Peak Resultant Moments

Peak resultant moments at the left shoulder (p=0.0004) and low back (p=0.002) were significantly lower following training for this task, while those at the right shoulder were not (Figure 17). Left shoulder peaked at 61.3±25.8 Nm and decreased approximately 26%, while the low back decreased by approximately 98 Nm.

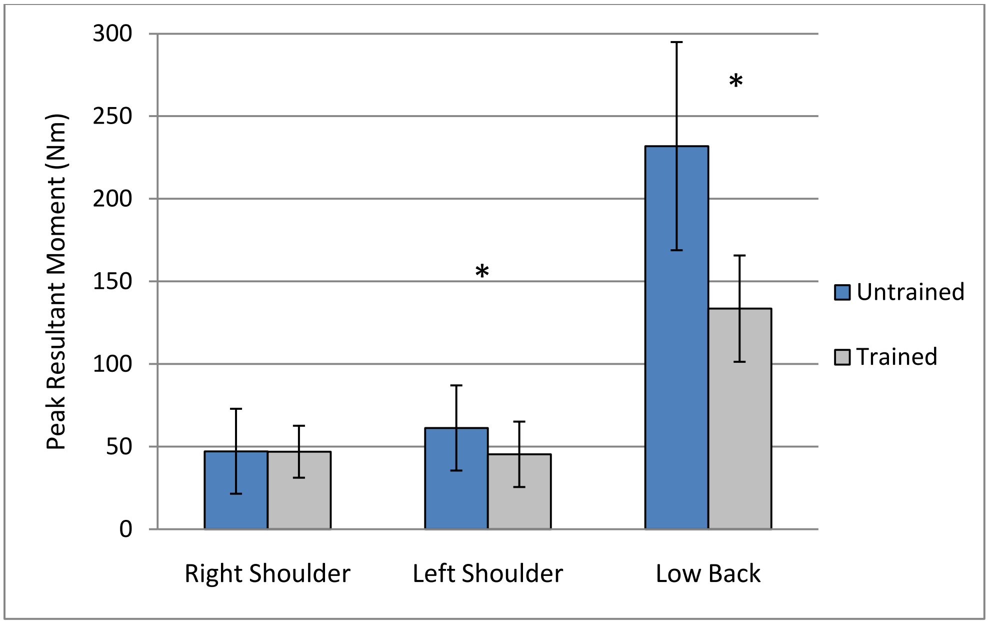


**Figure 17.** Joint specific peak resultant moment for Lie-to-Sit when considering training state as an independent factor

4.1.1.3 EMG

Total normalized muscle activity for each joint had significant decreases for each mean, peak and cumulative percent muscle activity. A significant (p=0.0001) overall decrease from 211.1±49.3% MVC to 153.7±30.5% MVC occurred across all muscles for mean percent muscle activity (Figure 18). There were also significant decreases among those muscles acting on the shoulders (p=0.0001) and low back (p=0.0001). A total change of approximately 156% MVC*sec (or 9.7% MVC*sec per muscle) occurred for peak normalized muscle activity, while cumulative normalized muscle activity decreased an average of 35% MVC*sec per muscle. Figure 19 is representative of the changes happening when considering peak total normalized muscle activity for all tasks, while cumulative normalized muscle activity experienced similar significant changes. Those specific figures can be found in Appendix A.

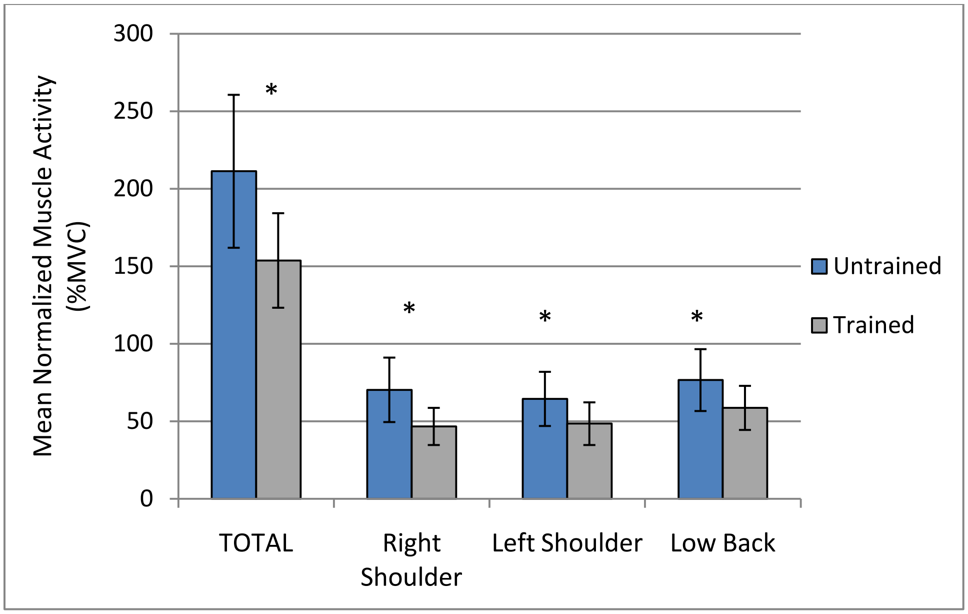


**Figure 18.** Joint specific total mean muscle activity for Lie-to-Sit when considering training state as an independent factor.

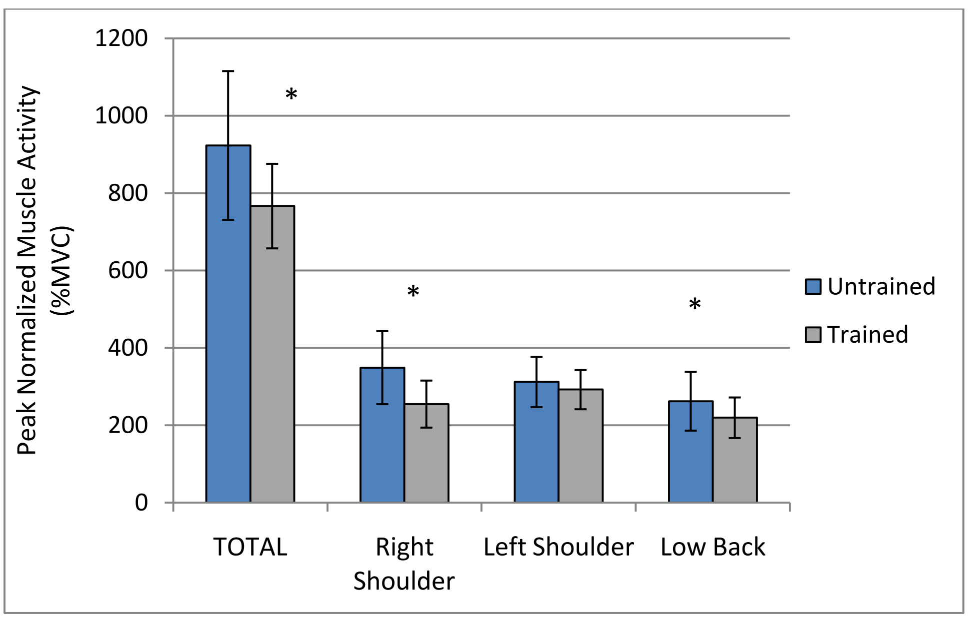


**Figure 19.** Joint specific total peak muscle activity for Lie-to-Sit when considering training state as an independent factor

A total of 12 of the 16 muscles significantly decreased following training for mean normalized muscle activity (Figure 20). Highest mean normalized muscle activity occurred at the right lumbar erector spinae in the untrained state (23 ±8.4% MVC), compared to the lowest in the untrained state at the left middle deltoid (6.0±4.2% MVC). The largest change between training states occurred at the right biceps brachii, which had a decrease (p=0.0001) of approximately 7.2% MVC.

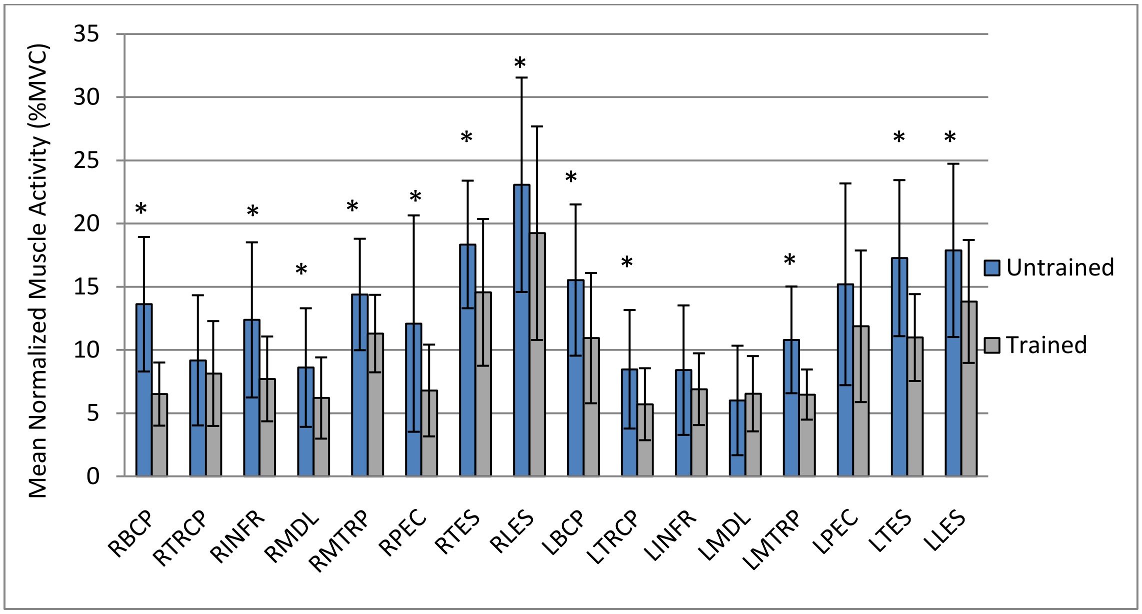


**Figure 20.** Individual mean normalized muscle activity for Lie-to-Sit when considering training state as an independent factor

Peak normalized muscle activity experienced significant decreases between the untrained and trained states in half of the muscles analyzed (Figure 21). The largest decrease occurred at the right biceps brachii (approximate 32% MVC decrease), followed by the left thoracic erector spinae (approximate 22% MVC decrease). A significant increase (p=0.007) occurred at the left middle deltoid (approximate 12% MVC increase), while non significant increases occurred at the right triceps brachii (p=0.053) and right thoracic erector spinae.

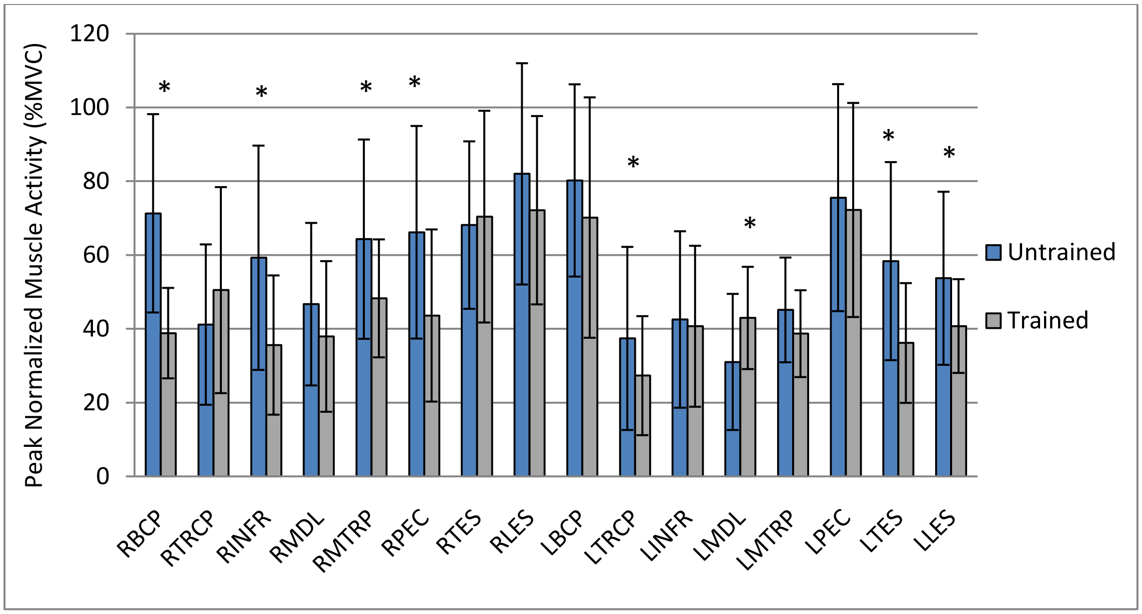


**Figure 21.** Individual peak normalized muscle activity for Lie-to-Sit when considering training state as an independent factor.

Half of the muscles measured had significant decreases in cumulative normalized muscle activity (Figure 22). The left middle deltoid experienced a non-significant (p=0.08) increase in cumulative normalized muscle activity (approximately 20% MVC*sec change), while the right thoracic and lumbar erector spinae did not have a significant decrease following training. Highest cumulative measures were seen at the right lumbar erector spinae in both the untrained (381.1±122.4 % MVC*sec) and trained (354±109.8% MVC*sec) conditions. The largest decrease in normalized muscle activity happened at the right biceps brachii (p=0.0001), where an approximate 102% MVC*sec decrease occurred.

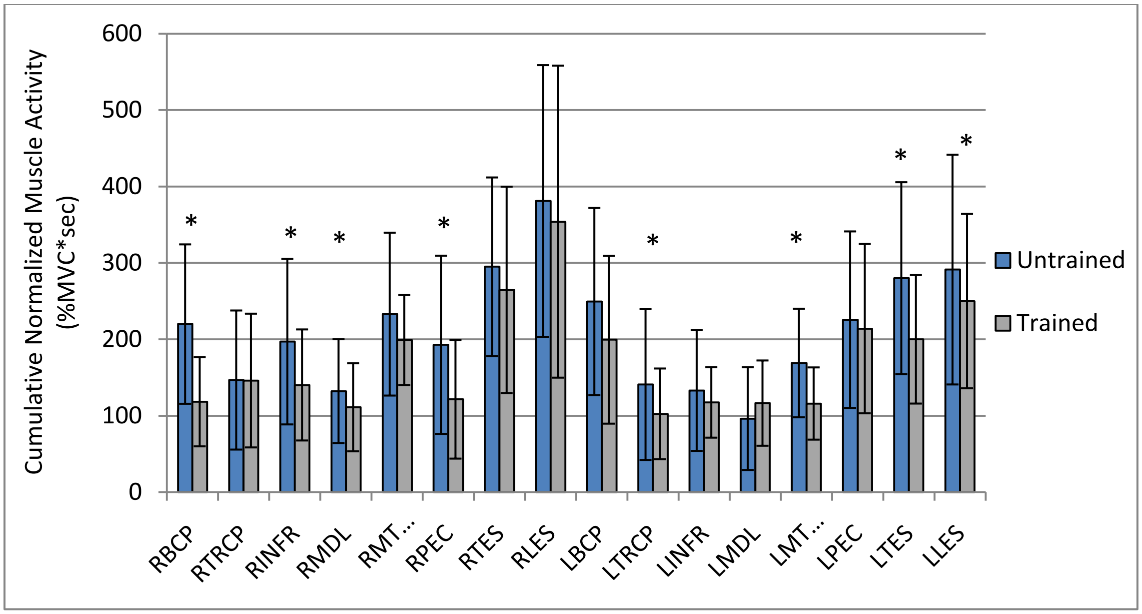

**Figure 22.** Individual muscle cumulative normalized muscle activity for Turn Lie-to-Sit when considering training state as an independent factor.

### *4.1.2 Reposition*

Ratings of perceived exertion, along with peak resultant moment and total muscle EMG all experienced significant decreases from pre training to post training (Table 12). Individual muscle analysis revealed three muscles on the left side of the body increasing in peak normalized muscle activity post training.

**Table 12.** Summary of findings for Reposition task, where arrows represent a significant increase or decrease in normalized muscle activity between the trained and untrained state. P-values are given for each measure.

| OUTPUT | MEAN | PEAK | CUMULATIVE |
|---|---|---|---|
| **MUSCLE ACTIVITY** | | | |
| **TOTAL MUSCLE** | | | |
| Total | ↓ 0.0001 | ↓ 0.0006 | ↓ 0.0006 |
| Right Shoulder | ↓ 0.0001 | ↓ 0.0016 | ↓ 0.0002 |
| Left Shoulder | ↓ 0.0001 | -- 0.083 | ↓ 0.0023 |
| Back | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.0013 |
| **INDIVIDUAL MUSCLE** | | | |
| Left Biceps Brachii | ↓ 0.0004 | ↓ 0.0031 | ↓ 0.0011 |
| Left Triceps Brachii | ↓ 0.0033 | -- 0.2467 | ↓ 0.0066 |
| Left Infraspinatus | ↓ 0.0089 | ↑ 0.0214 | ↓ 0.0355 |
| Left Middle Deltoid | -- 0.928 | -- 0.1412 | -- 0.9297 |
| Left Middle Trapezius | -- 0.0003 | -- 0.0991 | -- 0.3442 |
| Left Pectoralis Major | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.0045 |
| Right Bicep Brachii | ↓ 0.0001 | ↓ 0.0067 | ↓ 0.0002 |
| Right Tricep Brachii | ↓ 0.0022 | ↓ 0.0023 | ↓ 0.0023 |
| Right Infraspinatus | ↓ 0.0021 | ↓ 0.002 | ↓ 0.0059 |
| Right Middle Deltoid | -- 0.1541 | -- 0.2331 | -- 0.0877 |
| Right Middle Trapezius | -- 0.087 | -- 0.0505 | -- 0.0961 |
| Right Pectoralis Major | ↓ 0.006 | -- 0.792 | ↓ 0.0099 |
| Left Thoracic ES | ↓ 0.0005 | ↓ 0.021 | ↓ 0.0195 |
| Left Lumbar ES | ↓ 0.0008 | ↓ 0.0504 | ↓ 0.0176 |
| Right Thoracic ES | ↓ 0.0001 | ↓ 0.0015 | ↓ 0.0003 |
| Right Lumbar ES | ↓ 0.001 | ↓ 0.0028 | ↓ 0.0145 |
| **PEAK RESULTANT MOMENT** | | | |
| Right Shoulder | -- 0.2592 | | |
| Left Shoulder | -- 0.0985 | | |
| Low Back | ↓ 0.0008 | | |
| **RATING OF PERCEIVED EXERTION** | | | |
| Right Shoulder | ↓ 0.0016 | | |
| Left Shoulder | ↓ 0.0011 | | |
| Low Back | ↓ 0.0002 | | |

4.1.2.1 RPE

Low back (p=0.0002), right shoulder (p=0.002) and left shoulder (p=0.001) RPE decreased significantly for this task (Figure 23). The largest occurred at the left shoulder, with a decrease of 1.6 RPE in the trained state. Similar ratings were given for all three joints in the untrained condition, while the low back had the lowest rating in the post stage (1.7±1.1 RPE).

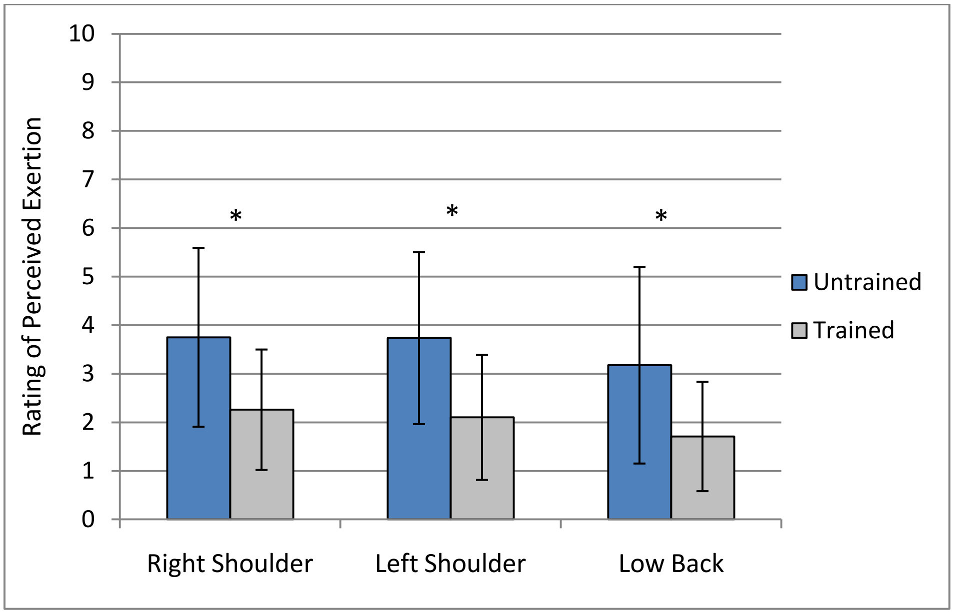


**Figure 23.** Joint specific RPE for Reposition when considering training state as an independent factor.

4.1.2.2 Peak Resultant Moments

While the right shoulder increased in peak resultant moment and the left shoulder decreased (Figure 24), significant differences occurred only at the low back (p=0.0001), with a large decrease of approximately 85 Nm.

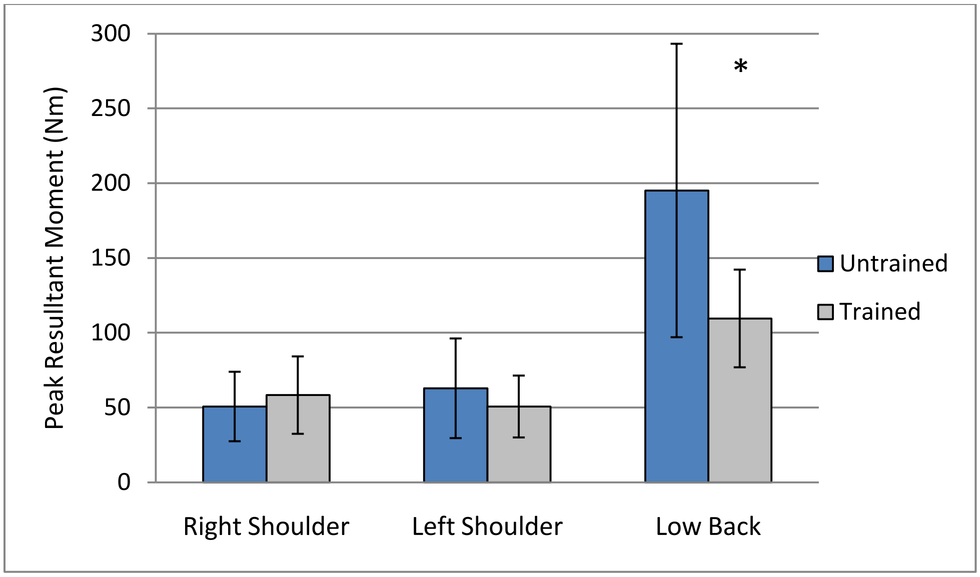


**Figure 24.** Joint specific peak resultant moment for Reposition when considering training state as an independent factor.

4.1.2.3 EMG

Similar to the previous task, Lie-to-Sit, total mean, peak and cumulative normalized muscle activity had a majority of significant decreases at each joint. The total right shoulder experienced larger decreases than the left shoulder for each mean, peak and cumulative measures, while the low back averaged an approximate 53% MVC decrease (or 13.3% MVC decrease in each muscle) in peak normalized muscle activity. Total mean muscle activity decreased approximately 4% MVC per muscle, while peak decreased 10.5% MVC per muscle. Cumulative measures for total muscle activity decreased an average of 4 % MVC*sec per muscle. For specific figures, please see Appendix A.

Individual muscle analysis revealed significant decreases across mean, peak and cumulative normalized muscle activity for a majority of muscles measured. Mean normalized muscle activity had significant decreases in 12 of the 16 muscles measured (Figure 25). There were no significant changes between the untrained to trained state at the right and left middle deltoid as well as the right and left middle trapezius. Right biceps brachii experienced the largest significant change (p=0.0001) in mean normalized muscle activity (approximate 8.5% MVC decrease), while the right lumbar erector spinae experienced the largest mean in both the untrained (21.0 ±11% MVC) and trained (16.3±8.87% MVC) conditions.

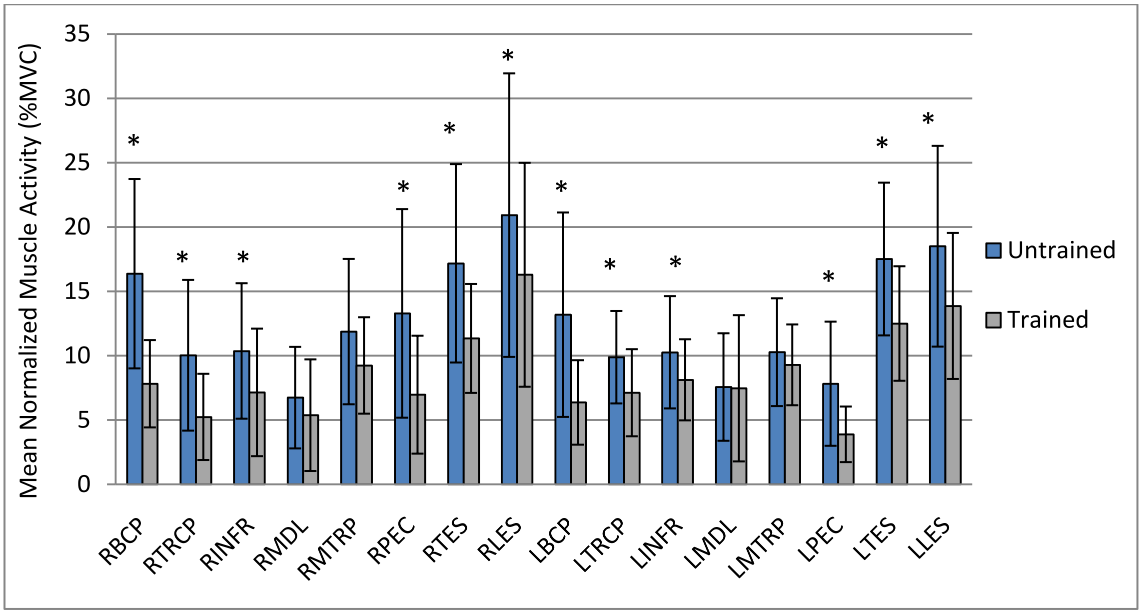

**Figure 25.** Individual muscle mean normalized muscle activity for Reposition when considering training state as an independent factor.

While most muscles experienced decreased peak normalized muscle activity using the recommended handling techniques, the left infraspinatus increased significantly (p=0.02) and the left middle deltoid and left middle trapezius (p=0.09) both increased with no significance (Figure 26). The largest increase happened at the left infraspinatus, with untrained peak normalized muscle activity of 43.1±25.3 % MVC increasing to a trained peak normalized muscle activity of 54.1±16.3 % MVC. Largest overall peak normalized muscle activity occurred at the right biceps brachii for untrained condition (83.5±35.5% MVC), while the left infraspinatus increased to the highest peak normalized muscle activity in the trained session (62.2±29.6% MVC). The largest decrease occurred at the right biceps brachii, followed closely by the left pectoralis major.

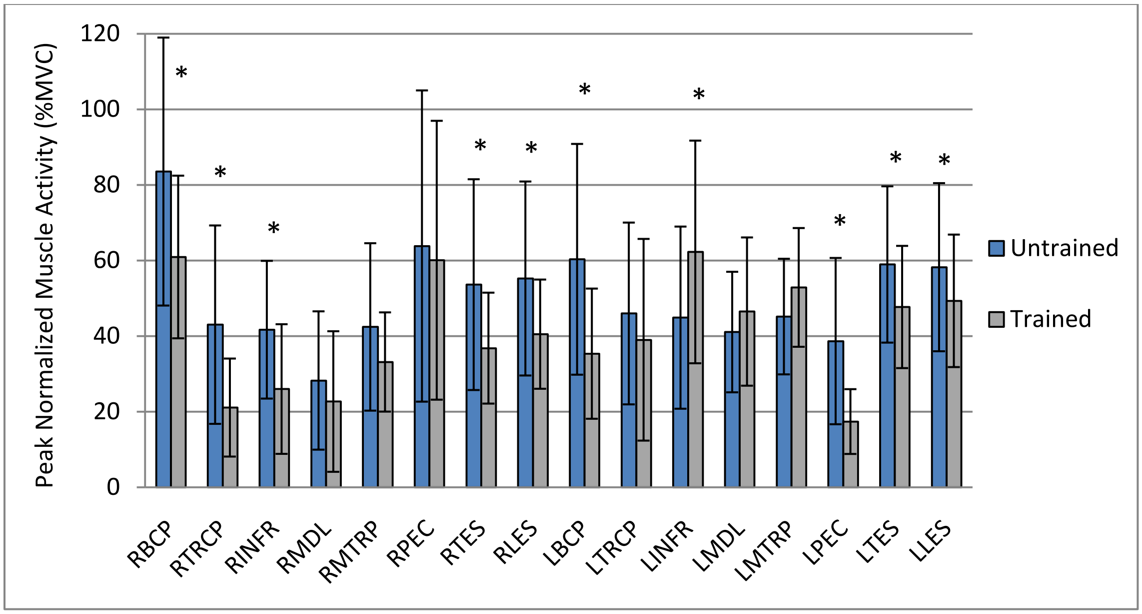


**Figure 26.** Individual muscle peak normalized muscle activity for Reposition when considering training state as an independent factor.

Except for an insignificant increase in the left middle deltoid, all muscles measured experienced a significant decrease in cumulative normalized muscle activity (Figure 27). The highest activity occurred for the untrained condition was in left lumbar erector spinae (224.6±118. % MVC*sec) and was very similar to the cumulative normalized muscle activity experienced at the right lumbar erector spinae in the untrained state. The largest decrease was experienced by the right pectoralis major, with a change of approximately 100 % MVC*sec untrained to trained.

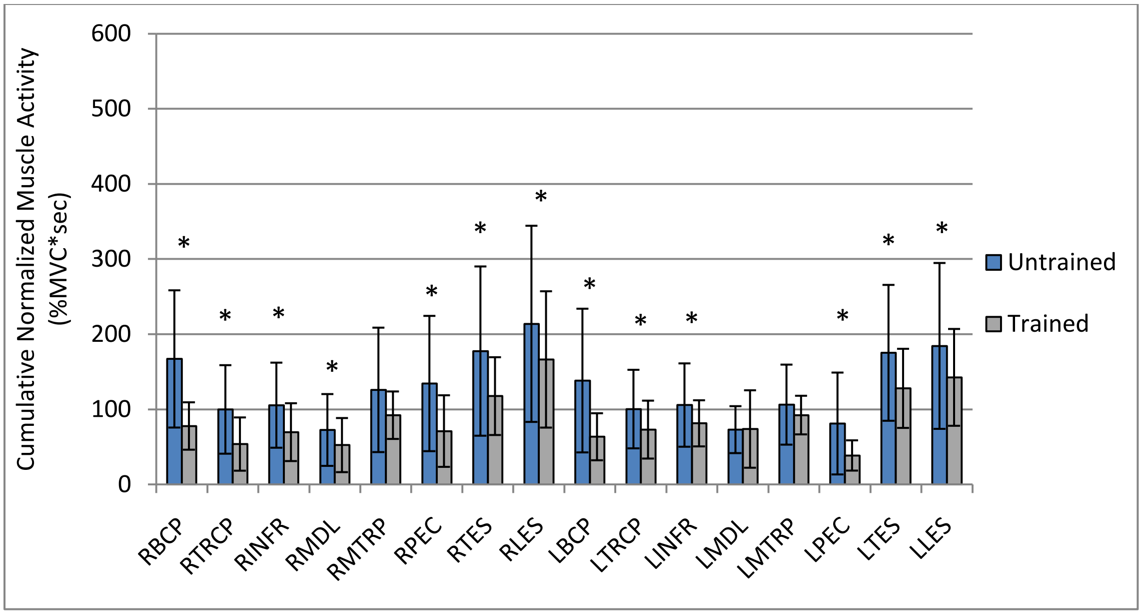


**Figure 27.** Individual muscle cumulative normalized muscle activity for Reposition when considering training state as an independent factor.

*4.1.3 Sit-to-Chair*

This task had more variable responses in normalized muscle activity than the previous two tasks, and also had similar (non significant) RPE reported for both training states at the right shoulder, left shoulder and low back (Table 13). Peak moment at both shoulders also increased post training, while low back decreased.

**Table 13.** Summary of findings for Sit-to-Chair task, where arrows represent a significant increase or decrease in normalized muscle activity between the pre and post training state. P-values are given for each measure.

| OUTPUT | MEAN | PEAK | CUMULATIVE |
|---|---|---|---|
| **MUSCLE ACTIVITY** | | | |
| **TOTAL MUSCLE** | | | |
| Total | ↓ 0.0001 | ↓ 0.0068 | -- 0.908 |
| Right Shoulder | ↓ 0.0001 | ↓ 0.0024 | -- 0.3503 |
| Left Shoulder | ↓ 0.0122 | -- 0.2892 | -- 0.5271 |
| Low Back | ↓ 0.0003 | ↓ 0.0217 | -- 0.426 |
| **INDIVIDUAL MUSCLE** | | | |
| Left Biceps Brachii | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.0003 |
| Left Triceps Brachii | ↑ 0.0027 | ↑ 0.0023 | ↑ 0.0015 |
| Left Infraspinatus | -- 0.1423 | -- 0.2886 | ↑ 0.0135 |
| Left Middle Deltoid | ↑ 0.015 | ↑ 0.0026 | ↑0.0018 |
| Left Middle Trapezius | ↓ 0.0127 | -- 0.2553 | -- 0.7851 |
| Left Pectoralis Major | ↓ 0.0025 | ↓ 0.009 | ↓ 0.0439 |
| Right Bicep Brachii | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.0007 |
| Right Tricep Brachii | ↑ 0.0001 | ↑ 0.0001 | ↑ 0.0001 |
| Right Infraspinatus | -- 0.1083 | -- 0.2145 | -- 0.8264 |
| Right Middle Deltoid | ↓ 0.0081 | -- 0.3123 | -- 0.9157 |
| Right Middle Trapezius | ↓ 0.0087 | ↓ 0.0467 | -- 0.8746 |
| Right Pectoralis Major | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.0001 |
| Left Thoracic ES | ↓ 0.0092 | ↓ 0.0245 | -- 0.5181 |
| Left Lumbar ES | ↓ 0.0001 | ↓ 0.0269 | -- 0.8852 |
| Right Thoracic ES | ↓ 0.0072 | -- 0.2259 | ↑ 0.186 |
| Right Lumbar ES | ↓ 0.0135 | -- 0.1366 | ↑ 0.2369 |
| **PEAK RESULTANT MOMENT** | | | |
| Right Shoulder | ↑ 0.0001 | | |
| Left Shoulder | ↑ 0.0002 | | |
| Low Back | ↓ 0.0255 | | |
| **RATING OF PERCEIVED EXERTION** | | | |
| Right Shoulder | -- 0.7693 | | |
| Left Shoulder | -- 0.5858 | | |
| Low Back | -- 0.1061 | | |

4.1.3.1 RPE

While both shoulders and the low back experienced decreases post training, there were no significant decreases reported. Figure 28 shows the change between the untrained and trained conditions for this task. Again, RPE remains highly variable in its response, especially at the shoulders, where responses ranged from 0 to over 4 on the Borg CR10 scale in the untrained condition.

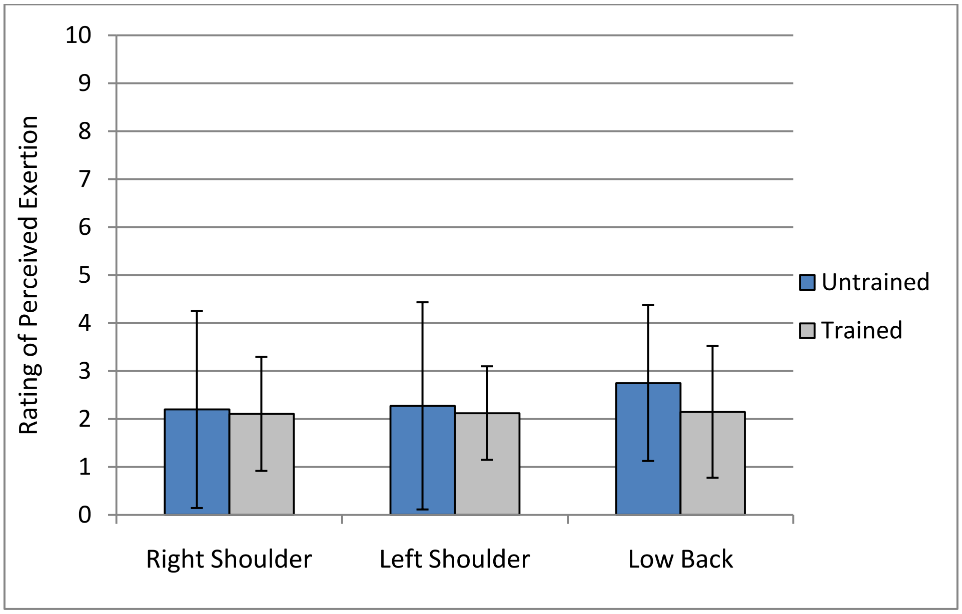


**Figure 28.** Joint specific RPE for Sit-to-Chair when considering training state as an independent factor.

4.1.3.2 Peak Resultant Moments

Peak resultant moments significantly increased at both the right shoulder (p=0.018) and left shoulder (p=0.01) during this task (Figure 29). Both shoulders experienced similar increases of 29.5 Nm (right shoulder) and 28.3 Nm (left shoulder). The low back had a significant decrease (p=0.001) of approximately 45 Nm.

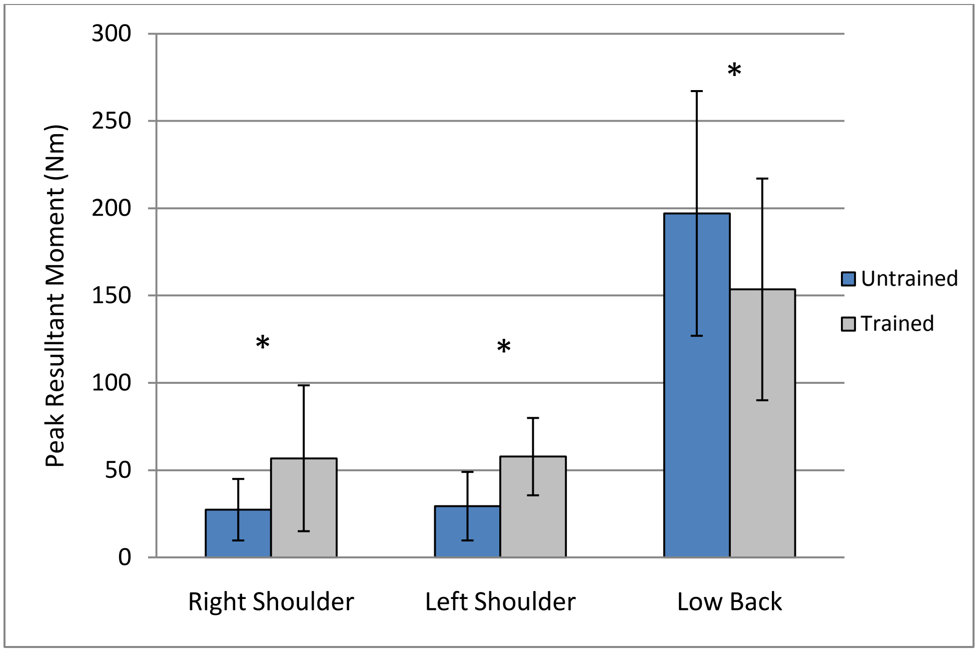


**Figure 29.** Joint specific peak resultant moments for Sit-to-Chair when considering training state as an independent factor.

4.1.3.3 EMG

While there were significant decreases for both total mean and peak normalized muscle activity for each joint, no joint experienced significant changes in cumulative normalized muscle activity (although increases in normalized muscle activity occurred). Total mean normalized muscle activity was significant for the right shoulder (p=0.0001), left shoulder (p=0.01) and the low back (p=0.0003), while total peak normalized muscle activity decreased (p=0.007) approximately 7% MVC per muscle. Specific figure details for total normalized muscle activity can be found in Appendix A.

Individual muscle analysis revealed a varied response to training for each mean, peak and cumulative normalized muscle activity. Mean normalized muscle activity analysis had a total of 14 of the 16 measured muscles experience significant decreases from untrained to trained (Figure 30). The largest decrease occurred at the right biceps brachii (p=0.0001), which went from

16.1±7.1% MVC to 4.84±2.6% MVC. Significant increases occurred at the right triceps brachii (p=0.0001) as well as the left middle deltoid (p=0.02), with the right triceps brachii increasing from 5.3±3.6% MVC to 10.7±4.7% MVC. Highest mean normalized muscle activity occurred at the right lumbar erector spinae for both untrained (20.8±9.3% MVC) and trained (17.8±8.6 % MVC) conditions.

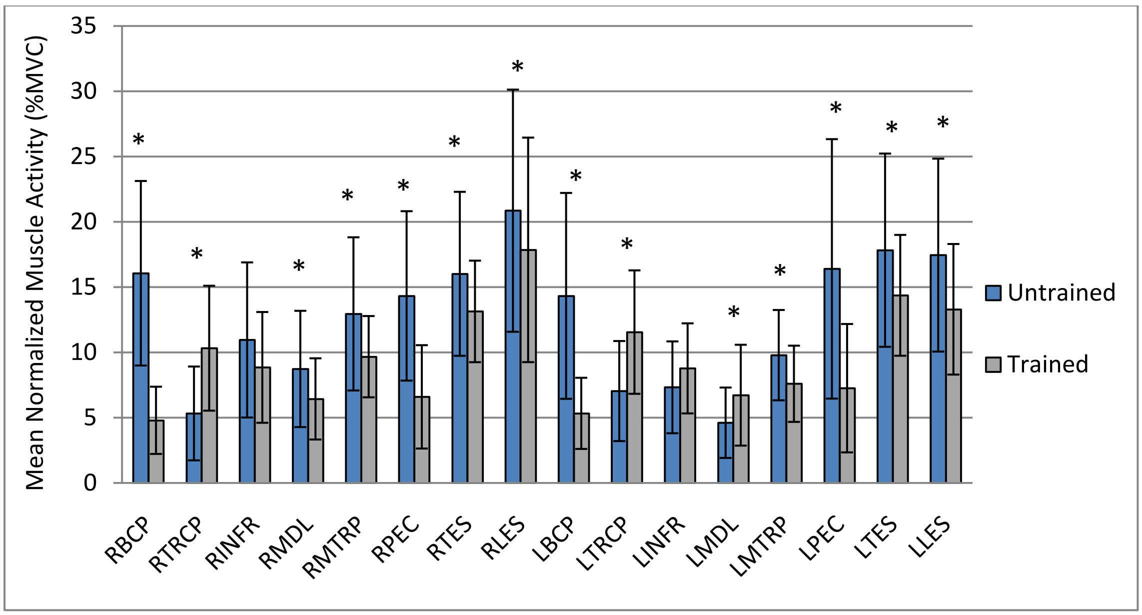


**Figure 30.** Individual muscle mean normalized muscle activity for Sit-to-Chair when considering training state as an independent factor.

Significant decreases occurred in 7 of the 16 muscles measured when analyzing peak normalized muscle activity (Figure 31), with the largest occurring at the right biceps brachii (p=0.0001) from untrained (69.1±36.2 % MVC) to trained (24.6±11.4% MVC). Significant increases from untrained to trained conditions occurred at the right triceps brachii (0.0001), left triceps brachii (p=0.0023) and left middle deltoid (p=0.0026), while the left infraspinatus had an increase, but it was not significant. The largest increase occurred at the right triceps brachii (an approximate 29.3% MVC change). Highest peak normalized muscle activity occurred at the right biceps brachii in the untrained state (69.1±36.2 % MVC), and at the right triceps brachii in the trained state (50.2±15% MVC).

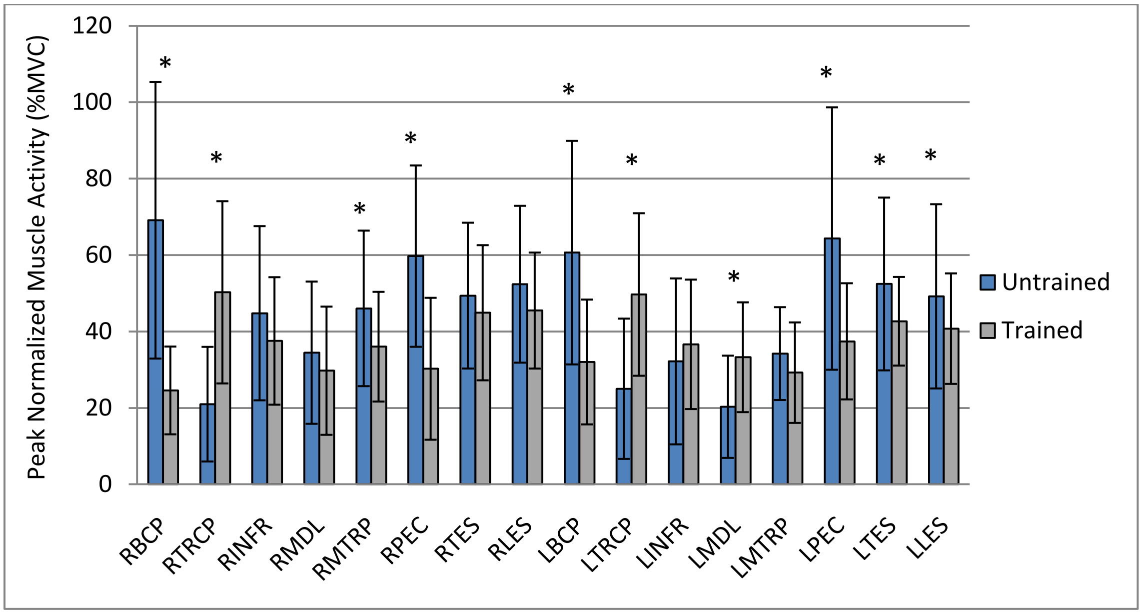


**Figure 31.** Individual muscle peak normalized muscle activity for Sit-to-Chair when considering training state as an independent factor.

There were highly varied responses from each muscle for cumulative normalized muscle activity (Figure 32). Significant decreases occurred at the right biceps brachii (p=0.0007), right pectoralis major (p=0.0001) , left biceps brachii (p=0.0003) , and left pectoralis major (p=0.044). The largest decrease of these, an approximate decrease of 123% MVC*sec, was at the right biceps brachii. Significant increases were seen at the right triceps brachii (p=0.002), left infraspinatus (p=0.014) and left middle deltoid (p=0.002) with the highest increase at the left tricep (p=0.002) with an approximate 118.6% MVC*sec increase. Increases at the left thoracic erector spinae, left middle trapezius and right infraspinatus were not significant. Highest cumulative normalized muscle activity was seen at the right lumbar erector spinae with 296.5% MVC*sec in the trained condition.

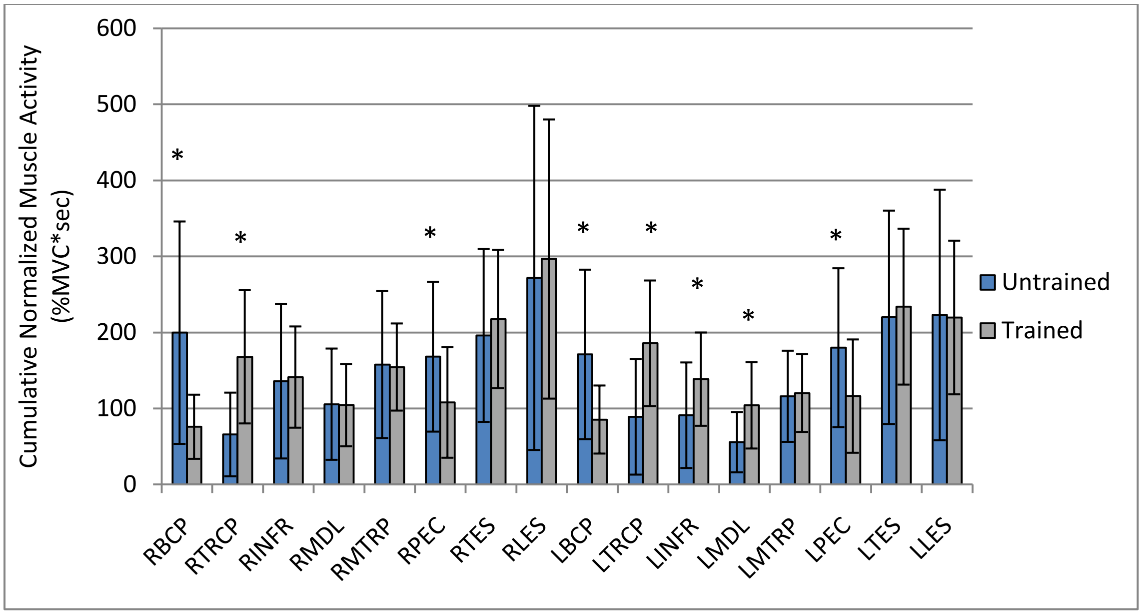


**Figure 32.** Individual muscle cumulative normalized muscle activity for Sit-to-Chair when considering training state as an independent factor.

### *4.1.4 Turn Away*

Total normalized muscle activity decreased at all joints for mean and peak normalized muscle activity, but only at the right shoulder for cumulative measures; individual normalized muscle activity decreased significantly across most muscles for mean and peak normalized muscle activity, but were variable in their response for cumulative measures (Table 14). Significant decreases at all joints were reported for RPE, while only the low back reported significant decreases for peak resultant moment.

**Table 14.** Summary of findings for Turn Away task, where arrows represent a significant increase or decrease in normalized muscle activity between the trained and untrained state. P-values are given for each measure.

| OUTPUT | MEAN | PEAK | CUMULATIVE |
|---|---|---|---|
| **MUSCLE ACTIVITY** | | | |
| **TOTAL MUSCLE** | | | |
| Total | ↓ 0.0001 | ↓0.0001 | -- 0.3256 |
| Right Shoulder | ↓ 0.0001 | ↓0.0001 | ↓ 0.0253 |
| Left Shoulder | ↓ 0.0001 | ↓0.0037 | -- 0.6231 |
| Low Back | ↓ 0.0001 | ↓0.0001 | -- 0.5424 |
| **INDIVIDUAL MUSCLE** | | | |
| Left Biceps Brachii | ↓ 0.0026 | ↓0.0018 | -- 0.4243 |
| Left Triceps Brachii | ↓ 0.0001 | ↓ 0.0409 | -- 0.9108 |
| Left Infraspinatus | ↓ 0.0192 | -- 0.1656 | -- 0.8329 |
| Left Middle Deltoid | -- 0.1093 | -- 0.9169 | ↑ 0.2908 |
| Left Middle Trapezius | ↓ 0.0003 | -- 0.9169 | -- 0.7472 |
| Left Pectoralis Major | ↓ 0.0393 | -- 0.0519 | -- 0.8957 |
| Right Bicep Brachii | ↓ 0.0001 | -- 0.0997 | -- 0.0593 |
| Right Tricep Brachii | ↓ 0.0001 | ↓0.021 | ↓0.0332 |
| Right Infraspinatus | ↓ 0.0001 | ↓0.0001 | ↓ 0.0095 |
| Right Middle Deltoid | ↓ 0.0042 | ↓0.0288 | -- 0.3996 |
| Right Middle Trapezius | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.017 |
| Right Pectoralis Major | ↓ 0.0001 | ↓0.0019 | -- 0.0687 |
| Left Thoracic ES | ↓ 0.0001 | ↓0.0008 | -- 0.0987 |
| Left Lumbar ES | ↓ 0.0001 | ↓0.0001 | -- 0.121 |
| Right Thoracic ES | ↓ 0.0001 | ↓ 0.0001 | -- 0.8041 |
| Right Lumbar ES | ↓ 0.0001 | ↓ 0.0001 | -- 0.4568 |
| **PEAK RESULTANT MOMENT** | | | |
| Right Shoulder | -- 0.1315 | | |
| Left Shoulder | -- 0.0834 | | |
| Low Back | ↓ 0.0001 | | |
| **RATING OF PERCEIVED EXERTION** | | | |
| Right Shoulder | ↓ 0.0062 | | |
| Left Shoulder | ↓ 0.002 | | |
| Low Back | ↓ 0.0096 | | |

4.1.4.1 RPE

Significant decreases between training states occurred at the right shoulder (p=0.006), left shoulder (p=0.002) and low back (p=0.01) (Figure 33). Highest reported RPE was at the left shoulder before training (2.7±1.4 RPE) where a range of 0.5 to 4.5 RPE were reported,  while the decrease experienced by each joint were very similar (approximately 0.9 RPE).

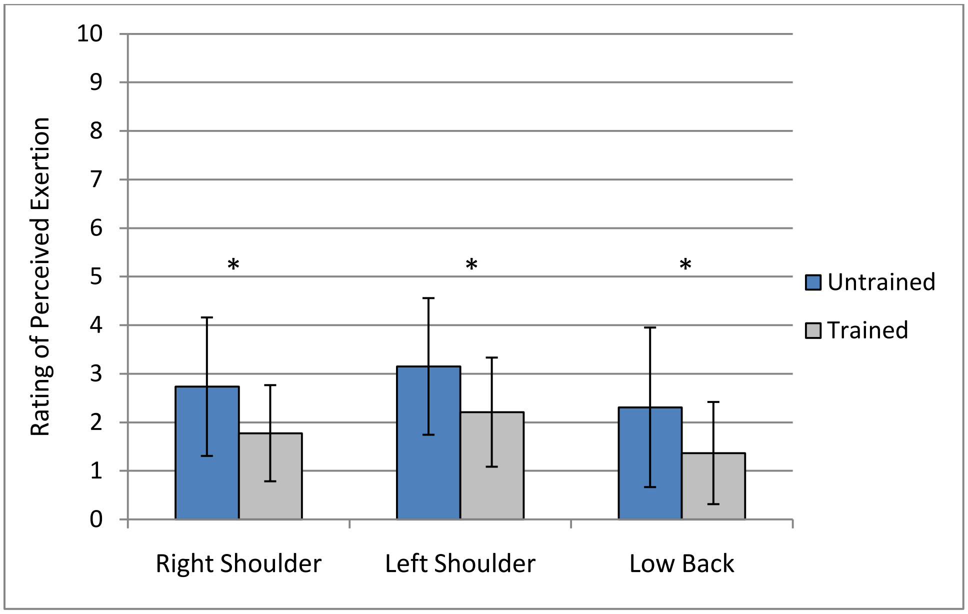


**Figure 33.** Joint specific RPE for Turn Away when considering training state as an independent factor.

4.1.4.2 Resultant Moments

While decreases occurred at the right shoulder and left shoulder, they were not significant. The low back decreased significantly (p=0.0001) from 206.8±51.2 Nm to 114.8±35.4 Nm (Figure 34).

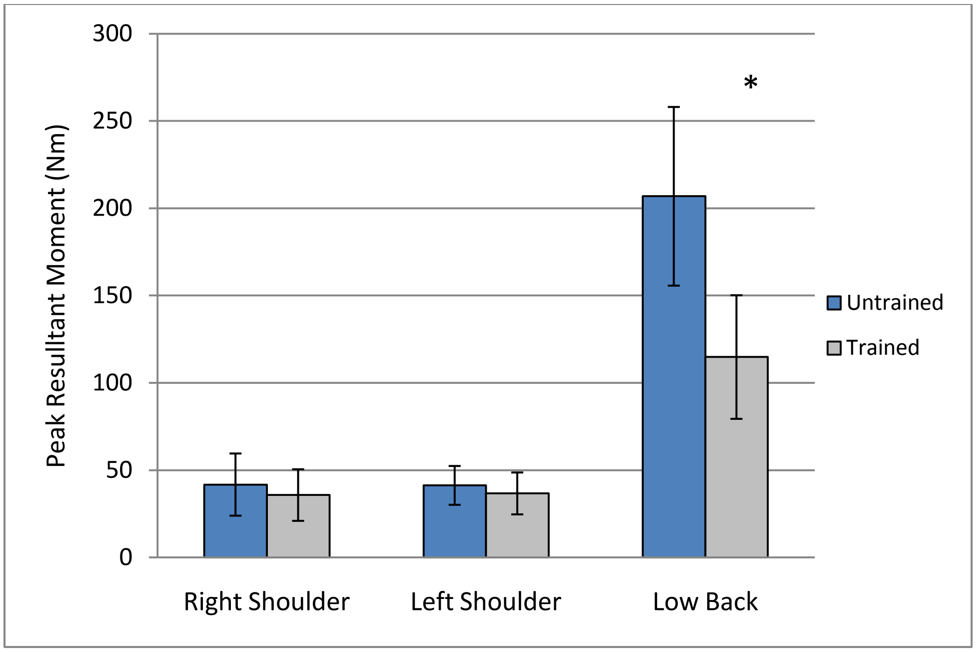


**Figure 34.** Joint specific peak resultant moments for Turn Away when considering training state as an independent factor.

4.1.4.3 EMG

Significant decreases were reported for mean and peak Total muscle, Total Shoulder muscles and Total Low back muscles (p=0.0001 for all but left shoulder peak normalized muscle activity, where p = 0.004). Total muscle decrease was approximately 61% MVC for mean normalized muscle activity, while each muscle decreased an average of 12% peak MVC. Only the right shoulder significantly increased (p=0.03) following training for cumulative normalized muscle activity by approximately 95% MVC*second. See Appendix A for figures.

Fifteen muscles showed a significant decrease in mean normalized muscle activity after the training period, with the largest being right middle trapezius (p=0.0001) with an approximate 6.4% MVC decrease (Figure 35). The largest mean normalized muscle activity occurred in the right lumbar erector spinae (p=0.0001) for both untrained and trained conditions (18.9±9.8% MVC and 14.5±8.9% MVC respectively). The left middle deltoid (p=0.1093) did not significantly decrease when implementing recommended training techniques.

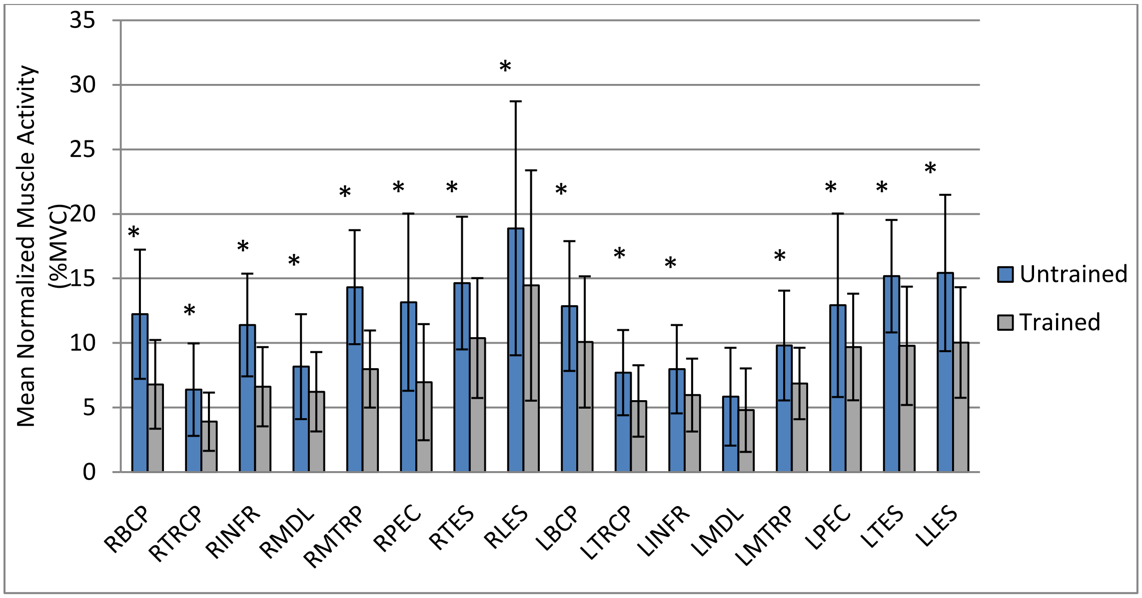


**Figure 35.** Individual muscle mean normalized muscle activity for Turn Away when considering training state as an independent factor.

Muscles affecting the low back significantly decreased following training, while a majority of those muscles on the right side of the body also significantly decreased (Figure 36). The highest peak normalized muscle activity occurred at the left biceps brachii for the untrained condition(67.0±26.7% MVC) while the left pectoralis major had the highest recorded peak normalized muscle activity in the trained state (55.9±15.9% MVC). The largest decrease occurred at the right middle trapezius (p=0.0001) with an approximate 22% peak MVC drop, while the left infraspinatus, left middle deltoid, left middle trapezius and left pectoralis major did not experienced significance changes following training.

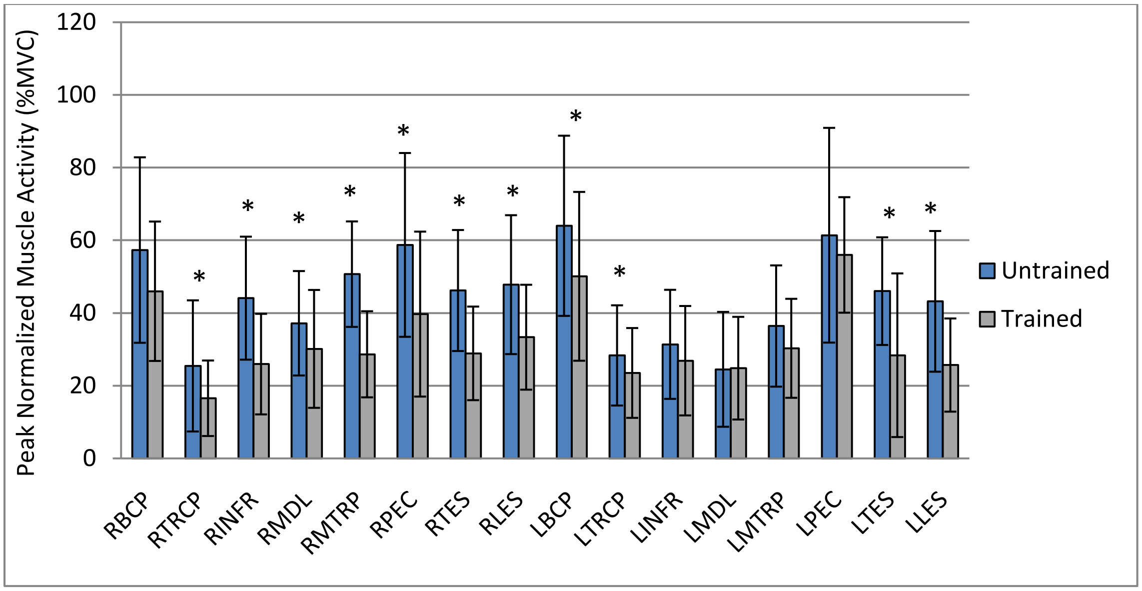


**Figure 36.** Individual muscle peak normalized muscle activity for Turn Away when considering training state as an independent factor.

Cumulative normalized muscle activity had significant decreases for the right triceps brachii (p=0.03), right infraspinatus (p=0.01) and right middle trapezius (p=0.02), while no other muscle experienced a significant change (Figure 37). The largest decrease occurred in the right middle trapezius (an approximate 28% MVC*sec change), while the largest cumulative normalized muscle activity for the trained condition was recorded for the right lumbar erector spinae with 181.4±126.3% MVC*sec. The largest increase in cumulative normalized muscle activity occurred at the right lumbar erector spinae (approximately 10% MVC*sec), although it was not significant.

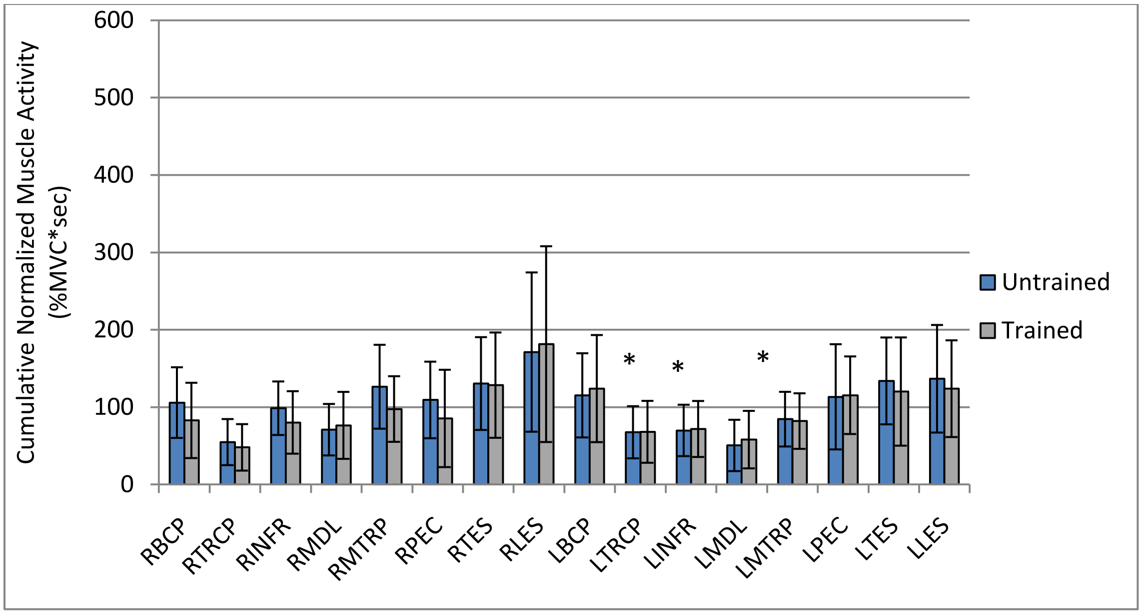


**Figure 37.** Individual muscle cumulative normalized muscle activity for Turn Away when considering training state as an independent factor.

### *4.1.5 Turn Toward*

The most variable of all the tasks for individual and total EMG, cumulative normalized muscle activity was nearly all significantly higher after the training period, while many individual muscles increased (or did not change) for both mean and peak normalized muscle activity measures (Table 15). RPE was once again significantly lower post training, except for at the left shoulder, while peak resultant moment decreased significantly for the left shoulder and low back.

**Table 15.** Summary of findings for Turn Toward task, where arrows represent a significant increase or decrease in normalized muscle activity between the trained and untrained state. P-values are given for each measure.

| OUTPUT | MEAN | PEAK | CUMULATIVE |
|---|---|---|---|
| **MUSCLE ACTIVITY** | | | |
| **TOTAL MUSCLE** | | | |
| Total | ↓ 0.0167 | -- 0.7952 | ↑ 0.0024 |
| Right Shoulder | ↓ 0.0044 | -- 0.4234 | ↑ 0.0052 |
| Left Shoulder | ↓ 0.0369 | -- 0.3577 | -- 0.2272 |
| Low Back | --0.428 | -- 0.6422 | ↑ 0.0001 |
| **INDIVIDUAL MUSCLE** | | | |
| Left Biceps Brachii | -- 0.7758 | -- 0.8433 | ↑ 0.0253 |
| Left Triceps Brachii | ↓ 0.002 | ↓ 0.0067 | -- 0.1198 |
| Left Infraspinatus | ↓ 0.0357 | -- 0.6557 | -- 0.1164 |
| Left Middle Deltoid | -- 0.6053 | -- 0.5497 | -- 0.1088 |
| Left Middle Trapezius | -- 0.2434 | -- 0.1754 | -- 0.0549 |
| Left Pectoralis Major | -- 0.9827 | -- 0.6694 | -- 0.1219 |
| Right Bicep Brachii | ↑ 0.0498 | ↑ 0.0038 | ↑ 0.0007 |
| Right Tricep Brachii | ↓ 0.0001 | ↓ 0.0001 | ↓ 0.003 |
| Right Infraspinatus | ↓ 0.0431 | -- 0.6339 | ↑ 0.0209 |
| Right Middle Deltoid | -- 0.9804 | -- 0.1872 | ↑ 0.0024 |
| Right Middle Trapezius | -- 0.0563 | -- 0.3682 | ↑0.0229 |
| Right Pectoralis Major | -- 0.0985 | ↑ 0.001 | ↑ 0.0027 |
| Left Thoracic ES | ↓ 0.0114 | -- 0.6523 | ↑ 0.0052 |
| Left Lumbar ES | -- 0.7553 | -- -0.3577 | ↑ 0.0024 |
| Right Thoracic ES | -- 0.1983 | -- 0.0651 | ↑ 0.0039 |
| Right Lumbar ES | -- 0.0531 | -- 0.8411 | ↑ 0.001 |
| **PEAK RESULTANT MOMENT** | | | |
| Right Shoulder | -- 0.4293 | | |
| Left Shoulder | ↓ 0.0292 | | |
| Low Back | ↓ 0.045 | | |
| **RATING OF PERCEIVED EXERTION** | | | |
| Right Shoulder | ↓ 0.0128 | | |
| Left Shoulder | -- 0.2399 | | |
| Low Back | ↓ 0.0186 | | |

4.1.5.1 RPE

The right shoulder (p=0.01) and low back (p=0.02) both reported significant decreases for this task, while the left shoulder had no change (Figure 38). The largest decrease occurred at the low back, going from untrained (2.0±1.3 RPE) to trained (1.3±1.1 RPE). The left shoulder experienced the largest reported RPE in the untrained and trained condition.

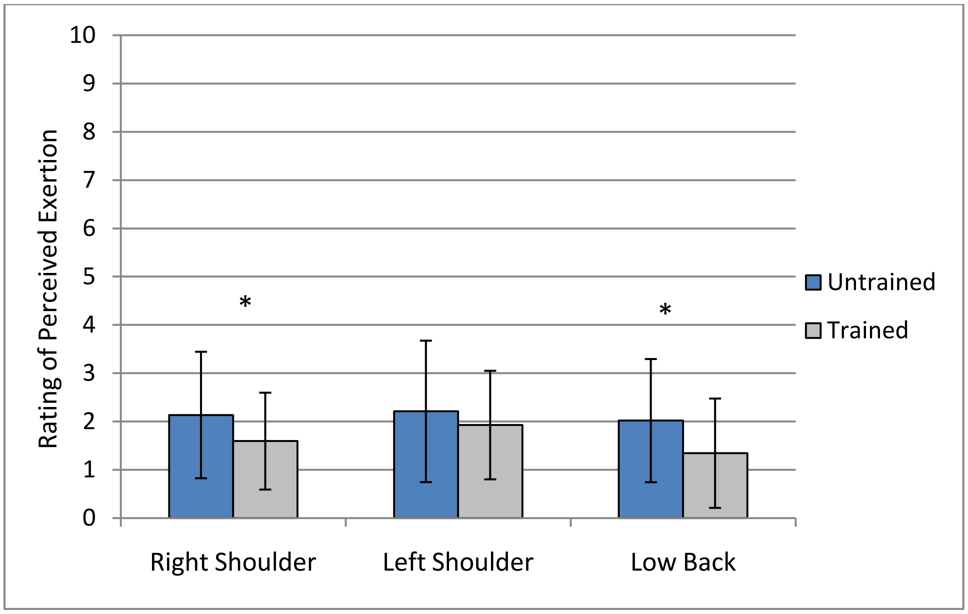


**Figure 38.** Joint specific RPE for Turn Toward when considering training state as an independent factor.

4.1.5.2 Peak Resultant Moments

Significant decreases occurred at the left shoulder (p=0.05) and low back (p=0.02) for peak resultant moment (Figure 39). The left shoulder experienced an approximately 12.1 Nm decrease from the untrained to trained conditions, while low back decreased from 145.7±52.8 Nm to 112.0±41.7 Nm. There was a small decrease at the right shoulder, but it was not significant. Resulting shoulder moments ranged from 25 to 100 Nm in the untrained condition, while a much lower range occurred while using the recommended techniques.

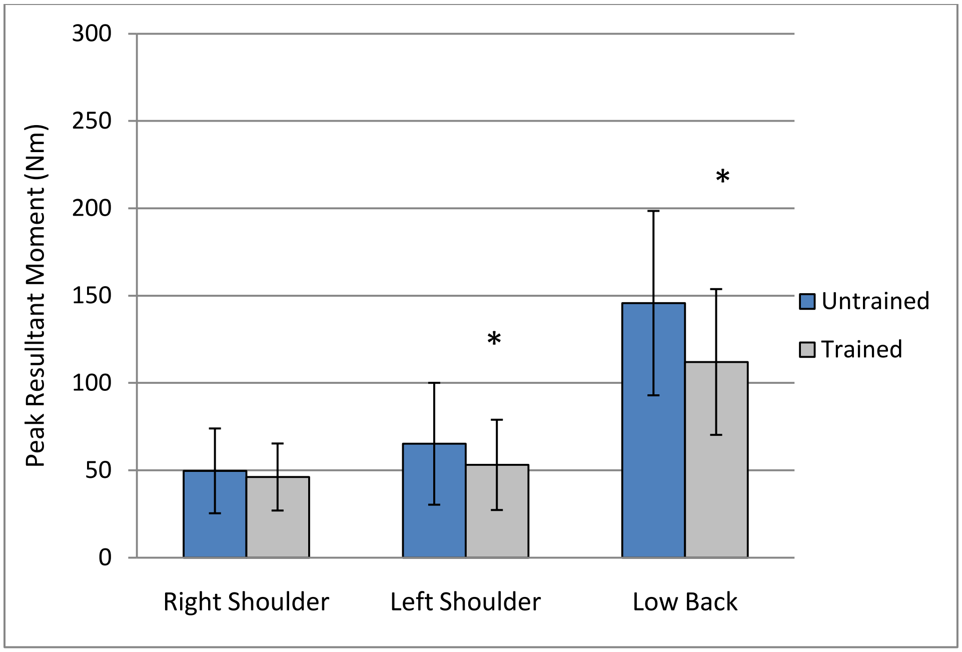


**Figure 39.** Joint specific peak resultant moments for Turn Toward when considering training state as an independent factor.

4.1.5.3 EMG

Total normalized muscle activity was much different for this task than any of the other four measured. Mean normalized muscle activity for left shoulder (p=0.04), right shoulder (p=0.004) and total muscle (p=0.02) decreased significantly for this task, while the low back experienced a decrease of 1% MVC (while not significant). Peak normalized muscle activity was not significant for any total joint , while cumulative normalized muscle activity increased significantly for total muscle activity (p=0.002), right shoulder (p=0.005) and the low back (p-0.0001), but an increase at the left shoulder was not significant (Figure 39). Total cumulative normalized muscle activity increased approximately 19% MVC*sec per muscle.

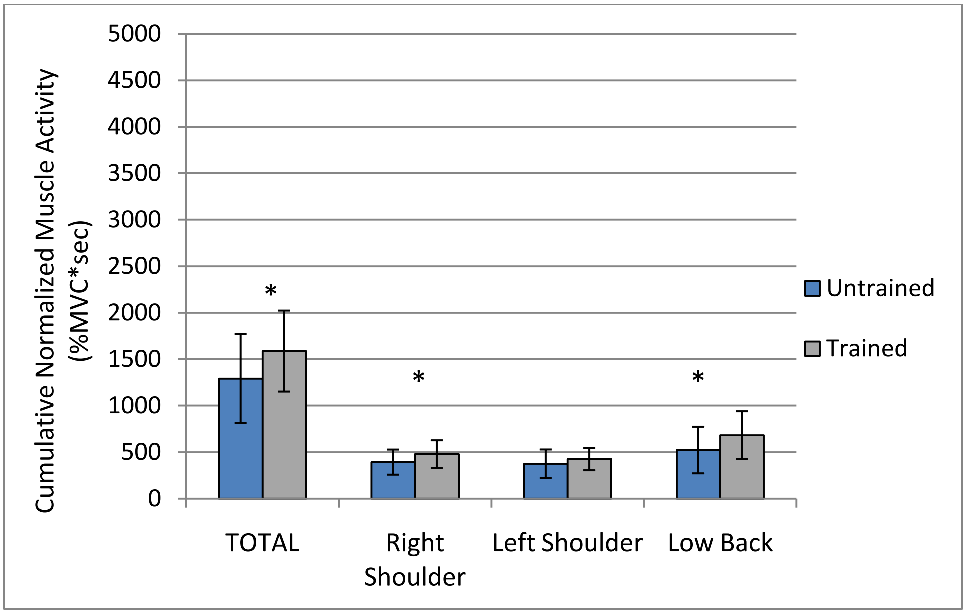

**Figure 40.** Joint specific cumulative normalized muscle activity resultant for Turn Toward when considering training state as an independent factor.

Individual muscle analyses revealed varied results among the measures and between the muscles. A significant decrease in mean normalized muscle activity occurred in 5 of the 16 muscles analyzed, while the right biceps brachii ($p=0.05$) reported a significant increase (Figure 41). The highest decrease ($p=0.0001$) occurred at the right triceps brachii (approximately 4.5% MVC), while the highest increase occurred in the right lumbar erector spinae (approximately 1.3% MVC). The highest reported mean normalized muscle activity was at the right lumbar erector spinae for both untrained and trained states (16.1±9.1% MVC and 17.5±8.2% MVC respectively).

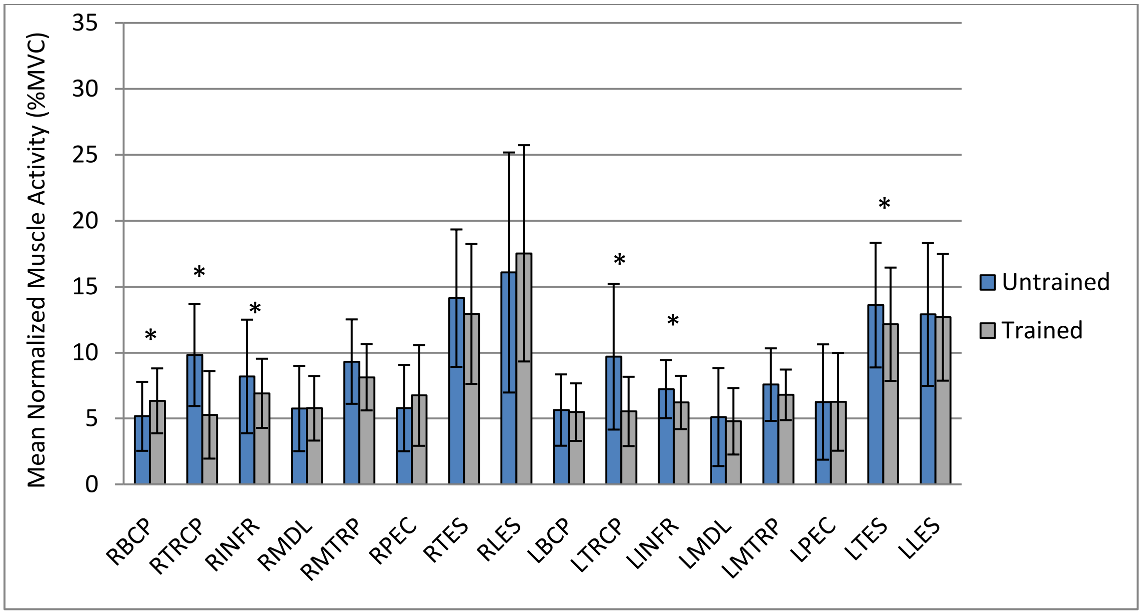


**Figure 41.** Individual muscle mean normalized muscle activity for Turn Toward when considering training state as an independent factor.

The right triceps brachii (p=0.0001) and left triceps brachii (p=0.007) decreased in peak normalized muscle activity after training, while the right biceps brachii (p=0.004) and right pectoralis major (p=0.001) had a significant increase, the largest of which came at the right pectoralis major with an approximately 17% peak normalized muscle activity increase (Figure 42). The largest decrease occurred at the right triceps brachii, which went from 48.7±20.4% MVC untrained to 28±22.2% MVC trained. The largest peak normalized muscle activity occurred at the right triceps brachii during the untrained condition, where a range of 25%MVC to 75% MVC was observed.

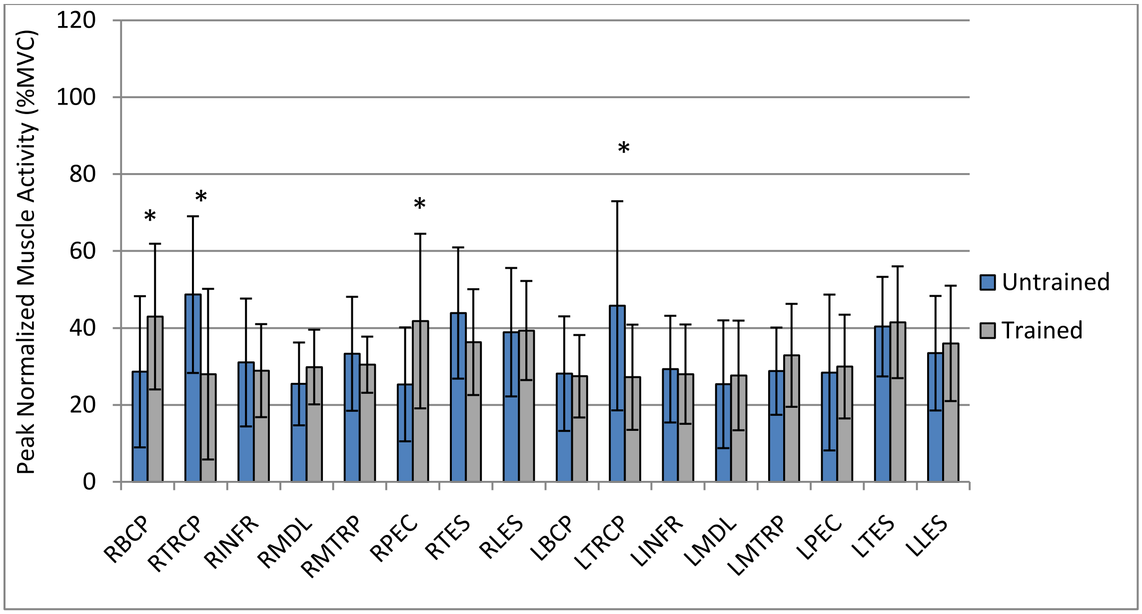


**Figure 42.** Individual muscle peak normalized muscle activity for Turn Toward when considering training state as an independent factor.

Cumulative normalized muscle activity analysis revealed a significant decrease (p=0.003) occurred at only the right triceps brachii (Figure 43). Significant increases in cumulative normalized muscle activity occurred, with only the left infraspinatus, left middle deltoid, left middle trapezius and left middle pectoralis major not significantly changing. The highest increase occurred at the right lumbar erector spinae, which increased by approximately 70% MVC*sec. The highest cumulative normalized muscle activity was recorded for the right lumbar erector spinae in the trained condition (219.3±116.7% MVC*sec).

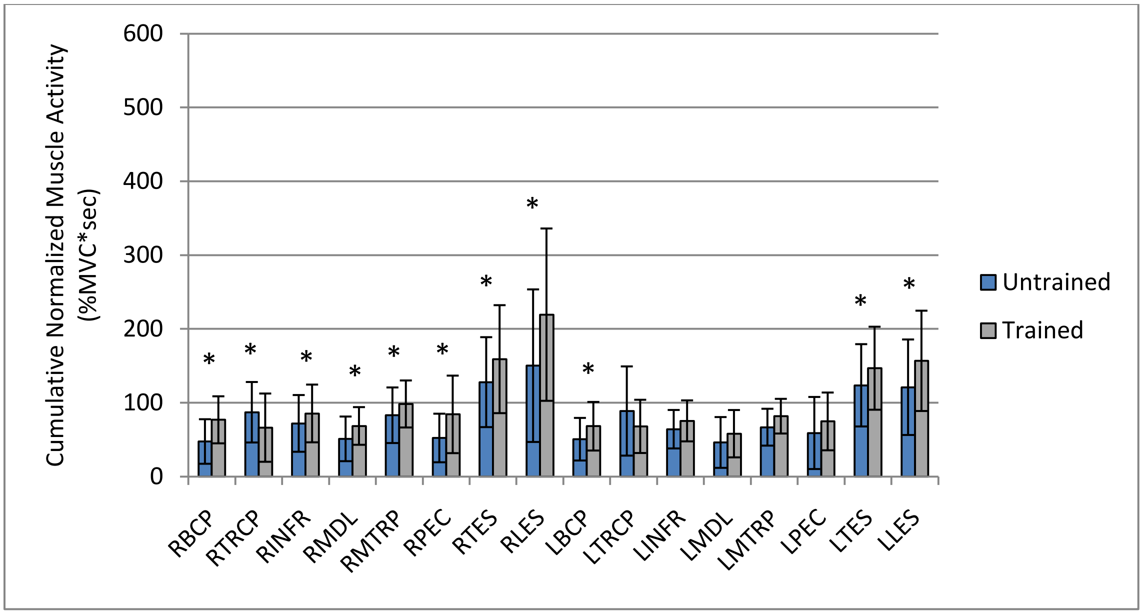


**Figure 43.** Individual muscle cumulative normalized muscle activity for Turn Toward when considering training state as an independent factor.

4.2 Comparison of Change between Training State Measures at Each Joint

While the low back, right shoulder and left shoulder experienced decreases for the majority of the tasks, there were obvious differences between the magnitudes of the changes. Increases also occurred for some measures (particularly cumulative normalized EMG and peak resultant moment), while the RPE consistently decreased (as well, the three joints were fairly similar in their magnitude of change). The overall trend observed was that the right shoulder eclipsed the low back in size of decrease for many tasks, while the left shoulder consistently experienced the smallest modification, including with some increases following training.

*4.2.1 Lie-to-Sit*

The right shoulder experienced the largest decrease in percentage change across all three EMG measures compared to the low back and left shoulder, but it had the smallest decrease for peak resultant moment (Table 16). The low back had a 42% decrease in peak resultant moment, nearly twice as much as the left shoulder, and also had the largest decrease in RPE. The left shoulder had the smallest percentage change between all the joints on every measure except peak resultant moment.

**Table 16.** Percent change analysis when averaging across muscles for Lie-to-Sit.

| Lie-to-Sit | | % Change Pre Training to Post Training | | |
|---|---|---|---|---|
| **Measure** | | *Right Shoulder* | *Left Shoulder* | *Low Back* |
| *EMG* | Mean | ↓32% | ↓22% | ↓24% |
| | Peak | ↓23% | ↓4% | ↓18% |
| | Cumulative | ↓24% | ↓12% | ↓15% |
| *Peak Resultant Moment* | | ↓0.61% | ↓25.99% | ↓42.41% |
| *RPE* | | ↓32% | ↓14% | ↓38% |

*4.2.2 Reposition*

The right shoulder reported a 15% increase in peak resultant moment following training, while the low back had a 44% decrease for the same measure (Table 17). The right shoulder had larger decreases for each measure of normalized muscle activity than the left shoulder, nearly four times the decrease in peak normalized muscle activity. All three joints had a similar decrease in RPE, with the low back experiencing the largest change with a 46% decrease.

**Table 17.** Percent change analysis when averaging across muscles for Reposition.

| Reposition | | % Change Pre Training to Post Training | | |
|---|---|---|---|---|
| **Measure** | | *Right Shoulder* | *Left Shoulder* | *Low Back* |
| *EMG* | Mean | ↓37% | ↓27 % | ↓27% |
| | Peak | ↓27% | ↓7% | ↓23% |
| | Cumulative | ↓39% | ↓28% | ↓26% |
| *Peak Resultant Moment* | | ↑15.03% | ↓19.36% | ↓43.85% |
| *RPE* | | ↓39% | ↓43% | ↓46% |

*4.2.3 Sit-to-Chair*

The low back experienced the largest decrease for each measure of EMG, along with the largest decrease for RPE, at approximately 22% (Figure 18). The right shoulder experienced the smallest decrease for RPE (4% decrease), while increasing more than 100% in peak resultant moment. The left shoulder also increased by nearly 97% for peak resultant moment, and also increased 12% for peak normalized muscle activity (while the other two joints decreased for the same measure).

**Table 18.** Percent change analysis when averaging across muscles for Sit-to-Chair.

| Sit-to-Chair | | **% Change Pre Training to Post Training** | | |
|---|---|---|---|---|
| **Measure** | | *Right Shoulder* | *Left Shoulder* | *Low Back* |
| *EMG* | Mean | ↓17% | ↓2% | ↓19% |
| | Peak | ↓4% | ↑12% | ↓15% |
| | Cumulative | ↑10% | ↑28% | ↑6% |
| *Peak Resultant Moment* | | ↑107.75% | ↑96.68% | ↓22.08% |
| *RPE* | | ↓4% | ↓7% | ↓22% |

*4.2.4 Turn Away*

The left shoulder increased an average of 4% for cumulative normalized muscle activity, while the low back decreased 4% and the right shoulder 15% (Table 19). Other measures of EMG had the left shoulder with the smallest decreases, and the low back and right shoulder with at least 30% decreases. The low back had a 44% decrease for peak resultant moment, more than doubling the left and the right shoulder (which had similar changes between them). The left shoulder decreased by 30% for RPE, where the right shoulder decreased 35% and the low back closer to 40%.

**Table 19.** Percent change analysis when averaging across muscles for Turn Away.

| Turn Away | | % Change Pre Training to Post Training | | |
|---|---|---|---|---|
| **Measure** | | *Right Shoulder* | *Left Shoulder* | *Low Back* |
| *EMG* | Mean | ↓40% | ↓25% | ↓31% |
| | Peak | ↓32% | ↓13% | ↓37% |
| | Cumulative | ↓15% | ↑4% | ↓4% |
| *Peak Resultant Moment* | | ↓14.38% | ↓11.14% | ↓44.52% |
| *RPE* | | ↓35% | ↓30% | ↓40% |

*4.2.5 Turn Toward*

While the low back experienced the largest decreases for RPE and peak resultant moment (33% and 23% respectively), it increased nearly 30% in cumulative EMG measures, experienced no change for peak measures, and decreased only 3% for mean, compared to 6% at the right shoulder and 13% at the left (Table 20). Both the left and right shoulder increased for cumulative EMG measures (17% and 28% respectively), while the right shoulder also increased for peak measures (12%). The left shoulder decreased 13% in RPE, half of the decrease seen at the right shoulder in the same measure.

**Table 20.** Percent change analysis when averaging across muscles for Turn Toward.

| Turn Toward | | % Change Pre Training to Post Training | | |
|---|---|---|---|---|
| **Measure** | | *Right Shoulder* | *Left Shoulder* | *Low Back* |
| *EMG* | Mean | ↓6% | ↓13% | ↓3% |
| | Peak | ↑12% | ↓3% | ↓1% |
| | Cumulative | ↑28% | ↑17% | ↑30% |
| *Peak Resultant Moment* | | ↓7.09% | ↓18.53% | ↓23.13% |
| *RPE* | | ↓25% | ↓13% | ↓33% |

4.3 Mean Population Strength Requirement Changes

Changes in mean population strength demand on the shoulder joints and low back varied across tasks, while the type of self-selected technique influenced the effect that performance of the recommended technique had on each joint (Table 21).

*Lie-to-Sit*

Using an untrained push (A) technique required nearly two times the mean population strength at the left (171%) and right (215%) shoulder, as well as the low back (199%). When performing the recommended technique, a decrease of approximately 35% occurred at each joint. Those who employed an untrained pull (B) technique experienced increases in required mean population strength at the right shoulder (100%) and the low back (12%), but a decrease at the left shoulder of 38% mean population strength.

*Reposition*

The recommended technique for this task required an increase in mean population strength regardless of untrained task (push or pull) selected. While those who chose Untrained A (push) needed 150% mean population strength at the left and right shoulder, the recommended technique increased the required strength by 12% at the right shoulder and no change at the left. The low back required an increase of 4% to 182% mean population strength. Untrained B (pull) users also needed more than 140% mean population strength at all three joints, and only the left shoulder decreased when using the recommended techniques (13%).

*Sit-to-Chair*

Small increases in required mean population strength occurred at the low back when using the recommended technique for both of the untrained selections (5% and 11% for high bed position and low bed position respectively). The recommended technique for this task required nearly 100% mean population strength at the right shoulder and 90% at the left shoulder, an increase of nearly 90% from Untrained high bed position (A) and 50% (at the right shoulder) for Untrained low bed position (B).

*Turn Away*

Decreases in required mean population strength occurred at each joint when using the recommended technique. The low back experienced the largest decrease (from 68% mean population strength to 32%), while smaller decrease were seen at the right and left shoulder (15% and 38%).

*Turn Toward*

A large decrease occurred at the low back (from 73% mean population strength to 35%) following implementation of recommended technique, while increases of 35% occurred at the right shoulder (to nearly 95% mean population strength) and 19% at the left shoulder (to 102% mean population strength).

**Table 21.** Comparisons of mean population strength fraction required for self selected MPH techniques versus recommended MPH techniques. A refers to a pull exertion, while B refers to a push exertion for Lie-to-Sit and Reposition. A is a high bed position while B is low bed position in Sit-to-Chair.

| TASK | Condition | Right Shoulder | Left Shoulder | Low Back |
|---|---|---|---|---|
| **Lie-to-Sit** | Untrained A | 2.15 | 1.71 | 1.99 |
| | Untrained B | 0.68 | 1.60 | 1.18 |
| | Trained | 1.36 | 0.99 | 1.32 |
| | % Change (A) | ↓36% | ↓42% | ↓33% |
| | % Change (B) | ↑101% | ↓38% | ↑12% |
| **Reposition** | Untrained A | 1.51 | 1.57 | 1.75 |
| | Untrained B | 1.40 | 1.79 | 1.49 |
| | Trained | 1.69 | 1.57 | 1.82 |
| | % Change (A) | ↑12% | 0% | ↑ 4% |
| | % Change (B) | ↑20% | ↓13% | ↑3% |
| **Sit-to-Chair** | Untrained A | 0.58 | 0.45 | 0.53 |
| | Untrained B | 0.70 | 0.89 | 0.50 |
| | Trained | 1.09 | 0.88 | 0.56 |
| | % Change (A) | ↑89% | ↑94% | ↑5% |
| | % Change (B) | ↑56% | ↓1% | ↑11% |
| **Turn Away** | Untrained | 1.19 | 1.40 | 0.68 |
| | Trained | 1.01 | 0.88 | 0.32 |
| | % Change | ↓15% | ↓38% | ↓53% |
| **Turn Toward** | Untrained | 0.70 | 0.85 | 0.73 |
| | Trained | 0.94 | 1.02 | 0.35 |
| | % Change | ↑35% | ↑19% | ↓52% |

# V. Discussion

Manual patient handling technique recommendations, in general, decreased both the general (joint level: moments, RPE) and specific (individual muscle activities) demands of five different manual patient handling (MPH) tasks. However, important exceptions existed. The study hypotheses were generally supported by the results of the current study:

(1) Ratings of perceived exertion significantly decreased for all three joints for a majority of the tasks, while no change occurred for Sit-to-Chair when using recommended techniques.

(2) Peak external joint moment magnitudes were reduced for the low back for each task, and some reductions were seen for the right and left shoulder.

(3) Normalized mean, peak and cumulative muscle activity were reduced at both the shoulders and the low back for a majority of the tasks when MPH tasks were performed using recommended techniques.

(4) A transfer of proportional joint strength demands from the low back to the shoulders occurred for some tasks after recommended techniques aimed at limiting exposures to the low back were implemented.

## 5.1 Influence of Task on Physical Demands during Patient Handling

Nurses perform a variety of tasks throughout the day, including different types of MPH transfers. The tasks investigated in this study are primary methods used to transfer and move patients, and are often performed manually (Evanoff et al., 2003, Owen et al., 2003). Previous studies have recognized that tasks require differential effort from a patient handler (Gagnon & Smyth, 1987; Garg & Owen, 1992b; Daynard et al., 2001; Skotte et al., 2002; Schibye et al., 2003; Skotte & Fallentin, 2008), and the current study results are consistent with this. The Lie-to-Sit task generally produced the largest mean, peak and cumulative normalized muscle activity. Peak muscle activity for the left biceps brachii and left triceps brachii exceeded 80% normalized muscle activity, while the same muscles surpassed 15% mean normalized muscle activity. Not surprisingly, the left shoulder for this task averaged an RPE of 3, greater than the right shoulder and low back. The Lie-to-Sit task overall had the highest reported RPE at all three joints. In general, however, RPE reported for each task was low, ranging from 1 to 5 on the Borg CR10 scale (depending on task and technique performed). These findings are consistent with Skotte et al. (2002), which found that while variance between the health care workers was high, individual participants perceived noticeable physical exertion. Peak resultant moments were quite similar between tasks for both shoulders, while Turn Toward resulted in the smallest low back peak moment. Turn Toward produced the lowest muscle activity amongst the tasks, however mean muscle activity consistently exceeded 5% and peak muscle activity was near 40% normalized muscle activity in low back muscles. Cumulative muscle activity results were similar, in that Lie-to-Sit was consistently the highest recorded, followed closely by Sit-to-Chair. Both of these tasks were rated among the most stressful MPH lifts by Santaguida et al. in 2005. Turn Away and Turn Toward were the smallest cumulative measured exposures of the tasks. It is fortunate that these two tasks produced the smallest magnitudes for EMG measures, as they are performed most often by nurses who use mechanical assists for patient transfers and need to apply the sling to the patient (Santaguida et al., 2005). The difference in risk between MPH tasks should encourage patient handlers to consider safer methods of patient transfer depending on the type of MPH task required to maneuver a patient.

5.2 Influence of Training on Physical Demands during Patient Handling

Manual patient handling training (in addition to the newer mechanical lift assist training) is pervasive in hospital-based ergonomic interventions, and has demonstrated at least transient benefits. The recommended techniques for each type of patient transfer may be practiced in short or long-term training sessions. When included with other types of interventions, hospitals typically see a decrease in the number of injuries compared to the levels existing prior to the intervention (Garg & Owen, 1992a; Daynard et al., 2001; Owen et al., 2002; Evanoff et al., 2003). Examples of these interventions and their effectiveness were reported by Garg & Owen, (1992b), who provided a hospital unit with hoists, walking belts to aid in a bed to wheelchair transfer and training sessions (two that lasted two hours) that took place on the hospital floor. Post intervention, back injury rate had reduced from 83/200,000 work hours to 47 injuries, while perceived stresses also decreased significantly. Evanoff et al. (2003) also implemented floor lifts and two hours of instructional hands on courses, reporting a 13.5% decrease in musculoskeletal injuries. Another type of training hospitals may typically give their staff was presented by Hodder et al. (2010b) who employed a well known back injury prevention program to novice lifters that consisted of three sessions on two consecutive days. The novice participants viewed a three minute video and performed three repetitions of three tasks in random order on the first day, and received two hours of standardized training on the second day. This training resulted in improved muscle activity and back posture during a repositioning task for the novice lifters, while the kinematics of older nurses were also positively affected.

While some studies have come to the conclusions that training and education alone are not sufficient for a decrease in musculoskeletal symptoms (Daltroy et al., 2007; Bos et al., 2006), it is evident that using the recommended techniques and training program in this study directly (and positively) affects the musculoskeletal demands on the shoulder joints and the low back. The results of the current investigation support previous findings of decreased lower back exposures when applying recommended manual handling techniques (Skotte et al., 2002; Schibye et al., 2003; Skotte & Fallentin, 2008). In general, the training resulted in reduced exposures for both shoulders and the low back across most measures. Across tasks, the low back exposures decreased as expected in terms of peak resultant moment and RPE after the training session. For the Lie-to-Sit task, the low back exposures decreased by 40% for peak resultant moment and RPE, and nearly 20% for mean and peak normalized muscle activity averaged across muscles. Conversely, the Turn Toward task had similar decreases for peak resultant moment and RPE, but only a 3% decrease and no change occurred for mean and peak normalized activity averaged across muscles, respectively. Some exceptions occurred for cumulative normalized activity for both Turn Toward and Sit-to-Chair, where there was a 30% increase at the low back and a 6% increase averaged across low back muscles. While Schibye et al. (2003) did not measure changes in normalized muscle activity, resultant torques at the low back were measured and are consistent with the decreases (50-100Nm depending on task) found for Sit-to-Chair, Reposition, Lie-to-Sit and Turn Away in this study.

Unlike the low back, previously unavailable shoulder exposure data collected in this study revealed a less consistent training effect, which was mostly stratified by task. Although RPE decreased for both the left and right shoulders following training within nearly every task (the exception being Sit-to-Chair, where there was no significant change and Lie-to-Sit and Turn Toward at the left shoulder), the decrease in shoulder RPE was a smaller percentage than the low back. The left shoulder, in particular, had the smallest decreases for each task. These muscles were also typically least affected by the MPH techniques for normalized muscle activity. Right shoulder decreases, when averaged across the muscles, were typically in the 20-30% range, while the left were approximately half that amount. In many cases, this may be due to the right shoulder experiencing higher initial loading in the self-selected techniques, and the shoulders have more equal distribution in the recommended techniques. However, there were some substantial increases in muscle activity at the left shoulder that were absent at the right shoulder. Calculated peak resultant moments at the right shoulder experienced increases for two of the five tasks (and no change for one), with significant changes for Sit-to-Chair, which increased over 100% (followed closely by 97% at the left shoulder). The increases seen at the shoulders, combined with a decrease at the back suggest a joint-level transfer of demand when performing the recommended technique for this task. This task has previously been identified as high risk, and is frequently targeted for replacement with mechanical lift assists (Santaguida et al., 2005). The recommended technique for Turn Toward as a task was the most variable among all measures. Cumulative total muscle activity increased at all three joints, with the back increasing more than both shoulders. The low back also experienced no change for peak muscle activity, and only 3% decrease for mean. The shoulders experienced a small decrease (no larger than 10% when averaging across the muscles), while the right shoulder increased in peak muscle activity by 12%. Right shoulder moment also experienced a non-significant change. Schibye et al. (2003) also found no significant decrease when comparing self selected techniques to recommended MPH techniques in mean values of low back peak torque for both of these tasks, while Zhuang et al. (1999) reported that combining the turn away and turn toward transfer techniques with a mechanical lift reduced low back compression by approximately 20% compared to a baseline transfer measure that was similar to a Sit-to-Chair type task. Even so, the rolling away and toward portion of a transfer was identified as the most stressful, resulting in an L5/S1 compressive force magnitude of nearly 2500N for each task. Recommended techniques are, therefore, generally effective at reducing metrics of overall exposure at both the shoulders and low back.

## 5.3 Potential Injury Mechanisms

Multiple factors influence the precipitation of an occupational related musculoskeletal injury. While psychosocial and environmental factors can play a role in the causation of an injury, biomechanical factors play a large part in increasing the risk (Kumar, 2001). A large impact force or overexertion may contribute to an acute type injury, while exposure to smaller forces over a period of time that progressively break down the tissue at a joint present higher risk of a cumulative injury (Kumar, 2001; Waters et al., 2006). Measuring these exposures at joints to assess the risk need to be as specific as possible, where one moment produced at the shoulder, for example, could be the result of any possible combination of shoulder muscle activity (Kronbeg, 1990; Hughes et al., 1995). Both of these mechanisms play an important part in determining whether or not there is risk for injury. Analyzing the changes in normalized muscle activity at each muscle in this investigation aided in understanding tissue level exposures during recommended patient handling techniques. Combining this knowledge with the peak magnitudes achieved during the task provides important insight into the acute risks of transferring a patient, while cumulative magnitudes reveal potentially problematic exposures that are likely incurred over time by performing these types of tasks many times throughout a shift and nursing career.

### *5.3.1 Tissue Level Exposures*

Although joint moments, overall muscle activity and reported perceived exertion provide insight into gross exposures at the joint level, tissue level exposures are often linked more directly to potential injury mechanisms (Herberts et al., 1984). Typically, multiple muscles differentially but simultaneously contribute to joint movement and stabilization, and an increased knowledge regarding these muscles can be beneficial towards improving ergonomic analysis tools. RPE, for example, can give researchers and ergonomists insight into potential over-loading at a joint or point of the body, but evidence (Dickerson et al., 2007b) suggests that perception of shoulder physical demands is integrative, making the attribution of its magnitude to constituents difficult. Looking at each task separately, joint level analyses identified overall decreases in total muscle activity, peak resultant moment and RPE at each joint, however investigating each individual muscle revealed a wider spectrum of specific changes in demand, which included notable increases for some muscles. Cases existed where the low back muscular activity did not decrease, although these tasks are designed to reduce loads and injury risk at that joint. Significant increases to the left and right thoracic and lumbar erector spinae existed primarily for cumulative normalized muscle activity during Sit-to-Chair. The right thoracic and lumbar erector spinae also experienced no change in peak normalized muscle activity for both Sit-to-Chair, Turn Toward and Lie-to-Sit. Non-significant changes occurred for both the left thoracic and lumbar erector spinae for peak normalized muscle activity during Turn Toward.

The change in shoulder muscle activity following training varied across tasks and muscles. The left middle deltoid only experienced a significant decrease for mean normalized muscle activity during Turn Away, while in every other task it experienced a significant increase or a non-significant change in all three EMG measures. For the Sit-to-Chair task, it increased for all three mean, peak and cumulative measures, while during Turn Toward it had non-significant changes for mean and peak, along with an increase in cumulative. When analyzing important changes in peak muscle activity, both the left infraspinatus and middle trapezius experienced no change (or an increase in muscle activity) for all five tasks. Muscles most affected on the right side of the body were the right triceps brachii (significant increase in all three measures for Sit-to-Chair) and right pectoralis major (significant increase for peak and cumulative measures (and no change in mean) in Turn Toward). Again, Turn Toward had the most variable response by the shoulder muscles, with many experiencing no significant change during the recommended technique. The analysis of these muscles that act on the low back and both shoulders reveals the different levels of exposures experienced by specific muscles during these tasks, and that each muscle is affected quite differently at each joint by the recommended positions.

### *5.3.2 Assessment of Potential Cumulative and Acute Risks Associated with MPH*

The types of musculoskeletal exposures a nurse may encounter throughout the day include acute and cumulative loading, making prediction of injury causality difficult. While only a small fraction (1.4% to 2.5%) of a typical 8 hour shift is spent transferring and lifting patients (Hodder et al., 2010a), the weight being manipulated may be substantial, depending on the patient. For this reason, analyzing peak normalized muscle activity gives valuable insight into the exposure experienced at the shoulders during MPH transfers. In recent years, the relationship between cumulative loading and low back pain has also emerged as a major issue among researchers and ergonomists alike, and recent meta-analyses have reported that workers with low back pain were more likely to have been exposed to cumulative spinal loading than those without back pain (Waters et al., 2005). Other types of tasks that make up a nurse's day, in addition to the transfer tasks, may also increase cumulative loading (Holmes et al., 2010).

Cumulative muscle activity increased for many muscles when using the recommended patient handling techniques versus the self-selected techniques, which support previous findings that recommended patient handling techniques may add to the time it takes to perform a task

(Garg & Owen, 1992a; Yassi, 2005), particularly in the context of generally lower muscular demands with the recommended techniques. Both the left and right thoracic and lumbar erector spinae muscles increased in cumulative normalized muscle activity for Turn Toward and Sit-to-Chair, while there was no change for Lie-to-Sit right erector spinae. The recommended techniques had the desired effect on these low back muscles for the other tasks. For muscles of the shoulder, all five tasks produced variable responses to the recommended techniques, with many muscles increasing in cumulative normalized muscle activity, and many experiencing no change. Turn Toward recommended techniques produced significant increases in nearly every muscle for the right side of the body, while muscles at the left shoulder experienced no change, and Sit-to-Chair produced increases in the left triceps brachii, infraspinatus and middle deltoid. While most of the other muscles for this task experienced no change because of the training, only left biceps brachii, left pectoralis major, right biceps brachii and right pectoralis major significantly decreased in cumulative normalized muscle activity.

The magnitude of a force exerted by a worker is a known cause of low back injury (Bernard, 1997; Keyserling, 2000), and high peak normalized muscle activity at this joint was found in this investigation. Lie-to-Sit, with the highest reported values out of all the tasks, reported nearly 80% normalized muscle activity for both the right thoracic erector spinae and right lumbar erector spinae, along with the left biceps brachii and left pectoralis major, even while decreasing from self-selected magnitudes. Reposition and Sit-to-Chair had similarly high reported magnitudes for peak muscle activity. Turn Toward and Turn Away had lower magnitudes on average for each muscle, however magnitudes of 40 to 60% of peak normalized muscle activity recorded. While mechanical lift assists have been put in place to replace the need to perform the more stressful tasks, there is no guarantee they will be used (Garg & Owen, 1992b; Evanoff et al., 2003; Engst et al., 2005), meaning the tasks evoking the highest normalized muscle magnitudes in this investigation may still be performed on a regular basis. The risk for an acute injury due to these exposures, then, is still possible whenever a nurse elects to perform a manual patient transfer, even if she uses a recommended technique. Another concern may be in performing Turn Away and Turn Toward more often throughout the course of a day for sling application and mechanical lift assist use. Not only did Turn Toward increase many muscles in peak normalized muscle activity, but for the right biceps brachii, right pectoralis major, left middle deltoid and left lumbar erector spinae, there were also increases (or no change) for cumulative and mean measures. The increase in exposure for all three measures for this task may create both short and long term risks.

### 5.4 Transfer of Joint Demands

Calculated peak resultant moment and individual muscle analysis in this study suggest possible transfers in exposure from the low back to the shoulders following training on recommended techniques for MPH tasks. For many tasks, the recommended techniques for transferring a patient lowered the peak resultant moment or peak normalized muscle activity at the back as expected; however, simultaneous increases at the left and right shoulder occurred. To evaluate these changes using a common scale, the postures assumed by the participants during peak force exertion were replicated within a static strength analysis program (3DSSPP) to interpret the moments created by the techniques with respect to population strength. This type of evaluation provides meaningful insight into the effectiveness of the recommended tasks as well as providing an estimation of how capable the study population (based on participant anthropometrics) is at performing the recommended techniques (Chaffin, 1997). For several tasks, the required strength at each joint was well over mean population strength for the recommended techniques, which puts a worker at an increased risk for injury (Chaffin et al., 1978; Keyserling et al., 1980). In many cases, the mean population strength at the low back increased when using a recommended technique, but not as markedly as the increases at the right and left shoulders. For example, while performing the recommended technique for Sit-to-Chair, the mean population strength at the low back increased from 53% to 56%, while the shoulders increased from around 50% mean population strength to nearly 100%. The Turn Away recommended technique greatly reduced the mean population strength required at the low back (68% to 32%) but decreases at the right and left shoulder were smaller (119% to 100% at the right and 140% to 88% at the left). The type of self-selected technique further influenced the nature of specific joint demand changes. In the case of Lie-to-Sit, a patient handler employing a push technique was worse off using the newer, recommended technique while a patient handler using a pull technique benefitted from the recommended technique (although in all cases, over 100% mean population strength was required).

A clear case of joint demand transfer existed during the Turn Toward task. The untrained technique balanced the exposure nearly equally amongst all three joints (around 75% mean population strength), but with the recommended technique, the mean population strength demand for the low back decreased to 35%, while the left and right shoulder increased to nearly 100% mean population strength. These scaled strength requirement changes at each joint complement the previously discussed exposure changes in normalized muscle activity and peak resultant moment, clearly establishing both the overall high demand of these MPH tasks, as well as the potential for transfer of demands between joints for certain MPH tasks.

5.5 Importance of Training Novice Nurses

The use of participants who were unfamiliar with manual patient handling produced information on a maximal training effect, as well as a new worker effect. While a short term training session outlining proper patient handling skills lowered several measures of physical exposures to both shoulders and the low back in the current study for a novice population, there is no guarantee that nurses who undergo similar training will continue to scrupulously use the recommended techniques (Evanoff et al., 2003). Several studies have reported that while new nurses receive training throughout their undergraduate careers as well as on the job training, when they are placed in a new job situation with experienced lifters, they will tend to mimic the lifting techniques performed by the more experienced persons (Kneafsey, 2007;, Kneafsey & Haigh, 2007; Cornish & Jones, 2007; Cornish & Jones, 2010). Explanations for this vary, but lean towards the new nurse wanting to assimilate and avoid confrontations. This is problematic, as new nurses continue to use the potentially injurious techniques and eventually promote these methods with subsequent nursing generations (Kneafsey, 2007; Kneafsey & Haigh, 2007; Cornish & Jones, 2007; Cornish & Jones, 2010).

However, certain recommended techniques, even if performed correctly, do not preclude the possibility of injury. After studying the differences between novice and experienced patient handlers, Keir and MacDonell (2004) and more recently Hodder et al. (2010b) reported that the shoulder activity (deltoid and trapezius) was higher during a reposition task and moving from a bed to a wheelchair task than the low back in experienced nurses. Both authors suggested that a learned behavior to protect the spine may have been developed by the experienced nurses. Again, applying the current results with this information, if nurses continue to learn the recommended techniques but in practice use slightly altered techniques, the risk to the shoulder may be even higher. The training program used by Hodder et al. (2010b) is urged by the author to explore patient handling techniques that have potentially negative effects on the shoulder and consider better options.

5.6 Strengths of Current Investigation

While providing information that the recommended patient handling techniques decrease both mechanical and psychophysical exposure metrics at the low back as well as most shoulder muscles, this study also increased the amount of available data for shoulder muscle demands during manual patient handling techniques. Previous studies sampled one or two muscles of the shoulder (Gagnon & Smyth, 1987, Keir & MacDonell, 2004, Hodder et al., 2010b), whereas this study provides insight into what is happening for six muscles bilaterally while performing MPH tasks (both self-selected and recommended techniques). By analyzing the shoulder, and including many muscles known to affect synergistic shoulder movement, more information regarding possible trade-offs (and muscle activity in general) while performing these low back techniques was gained. Peak resultant moments (derived from a quasi-dynamic biomechanical model) and RPE add to this increase of information regarding shoulder loading.

Use of a motion capture system provided simultaneous capture of kinematic data for the quasi-static biomechanical model. Thirty-five wireless reflective markers on the upper limbs and torso allowed the participant to perform the self selected techniques and recommended techniques uninhibited, while increasing the accuracy of the model. Use of calibrated and estimated hand forces to determine shoulder joint loading contributes and helps to build upon the minimal amount of research regarding estimating hand force magnitudes. Using these same inputs for a joint transfer analysis using 3DSSPP allowed for more meaningful insight regarding population strength capabilities for each of the recommended patient handling techniques.

Previous studies have reported a learning effect that experienced nurses may employ when performing proper manual handling techniques that may negatively affect the muscles of the shoulder (Keir & MacDonell, 2004; Hodder et al., 2010b). Using young participants with no previous experience lifting or moving patients helped simulate how the recommended techniques may affect both the shoulder and the back in a novice working population. Using a female population similar to those employed in nursing in Canada, where 94% of working nurses are female (Canadian Nursing Association, 2009), also mimicked the exposures this group may have encountered while transferring patients using these manual methods. By observing the effect recommended techniques had on those with no previous experience, insight was given into how they may continue to exposure the shoulder to higher magnitudes over the course of performing these types of lifts daily.

Using a patient with a weight of 92kg (75$^{th}$ percentile male) rather than a lighter patient (Gagnon & Smyth, 1987; Garg & Owen, 1991a; Marras et al., 1999; Silvia et al., 2002) represents the type of patient that would be admitted onto a hospital floor in Canada today. Obesity rates are high in this country, as well as the United States, with the measured rate of obesity in 2005 near 25% (Obesity in Canada Snapshot, 2009) and over 1100 bariatric surgeries were performed in 2003 (Padwal, 2005). Hospitals may not be equipped with proper bariatric lifts and nurses must move the heavy patients in teams or groups. Weight of the patient also plays an important role on the magnitude of forces at the low back, where a larger patient may cause increased and more harmful exposures to a nurse performing the transfer (Zhuang et al., 1999). Finally, consultation with currently practicing nurses who have been trained with low back programmes yearly (10-15 years minimum) helped to verify the accuracy of the techniques being used in this study.

## 5.7 Limitations of Current Investigation

Studying patient handling is extremely challenging due to the complex interaction between nurse and patient in a variety of situations. Many previous studies have focused on implications these types of MPH transfers have on the low back, where the current study was more interested in possible effects on the shoulder. Previous studies have also been challenged by the fact there is no benchmark for accurately recording separate right and left hand forces (Radwin et al., 1991; Bao & Silverstein, 2005; Yassi, 2005). The current study did not want to compensate accurate manual patient handling techniques by encumbering the participant with heavy equipment, nor did it want EMG measures to be influenced by manual demands associated with holding hand dynamometers and maneuvering the patient, as hand demands are known to affect shoulder muscle activity (Antony and Keir, 2010; Brookham et al., 2010). While previous similar techniques (Yassi, 2005) reported this method to possibly under-report values for compression at the low back compared to using force plates the investigation did not comment on how it may affect the shoulder peak moment. Using this method limits the analyses possible for calculating joint moments, in that only peak exposures were estimated. Absolute direction of the force applied was also estimated, leaving room for under or overestimation of peak moments occurring at each joint. These limitations are also carried over into the 3DSSPP joint transfer analysis, as estimations of hand forces and direction are inputted for each posture. However, this study was primarily interested in changes related to training and task type, and relative, rather than absolute, magnitudes reported were interpreted more intensively. Current resulting magnitudes, however, were of similar shoulder moment magnitudes for a reposition task performed by Yassi (2005).

The range of recommended manual patient handling techniques was not exhaustive. The tasks chosen represent those that see continued usage despite established preferred mechanical lift assist techniques, and that even with these improvements in mechanical aids, will most likely still be performed. As well, each participant was limited to approaching the left side of the bed for each task, which may have influenced the self-selected techniques. There is a good chance that had the patient and participant been oriented to the other side and end of the bed, the opposite effect would have been seen at the left and right shoulder joints for each measure, but would not affect how one would analyze the situation. Anecdotal evidence from practicing nurses, however, suggests that a nurse typically does not take handedness into account when approaching a bed to transfer or shift a patient, while Keir and MacDonell (2004), found that regardless of side of bed, similar muscle activity levels were produced.

## 5.8 Implications and Future Directions

This study supports a recommendation of continued implementation of these manual handling techniques, however not without certain cautions. Two tasks seem to adversely affect the shoulder the most. Sit-to-Chair and Turn Toward have both previously been identified as stressful nursing tasks (Santaguida et al., 2005; Zhuang et al., 1999). ). The recommended techniques evaluated in this study were aimed specifically at lowering low back injury exposures, but this was not achieved for all tasks. There is also evidence that the tasks may be transferring some of that risk to the shoulder (both left and right). While Sit-to-Chair tasks can potentially be eliminated through the use of overhead and floor lifts that move a person from a bed to a chair, Turn Toward will always be necessary in order to apply a sling that is attached to the mechanical lift. An obvious recommendation, and one previously made by Zhuang et al. (1999) in regards to low back loading only, would be to recommend nurses only Turn Away, which keeps the hands close to the body when they apply a push force, rather than applying that force with the arms outstretched. Compliance, however, may be low. Since using the mechanical lift already adds to the amount of time it takes to complete a transfer, recommending the nurse go out of his or her way to only perform Turn Away may not be adhered to, nor may it be feasible depending on a number of factors (room design, type of bed or patient needs).

Future investigations should focus on patient handling techniques that do not transfer risk to other areas of the body, or at the very least minimize the amount of exposure that is at risk for transfer. Since mechanical lifting assists are becoming more commonplace in a hospital setting (acute and long term), future investigations should also focus on how the shoulders may be affected while using these types of devices. This would be especially important considering the risk of cumulative injury at the shoulder already present while performing manual tasks necessary to use the mechanical aids. In order to more accurately address shoulder loading during patient handling tasks (whether it be manual or mechanical), a 'best practice' model for estimating hand forces should be developed. This would be beneficial for both ergonomic field studies and laboratory research. Finally, considering the influence recommended techniques specifically for MPH for one joint appear to have on other joints, it would be informative to investigate whether techniques for MMH have similar demand reallocation effects.

## VI. Conclusions

The continued use of recommended manual patient handling strategies for nurses is supported by the results of this study, however, there are some exceptions as exposures at both the both shoulders and the low back for both Sit-to-Chair and Turn Toward tasks were higher. Conclusions stemming from the evidence presented by this investigation include:

- Recommended training techniques lowered exposures experienced by novice patient handlers over self-selected techniques.
- This reduction in exposure was more consistent at the low back. For two tasks, both the left and right shoulder experienced some increases in magnitude for both muscle activity (mean, peak and cumulative measures) as well as peak resultant moment.
- The investigation of joint loading versus tissue loading allowed for individual muscles that act on both the shoulders and the low back to be analyzed closely, revealing certain muscles are more affected than others when using the recommended patient handling techniques.
    - The increase of normalized muscle activity for some shoulder muscles combined with the decrease of low back normalized muscle activity during the performance of these tasks indicate that a trade-off of muscle demand may occur during some manual patient handling tasks.
- Training techniques that consider both the shoulder and the low back being taught to beginners and a continuation of learning for experienced nurses is important, as newly trained novice workers experience exposures that may present an injury risk at the shoulder joints.

While the manual Sit-to-Chair technique may be substituted with mechanical lifting devices where they are available, Turn Toward will most likely see continued use as it is a necessary prerequisite to applying a sling to the patient that attaches to the mechanical lift. Future training programs should include the recommendation to perform Turn Away technique in lieu of Turn Toward when the situation allows, while patient handling techniques should be modified in order to avoid increasing the risk of exposure at the shoulder that is seen in current recommended techniques.

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**Appendix A:** By Task Model considering Pre-Post as an Independent Factor

Figures in this appendix represent the changes for each task in the trained state for total muscle normalized activity at the right shoulder, left shoulder and low back. Significant decreases were found for the majority of tasks for each joint, however exceptions occurred, specifically at the left shoulder.

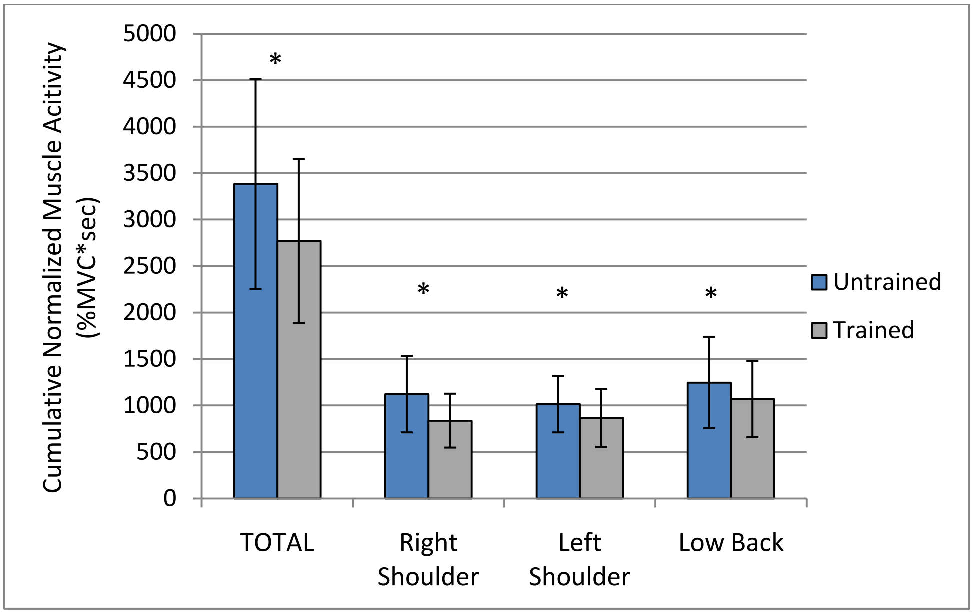



**Figure A1**. Joint specific total cumulative muscle activity for Lie-to-Sit when considering training state as an independent task.

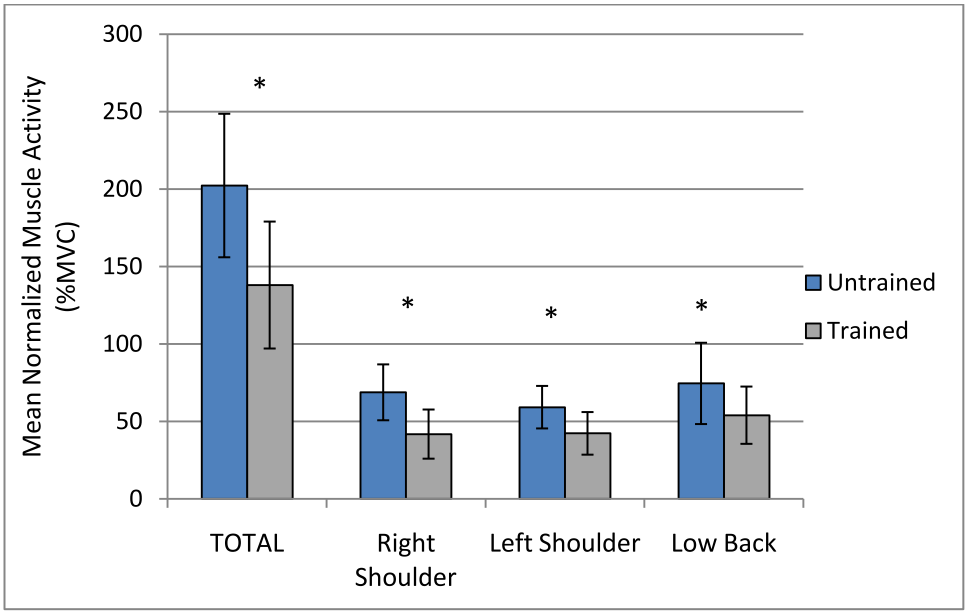



**Figure A2**. Joint specific total mean muscle activity for Reposition when considering training state as an independent task.

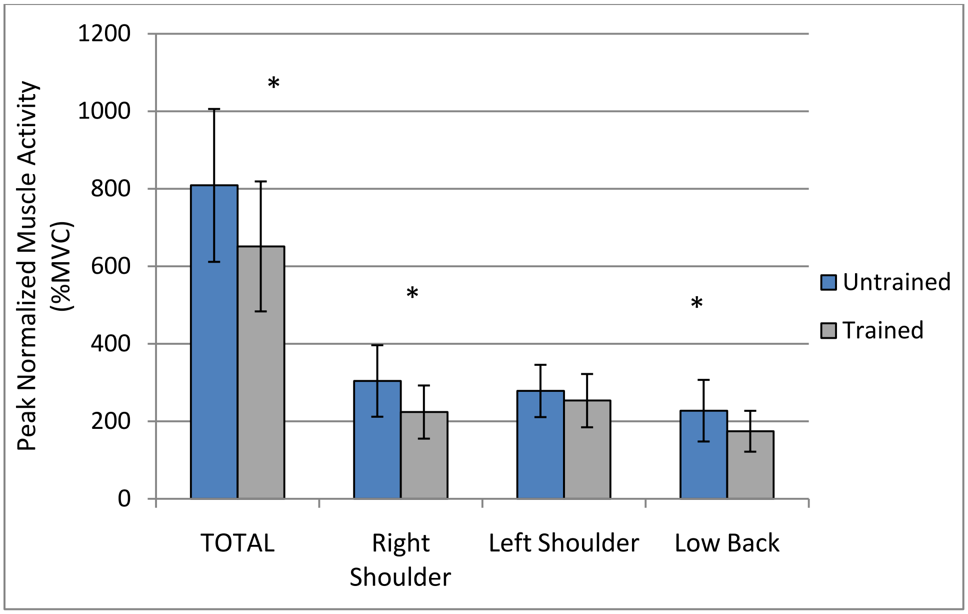



**Figure A3**. Joint specific total peak muscle activity for Reposition when considering training state as an independent task.

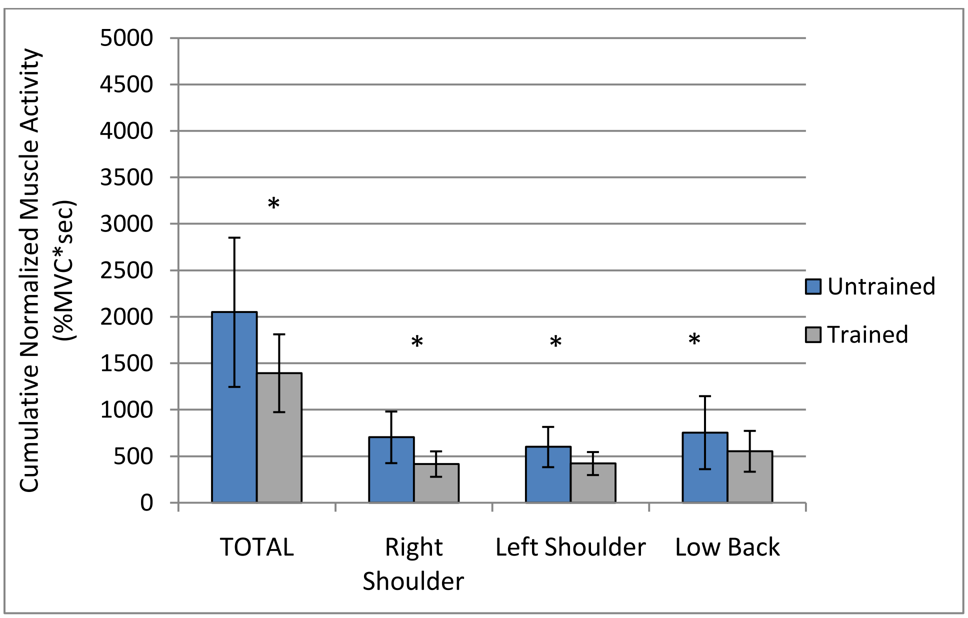



**Figure A4**. Joint specific total cumulative muscle activity for Reposition when considering training state as an independent task.

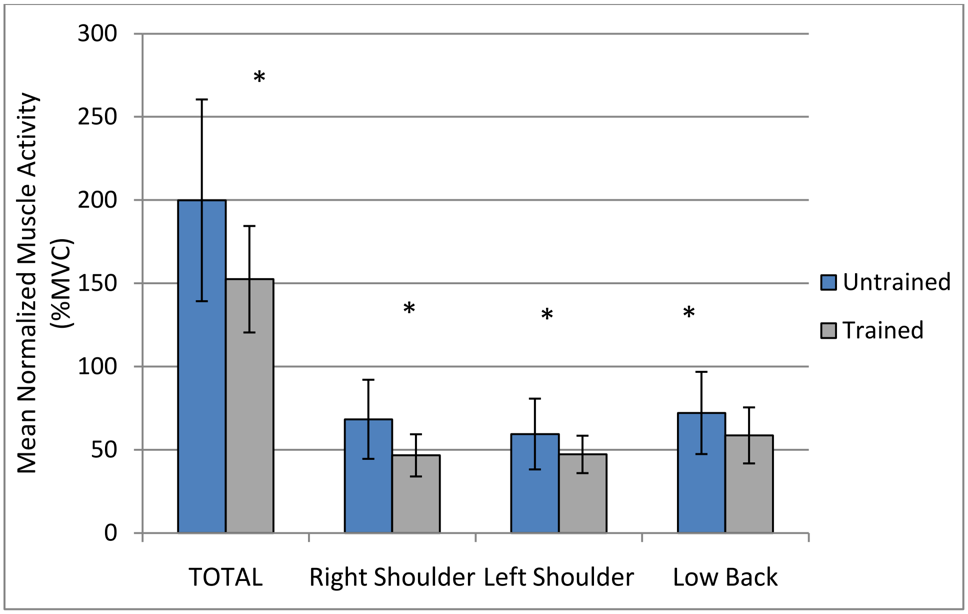



**Figure A5**. Joint specific total mean muscle activity for Sit-to-Chair when considering training state as an independent task.

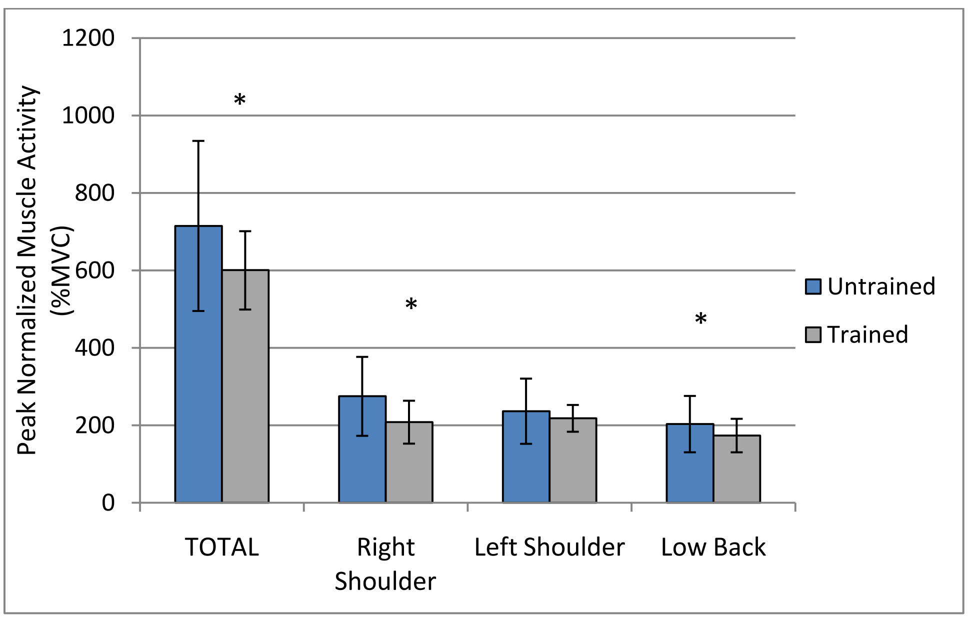



**Figure A6**. Joint specific total mean muscle activity for Sit-to-Chair when considering training state as an independent task.

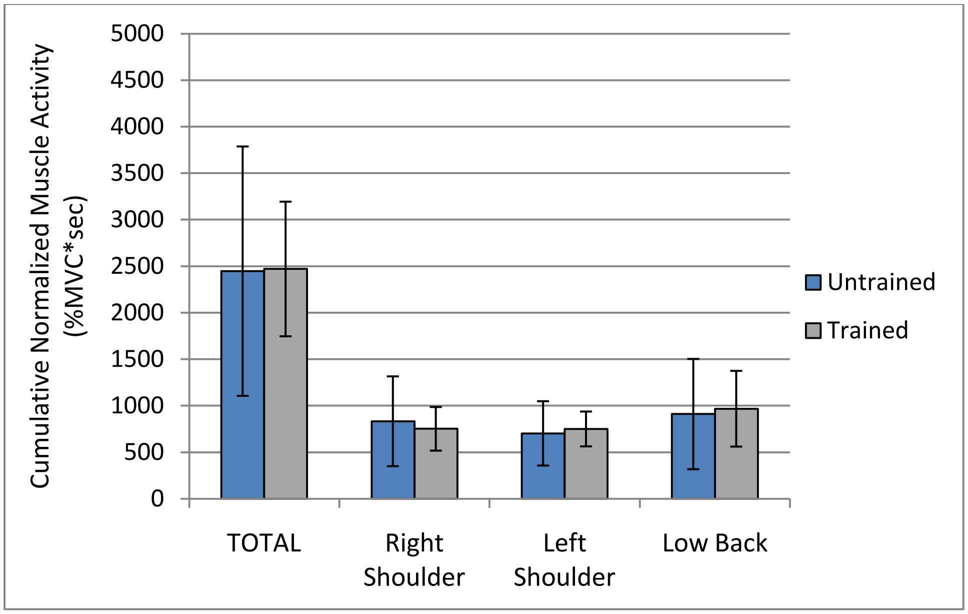



**Figure A7.** Joint specific total cumulative muscle activity for Sit-to-Chair when considering training state as an independent task.

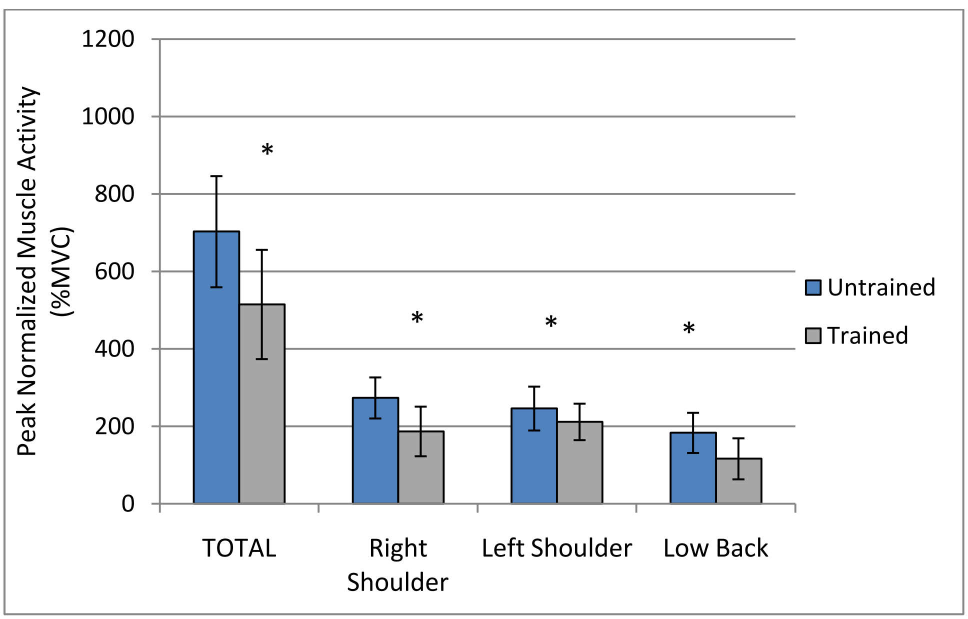



**Figure A8**. Joint specific total mean muscle activity for Turn Away when considering training state as an independent task

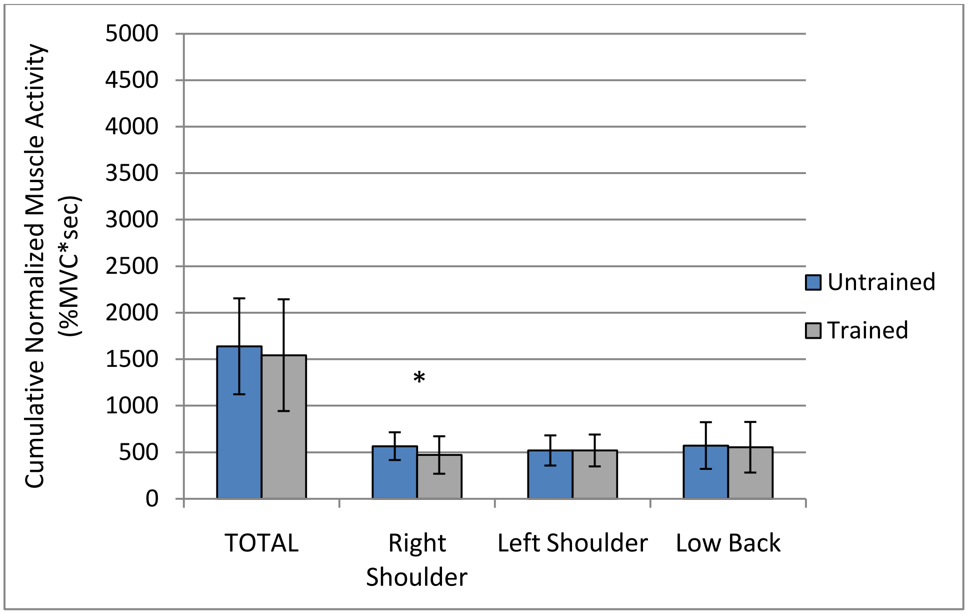



**Figure A9**. Joint specific total peak muscle activity for Turn Away when considering training state as an independent task

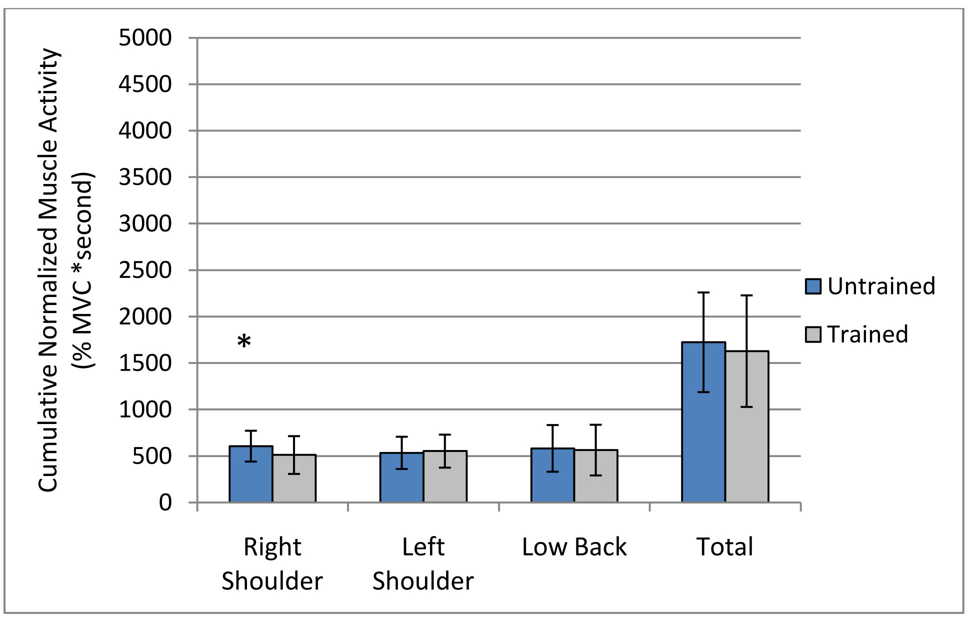



**Figure A10**. Joint specific total cumulative muscle activity for Turn Away when considering training state as an independent task.

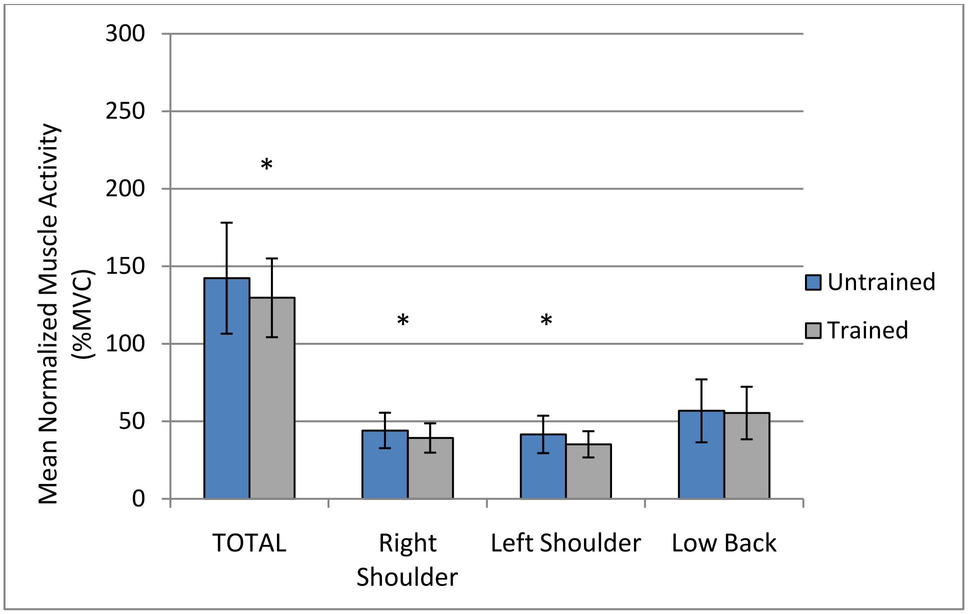



**Figure A11**. Joint specific total mean muscle activity for Turn Toward when considering training state as an independent task.

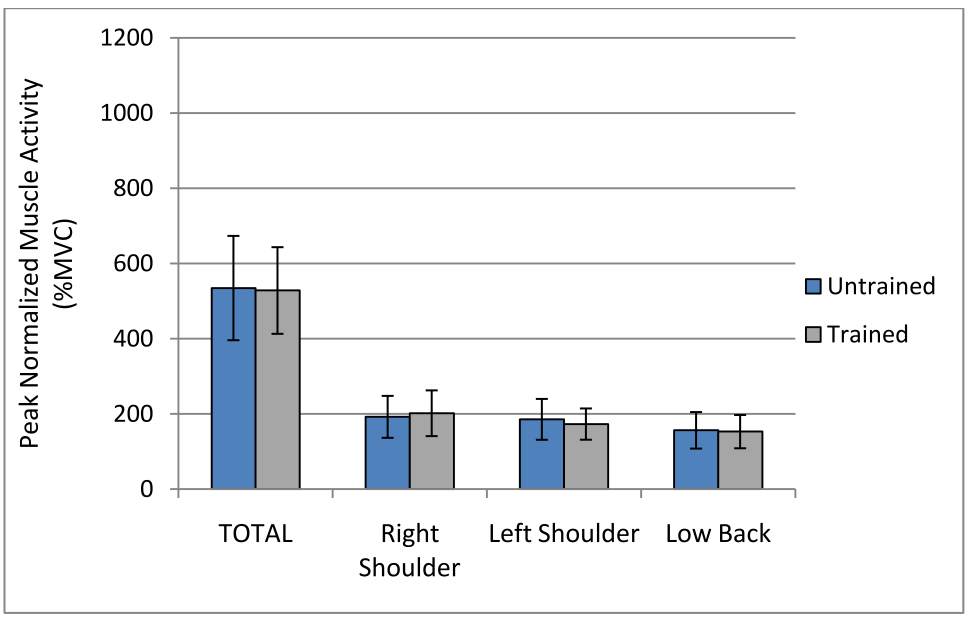



**Figure A12**. Joint specific total peak muscle activity for Turn Toward when considering training state as an independent task.

## **Appendix B:** Training Program Presentation Slides

Presented here is the training presentation shown to the participants during the training session. Written instructions are provided alongside pictures describing the movement. Key points to remember are given for each task, and video was also made available to view after the written instructions were completed.

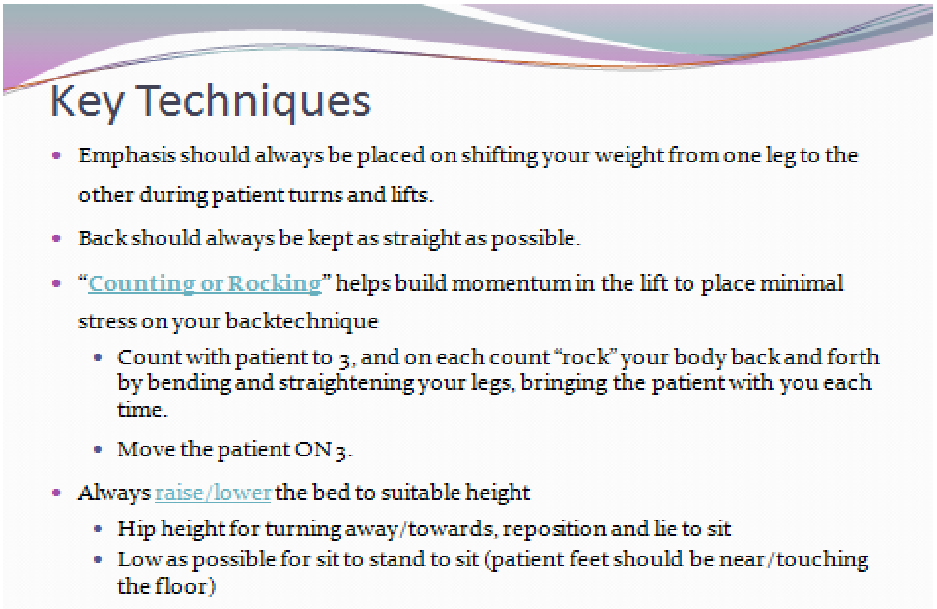



**Figure B1.** Slide from training presentation giving technique points for all tasks.

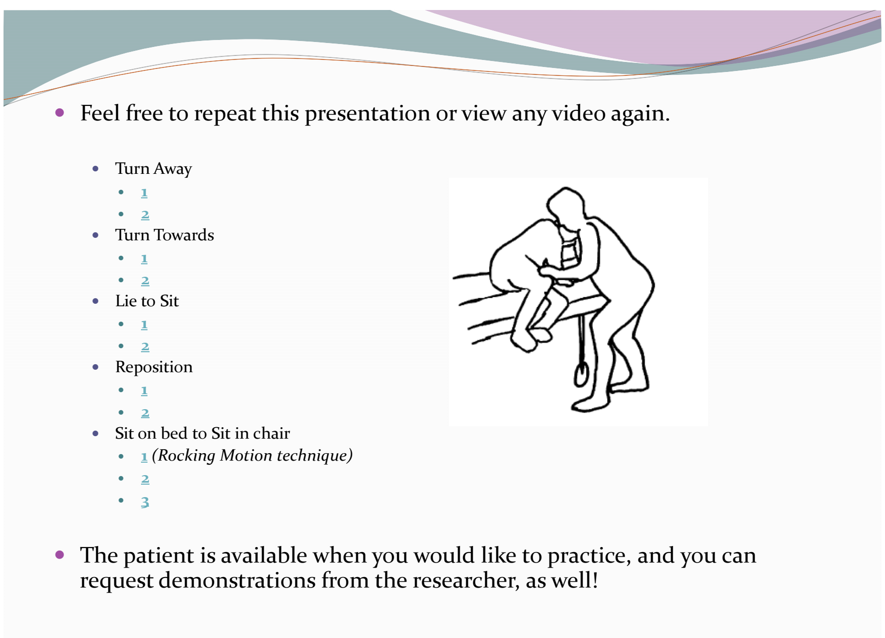



**Figure B2**. End slide with links to videos for each technique.

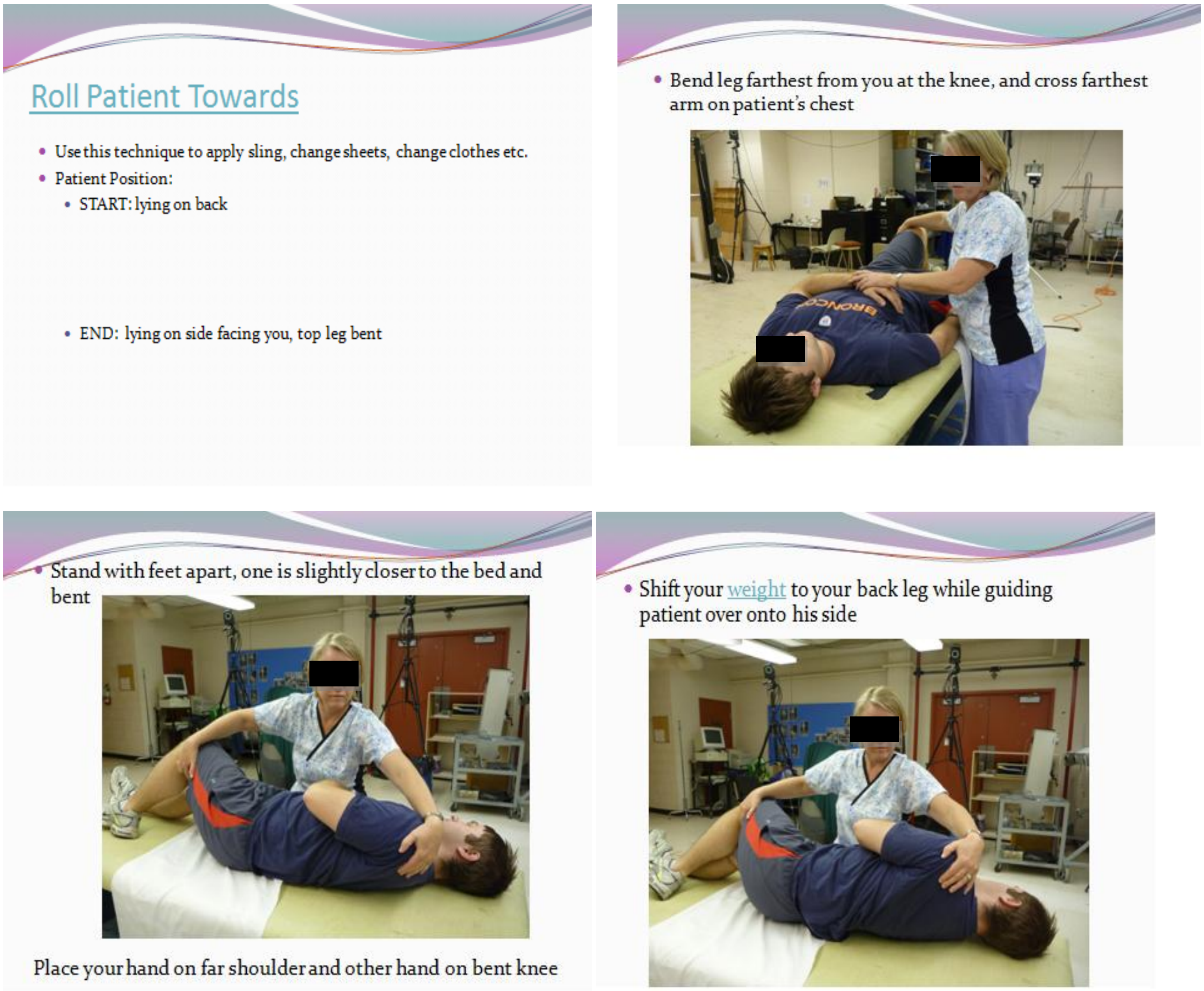



**Figure B2**. Instructional slides for Turn Toward task.


**Figure B4**. Instructional slides for Turn Away technique.

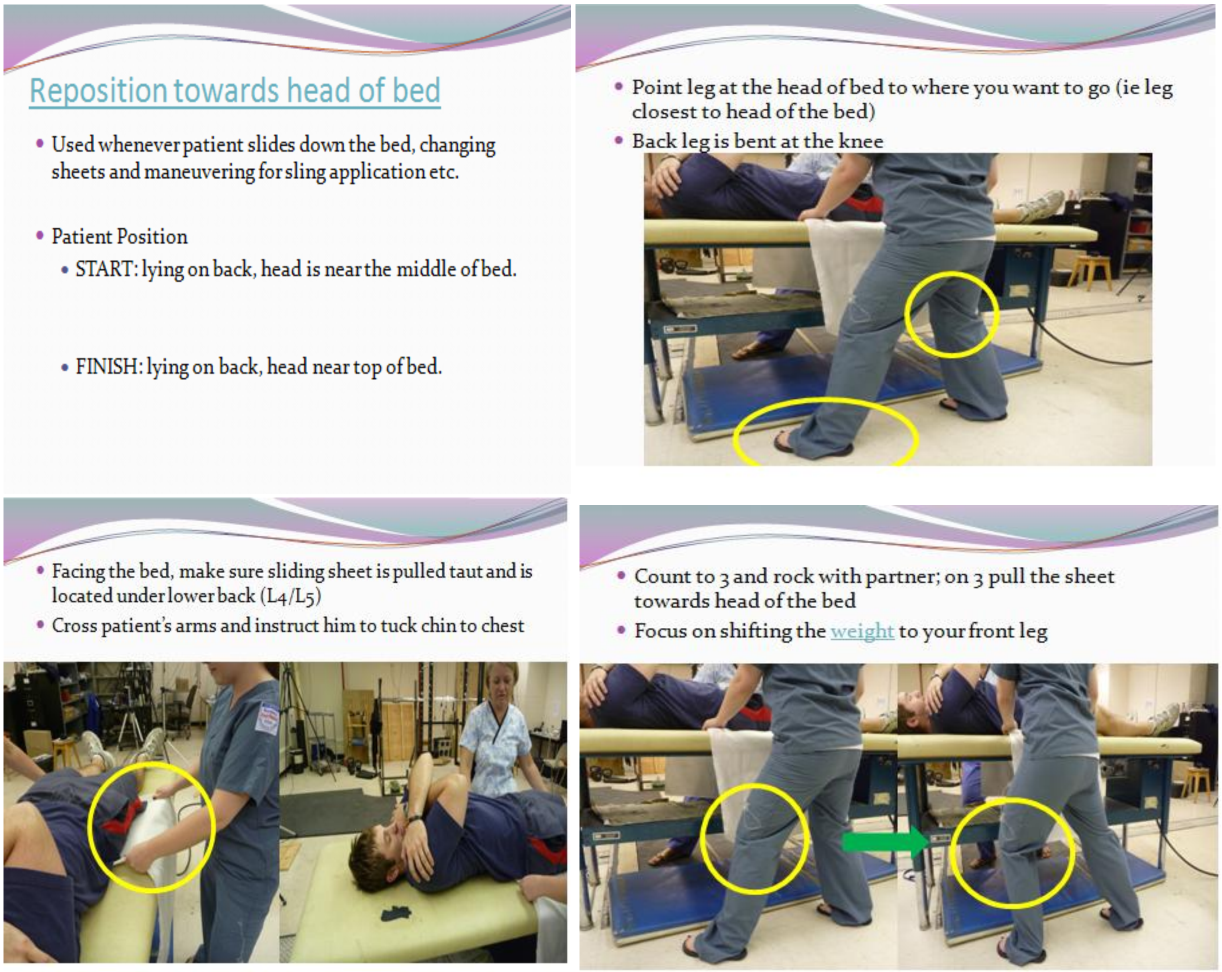
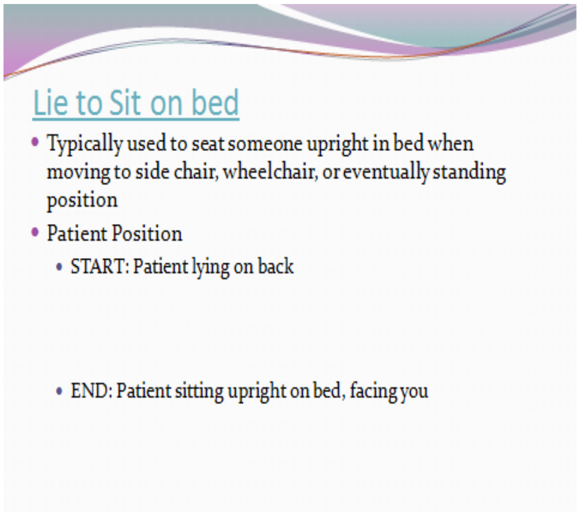
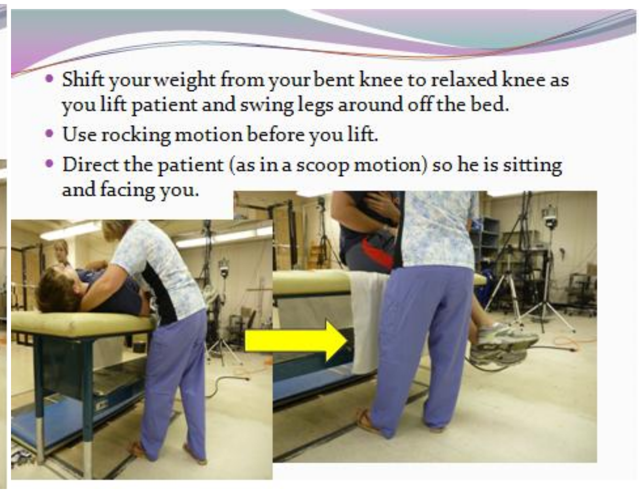



**Figure B5**. Instructional slides for Reposition technique.





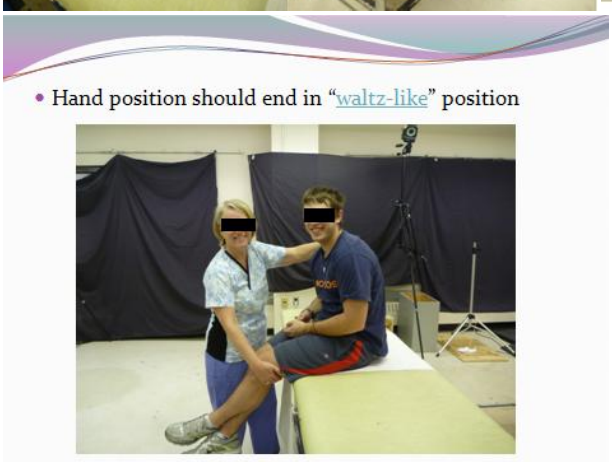




**Figure B6**. Instructional slides for Lie-to-Sit technique.


**Figure B7**. Example of slides for specific Sit-to-Chair task description.

**Appendix C:** 3DSSPP Model Positions for Self-selected and Recommended MPH techniques

This appendix contains positions created in 3DSSPP to analyze mean population strength of each joint in the position where peak force was applied in the self-selected MPH techniques as well as the recommended techniques. Video analysis and pictures of participants performing the tasks assisted in creating accurate 3DSSPP replicas.

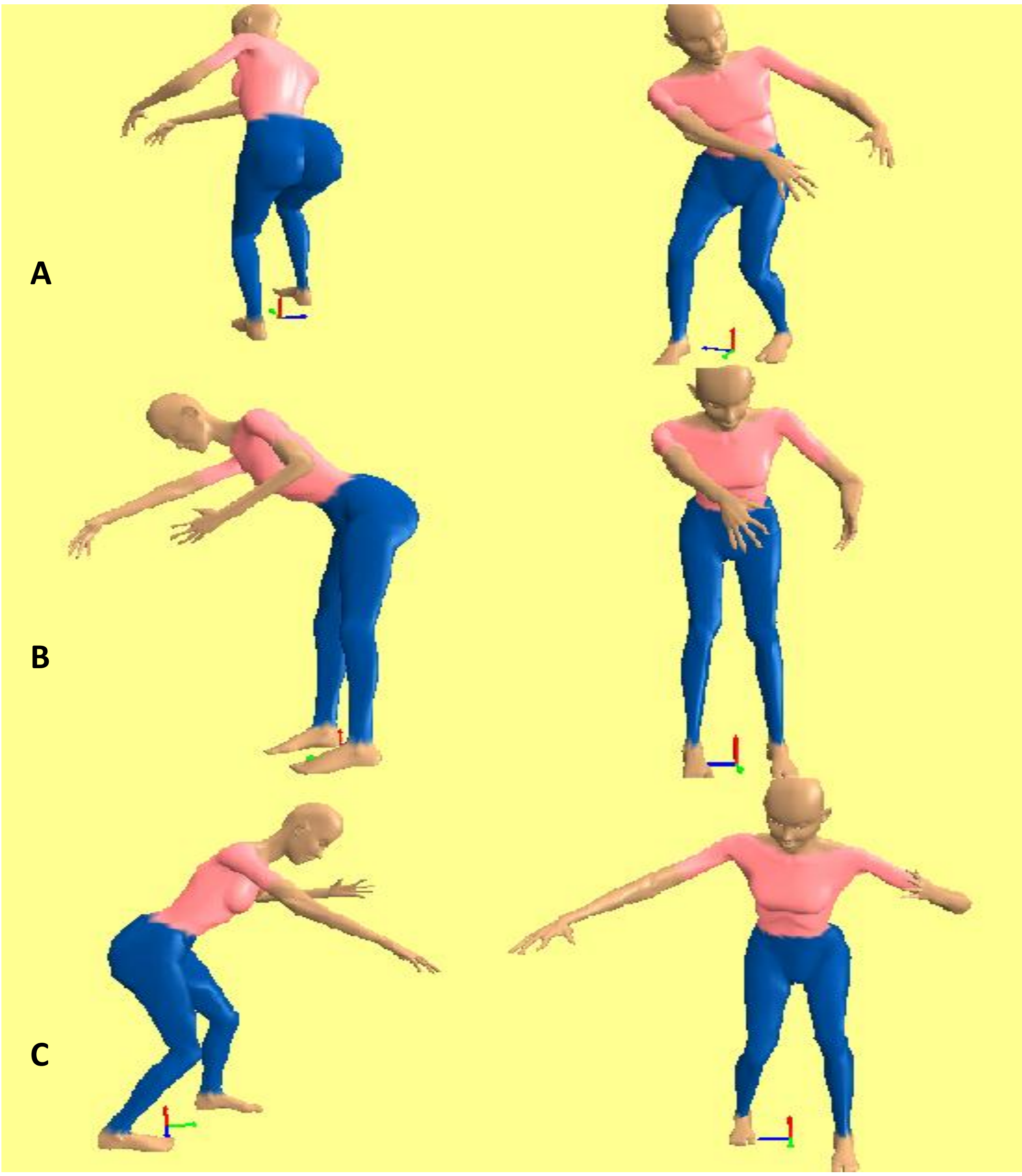



**Figure C1**. Lie-to-Sit 3DSSPP figures replicating peak force application in sagittal and frontal views. A-Untrained pull, B-Untrained push, C-Trained.

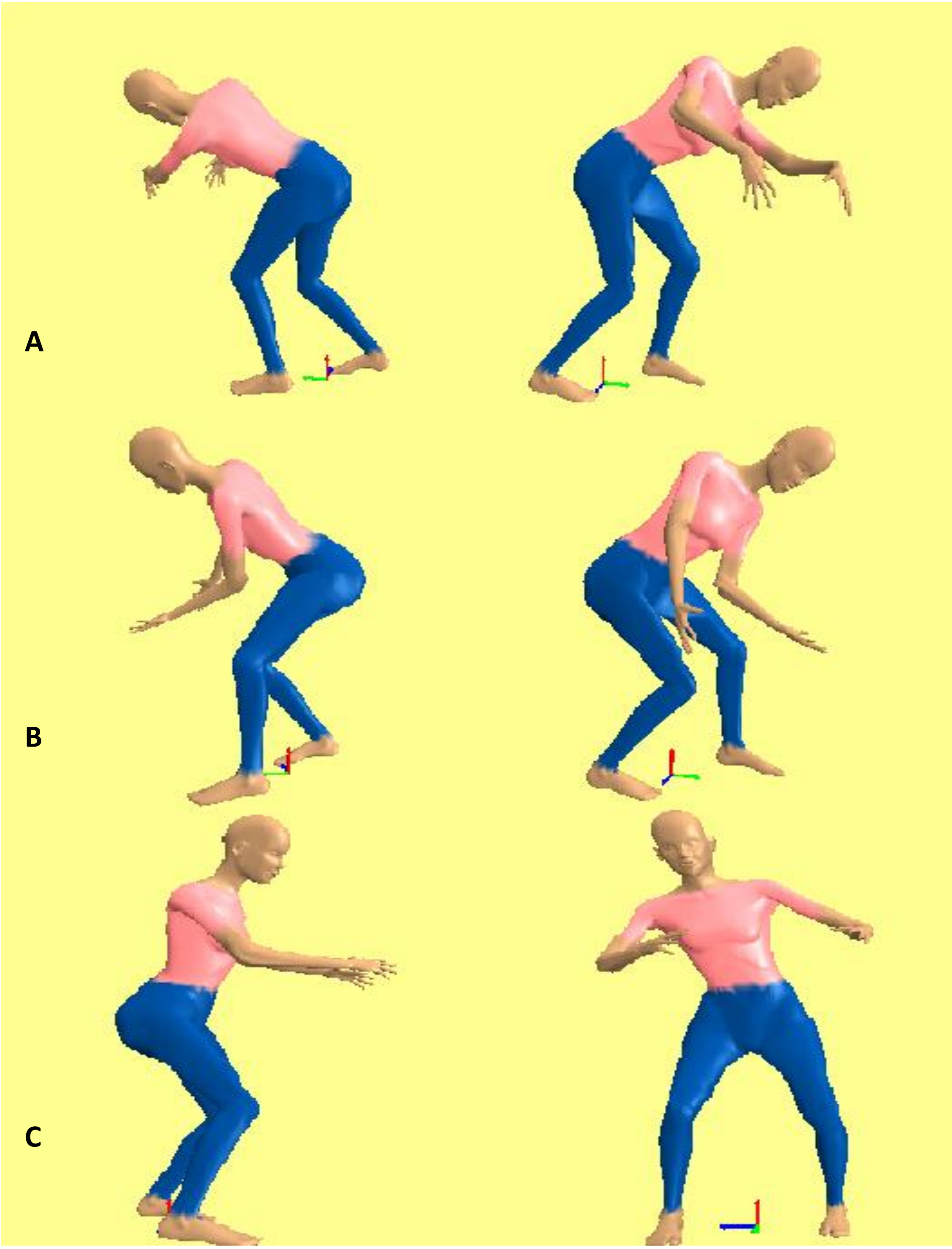



**Figure C2**. Reposition 3DSSPP figures replicating peak force application in sagittal and frontal views. A-Untrained pull, B-Untrained push, C-Trained.

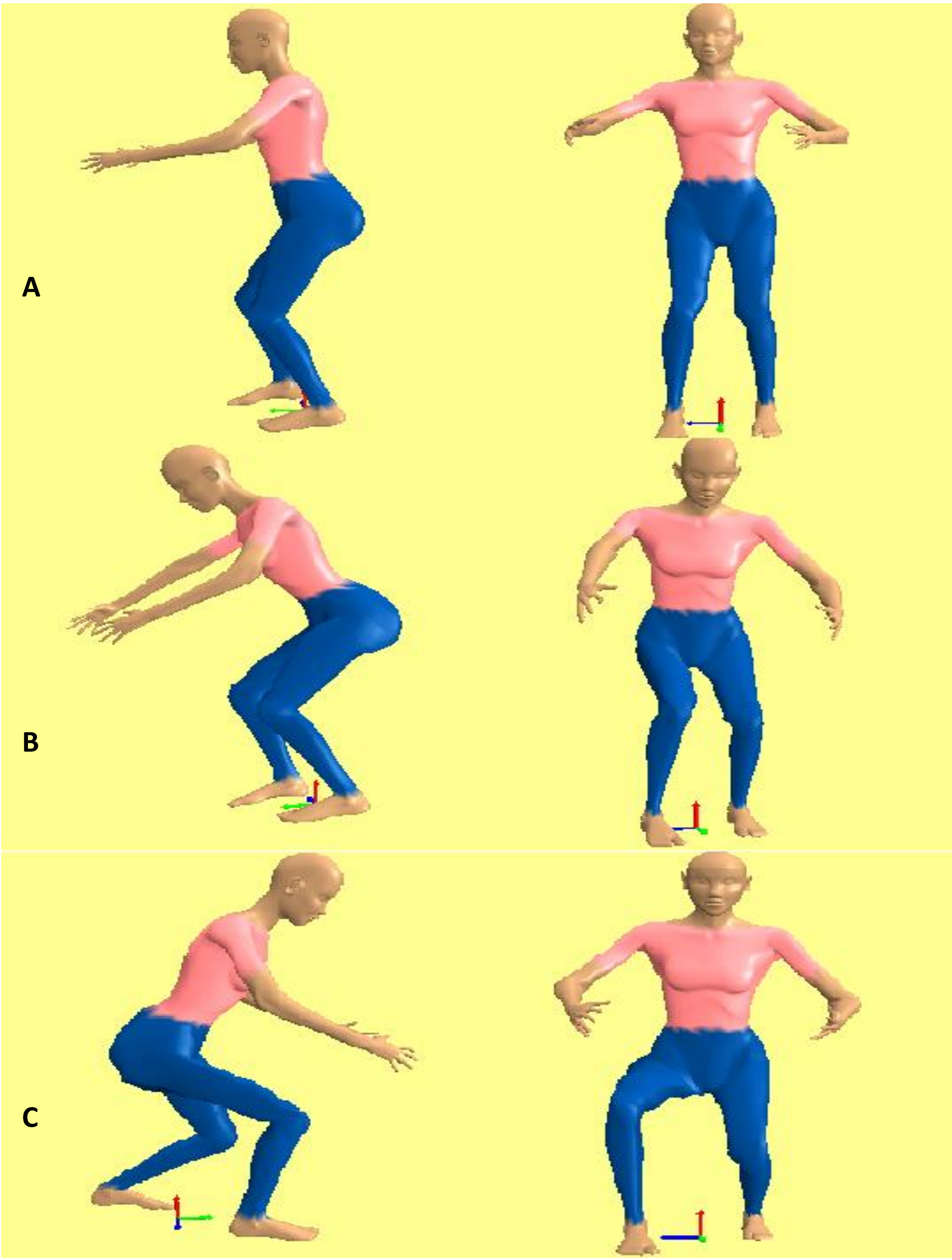



**Figure C3**. Sit-to-Chair 3DSSPP figures replicating peak force application in sagittal and frontal views. A-Untrained high bed position, B-Untrained low bed position, C-Trained.

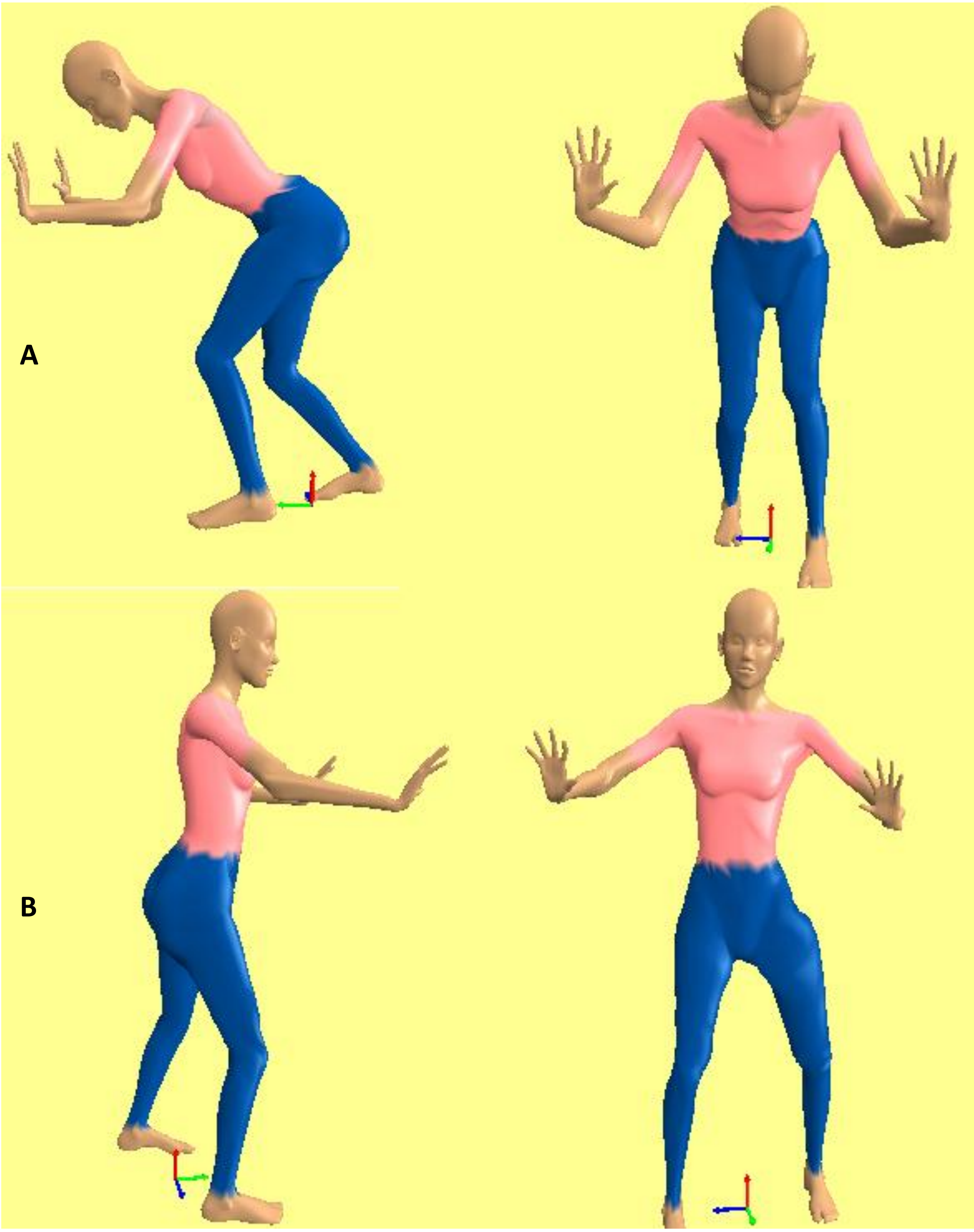



**Figure C4**. Turn Away 3DSSPP figures replicating peak force application in sagittal and frontal views. A-Untrained, B-Trained.

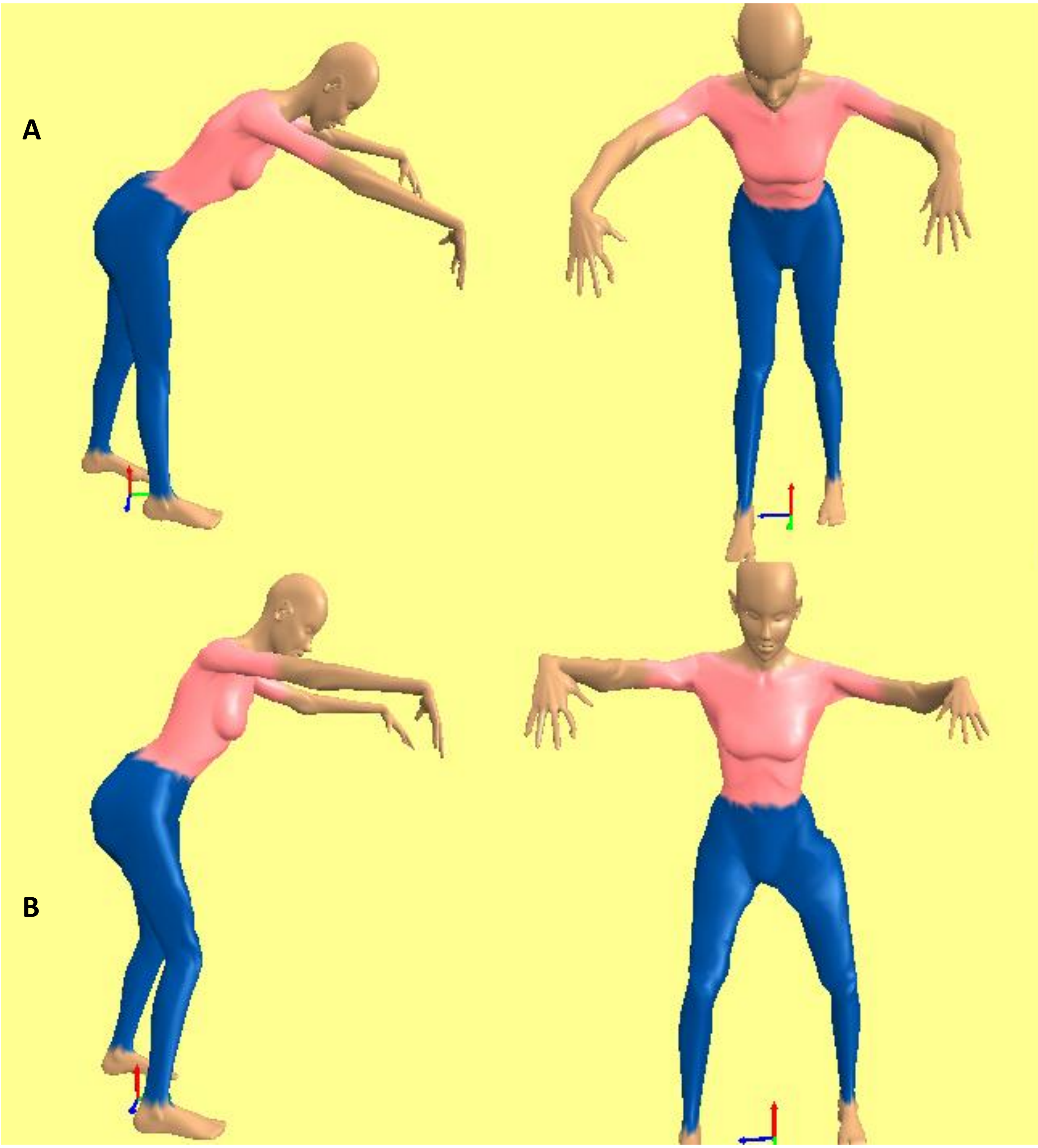


**Figure C5**. Turn Toward 3DSSPP figures replicating peak force application in sagittal and frontal views. A-Untrained, B-Trained.