USE YOUR LEGS, NOT YOUR BACK: AN INVESTIGATION INTO THE LINKS BETWEEN LOWER BODY WORK AND SPINE ANGLES AND MOMENTS DURING PARAMEDIC RELATED LIFTING TASKS

by

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Abstract

**Background:** Paramedics commonly suffer back injuries as a result of lifting. Improving lifting technique is often cited as an injury prevention approach; however traditional postural-based technique classifications have yet to identify an optimal technique. Instead, this thesis explored the hypothesis that an increased contribution of work done by the lower body relative to the trunk will be associated with lower peak sagittal plane trunk angles and moments experienced by paramedics while performing common paramedic lifting – a spine sparing strategy. Additionally this thesis explored whether higher peak lower body power capacity (calculated using vertical jump scores) was associated with reduced trunk angles and moments during lifting.

**Methods:** Thirty-three healthy paramedics performed three lifting tasks and completed a vertical jump test. A 3D linked-segment model computed sagittal plane trunk moments and angles, as well as joint power and the corresponding work done by the ankle, knee, hip, and trunk during lifting. Peak lower body power capacity was computed using vertical jump height. A correlational analysis determined the associations between lower body work contribution, lower body power capacity (calculated from the vertical jump score), and peak sagittal trunk angles and moments.

**Results:** Paramedics that completed the lifting tasks with an increased contribution of work from the lower body also experienced lower peak spine angles and moments in the sagittal plane. Peak lower body power capacity was not associated with any variable.

**Conclusion:** These results provide partial support for the overarching thesis, where an increased contribution of work from the lower body provided a spine sparing lifting strategy. This finding supports the need to continue coaching and training paramedics to generate more work from the lower body while lifting, as a spine sparing tactic. However, future work should try to identify relevant screening tools that can quickly determine if a paramedic is likely to adopt this strategy, or if they should be re-directed for more coaching and training.
Co-Authorship

Both of the manuscripts were developed with the help of a research team. The student was responsible for developing the biomechanical data collection protocol, with the help of the research team and members of the Ottawa Paramedic Service, and was also responsible for all of the biomechanical data collection. Other members of the research team measured the vertical jump height of participants used for peak lower body power calculations.

The biomechanical data were analyzed by the student, using modeling software, to compute variables of interest (joint power and work; trunk angles and moments). The statistical analysis was performed by the student, with feedback from the proposal committee. The manuscripts were drafted by the student, with critical revisions from the supervisor and the Biomechanics and Ergonomics group.
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Chapter 1

Introduction

Paramedics, who are generally the first responders in emergency situations, perform a number of tasks besides medical care that range widely and include lifting patients, carrying equipment, providing transportation, and filling out paperwork (Broniecki et al., 2010). Performance of these tasks is sporadic, and paramedic work can be characterized by long periods of sedentary activity punctuated by bouts of high intensity work (Broniecki et al., 2010).

Paramedic work is taxing on the body, often resulting in injury (Maguire, 2014; Maguire, 2013; Hogya & Ellis, 1990). Many of these injuries are the result of the numerous lifting tasks paramedics perform when transporting patients who are unable to move (Maguire, 2014; Maguire, 2013; Hogya & Ellis, 1990). These tasks expose paramedics to large forces and moments, as well as awkward and extreme postures (Cooper & Ghassemiah, 2006; Lavender, Conrad, Reichelt, Johnson, & Meyer, 2000; Prairie & Corbeil, 2014). For example, vertically lifting a patient on a backboard can produce spine compression values of over 5000 N. Higher exposure to mechanical factors such as peak loads, moments, and angles are associated with increased injury risk (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005). Therefore, techniques that elicit lower exposures (i.e. are more spine sparing), are desirable.

Technique-based lifting interventions are often used to help reduce injury risk. These posture-focused interventions, however, are not consistently effective (Martimo et al., 2008). Additionally, there is little consensus regarding the ideal or optimal posture to teach during these interventions (van Dieën et al., 1999; Burgess-Limerick, 2003). As an alternative to a postural guided approach, assessing technique by considering the dynamics of lifting may prove to be more useful, particularly given its effectiveness when employed to better understand techniques
to support heavy pushing tasks (Nadeau & Gagnon, 1996). A similar analysis may help to identify optimal lifting technique.

Should an optimal lifting technique be identified, it would be useful to identify a means of screening for lifters who employ it. This screening tool would allow training officers to identify paramedics who lift more spine-sparingly, without the use of technical instrumentation. The generation of a generic screening tool complies with the Paramedic Association of Canada National Occupational Competency Profile (2015) requirement that paramedics display adequate fitness levels for the job.
Chapter 2

Literature Review

Paramedic Work

Paramedic work is demanding both physically and mentally, and can be characterized by long periods of sedentary behaviour that are regularly punctuated by short intervals of high intensity work (Broniecki et al., 2010). The clinical needs of patients can vary widely, and as a result the physical strain placed on paramedics can also vary widely. A recent physical demands description of Canadian paramedic work identified the frequency with which different tasks were performed, and the tasks paramedics perceived to be the most physically demanding (Coffey, MacPhee, and Fischer, 2014). Lifting patients and equipment occurred frequently, and was often perceived as the most physically demanding task that paramedics performed.

Paramedic Injuries

Considering the frequency and perceived demands associated with lifting, it is not surprising that paramedic work is associated with a high rate of injury (Maguire, 2014; Maguire, 2013; Hogya & Ellis, 1990; Ambulance Paramedics of British Columbia, 2000). In fact, in Australia, paramedic work has been reported to have the highest rates of serious injuries compared to all other occupational groups, with a rate of 94.6/1000 workers (Safe Work Australia, 2013). For reference, the next highest rate of injury was among skilled agricultural workers, with a rate of 82.9/1000 workers, where the national average was 13.0/1000 workers (Safe Work Australia, 2013). These injuries have a myriad of reported causes. Some, like assault by a person, account for a relatively low percentage of these injuries: approximately 2% in
Australia and 3% in the United States (Maguire, 2014; Maguire, 2013). However, the most common cause of injury is muscular stress while lifting, carrying, or putting down objects, accounting for 44% of injuries in Australia and 37% of injuries in the United States (Maguire, 2014; Maguire, 2013).

These injuries fall into the category of Work-related Musculoskeletal Disorders (WMSDs), defined as:

- injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs,
- [...] which the work environment and performance of work contribute significantly to the condition and/or the condition is made worse or persists longer due to work conditions (Centers for Disease Control and Prevention, 2013).

The most prevalent site for the development of WMSDs among paramedics is the low back. For example, Hogya and Ellis (1990) reported that back injuries made up 36% of all paramedic injuries, with more than 60% of these injuries occurring as a result of lifting. Among Canadian paramedics, the rate of low back injuries may be even higher, accounting for 48% of injuries (Ambulance Paramedics of British Columbia, 2000). This injury data aligns with paramedics’ perceptions, identifying lifting as a cause for concern.

**High Risk Mechanical Factors**

Lifting in any context is a physically demanding task. To date, there is no epidemiological literature that links specific mechanical factors to back injury within the paramedic context. However, research done in a manual materials handling setting provides insight into mechanical factors that seem to predispose individuals to low back injury (Marras et al., 1993; Norman et al., 1998; Wrigley, Albert, Deluzio, & Stevenson, 2005). The work done by
Marras et al. (1993) was comprehensive, and parsed out 48 different manual materials jobs into risk-quartiles based on their injuries rates. Trunk motion characteristics associated with low-risk (i.e. quartile with lowest injury rate) and high-risk (i.e. quartile with highest injury rate) work were identified. They concluded that high peak trunk moments and velocities in the sagittal plane were characteristics of jobs with high rates of injuries. A case-control study performed by Norman et al. (1998) found similar results among automotive workers, where reporters of low-back pain were exposed to significantly higher peak trunk moments and experienced larger ranges of motion at the trunk than their matched controls. Wrigley et al. (2005) demonstrated similar findings using data obtained from a cohort of manual materials handlers monitored over a two-year period. In this study they compared lifting technique between those that developed low back injury and those that did not. Their results also indicated that high peak trunk moments in the sagittal plane were associated with an increased likelihood of injury. Given the high rate of low back injuries among paramedics, it is likely that these parameters may also play a role in paramedic related low back injuries, and therefore should be considered in biomechanical analyses of paramedic lifting tasks.

**Mechanical Factors during Paramedic Work**

There is a small body of evidence that describes the biomechanics of different paramedic tasks. A number of frequently performed paramedic tasks, including loading a stretcher into an ambulance (Cooper and Ghassemieh, 2006), and lifting a patient on a backboard from the ground to waist height (Lavender et al., 2000) have been shown, using biomechanical modeling techniques, to produce spine compression values that exceed National Institute of Occupational Safety and Health’s recommended action limit of 3400 Newton’s (N) (Waters, Putz-Anderson,
Garg, & Fine, 1993). Further examination of these tasks would help to verify their results. There is also no data that exists to describe the biomechanics associated with raising a stretcher up, from rolling to loading height, as required to allow the stretcher to be loaded into the ambulance, another commonly performed and demanding task (Coffey, MacPhee, and Fischer, 2014).

In a field-based setting, researchers have also been able to quantify many of the postures and motions required by paramedics during actual emergency situations (Prairie & Corbeil, 2014). Paramedics wore a CUELA (a German acronym that translates to: computer-based measurement and long-term analysis of stresses upon the musculoskeletal system, (German Social Accident Insurance, 2014)) back monitor to track trunk posture and motion as they carried out their daily job tasks. Their results indicated that lifting tasks, regardless of the urgency of the situation, resulted in the most extreme trunk angles. This information, when coupled with the previous force information gathered and the epidemiological research citing lifting as a major cause of injury, indicates that paramedic lifting should be a target for intervention.

**Mechanical Factors and Lifting Technique**

Historically, attempts have been made to identify an ideal lifting technique that minimizes spine loading (spine sparing) in a manual materials handling setting (van Dieën, Hoozemans, & Toussaint, 1999; Burgess-Limerick, 2003). Technique in this context has often been defined by the initial static posture an individual assumes at the moment of lift initiation (van Dieën et al., 1999; Burgess-Limerick, 2003). The two techniques that are predominantly assessed are the stoop technique, where the load is lifted using minimal knee flexion, and the squat technique, where the load is lifted using minimal trunk flexion (Burgess-Limerick, 2003). The semi-stoop posture has also been assessed, a posture representing a middle ground between
the stoop and squat, where the load is lifted with some knee and some trunk flexion (Burgess-Limerick, 2003). It is generally assumed that a squat posture will result in a lift that primarily uses the lower body, while a stoop posture will result in a lift that primarily uses the upper body (Zhang, Nussbaum, & Chaffin, 2000).

Despite the emphasis on the assessment of stoop versus squat lifting, there is little consensus about which technique produces the lowest spine loads and subsequently, injury risk. A systematic review conducted by van Dieën et al. (1999) addressed the inconsistencies in the literature. A number of studies that used a static biomechanical model reported higher spinal compression values during squat lifting, however this effect disappeared when the horizontal distance of the object from the person was controlled (van Dieën et al., 1999). Studies that used dynamic biomechanical models found either no difference between techniques, or slightly higher compression values during squat lifting (van Dieën et al., 1999). Only one study that was included in the review assessed sagittal trunk moments, where their results indicated that moments were lower when the squat posture was employed. To date, there has been no study that unequivocally shows the superiority of one technique over the other. These inconsistencies may be caused by method of lift classification: identifying lifts based on the initial static posture does not provide any indication about the dynamics of the lift. For example, an individual may assume an initial posture that appears squat-like, but then employs a lifting technique that involves primarily the back (Zhang, Nussbaum, & Chaffin, 2000). Since static postural analyses do not appear to be able to identify an ideal lifting technique, a dynamic analysis may provide a better means of assessment.
Dynamic Assessment of Lifting Technique

Using dynamics to assess lifting technique involves calculating the joint mechanical power and work done by each joint during lifting. This can be done in a number of ways, but in biomechanics it is primarily done by multiplying the joint angular velocity and the joint moment, at each frame, in order to obtain a joint power for the duration of the movement. The integral of the resulting joint power curve is then calculated in order to obtain the work performed by the respective joint during the movement (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2014). This method of joint power and work calculation has been previously compared to other methods including: investigating for changes in energy content of the segments and by using the rate of change of energy content considering the ground reaction force (de Looze, Bussman, Kingman, & Toussaint, 1992). There was a high degree of agreement between methods, which provides some evidence that the angular velocity and moment method is useful.

Joint power and work analyses have been used previously in a number of lifting studies. The purposes of these studies vary, ranging from examining the contribution of different joints to maximum effort back squats (Flanagan, Kulik, & Salem, 2015), to the contribution of different joints during stoop and squat lifting (Hwang, Kim, & Kim, 2009). It has also been used to examine the mechanical efficiency of stoop and squat lifting at different lifting frequencies (Welderbergen, Kemper, Knibbe, Toussaint, & Clyssen, 1991), and to examine the relative contribution of different joints during box lifting and lowering at different loads (Gagnon & Smyth, 1991). However, only one study has examined links between contributions of power and work and associated spine mechanics; albeit during maximal pushing tasks (Nadeau & Gagnon, 1996). Their results indicated that a greater contribution of power and work by the lower body resulted in reduced loading of the spine. Though lifting and pushing are different movements, it
is useful to determine if a similar power and work based analysis could be informative to better understand determinants of lifting that are spine sparing. A joint power and work-based assessment may provide a different method for operationalizing technique beyond the traditional postural assessment.

**Linking Occupational Performance to Individual Capacity**

To help reduce injuries, the Paramedic Association of Canada (PAC) has stated that paramedics must demonstrate adequate strength and fitness for practice (Paramedic Association of Canada, 2015). At present, this guideline is very general and does not provide any specific indication regarding what physical attributes paramedics must possess. While there is limited data on paramedic fitness, they possess normal levels of aerobic capacity, as well as muscle endurance and strength (Chapman, Peiffer, Abiss, Laursen, 2007). Also, there is limited evidence to demonstrate which of these characteristics are indeed relevant. To date, only Barnekow-Bergkvist et al. (2004) have demonstrated any association between fitness and paramedic job performance, where their results indicated that increased levels of aerobic capacity (measured by \( \text{VO}_2 \text{maximum} \)) and muscular endurance of the back muscles were associated with a decrease in physiological markers of fatigue (i.e. blood lactate concentration) during a prolonged stretcher carrying task. Given the detrimental effects of lifting, it would be beneficial to add to this knowledge by identifying potential fitness related determinants of lifting performance for paramedics. In this context, performance would be defined as the ability to complete the lifting task in a manner that minimize exposure to high moments and large amounts of trunk flexion, given their association with back injury (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005). This will help organizations like PAC to better define what types of strength and fitness
are required, enabling the development of job-specific screening tools that can help to identify paramedics who display adequate the job relevant strength and fitness.

Considering the requirement to lift heavy loads, it is plausible that lower body power could be an important determinant of a paramedics lifting performance. Recently, it has been shown that paramedics possess higher levels of peak lower body power than the average population (Weidman et al., 2015), indicating that it may be an important factor for paramedic work. Higher peak lower body power capacity has also been associated with improved lifting performance (i.e. one repetition back squat, clean-and-jerk, and snatch maximum) among Olympic lifters and Australian Rules Football players (Carlock et al., 2014; Hori et al., 2008). One popular generic screening tool for lower body power is the vertical jump (CSEP, 2013). This measurement can be used to calculate peak lower body power capacity using a standard equation (Sayers et al., 1999). Considering paramedics’ high levels of peak lower body power, and its association with improved lifting performance in other fields, a common vertical jump test may be a suitable predictor of paramedics’ lower body power, and ultimately, their lifting performance.

**Problem Statement and Purpose**

Paramedic lifting often results in low-back injuries (Maguire, 2014; Maguire, 2013; Ambulance Paramedics of British Columbia, 2000; Hogya & Ellis, 1990). Lifting exposes paramedics to mechanical factors, such as high peak sagittal plane angles and moments at the spine, which are associated with elevated injury risk (Lavender et al., 2000; Cooper and Ghassemieh, 2006; Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005). Previous efforts to evaluate lifting technique have focused predominantly on relationships between initial
lifting posture and spinal loading, which has produced mixed results (van Dieën et al., 1999). A
dynamic assessment of lifting, focusing on joint power and work may help to identify spine
sparing techniques that result in lower trunk angles and moments (de Looze, Bussman, Kingman, & Toussaint, 1992; Flanagan, Kulik, & Salem, 2015; Hwang, Kim, & Kim, 2009; Welderbergen, Kemper, Knibbe, Toussaint, & Clyssen, 1991; Gagnon & Smyth, 1991; Nadeau & Gagnon 1996). The vertical jump, a measure of lower body power capability, may be a useful tool for
identifying paramedics who display lower trunk moments and angles, given its relationship to
performance in other types of lifting (Carlock et al., 2014; Hori et al., 2008). As such, there are
three purposes of this project. First: to describe the peak sagittal L4/L5 moments and peak
sagittal trunk angles associated with three commonly performed paramedic tasks (stretcher
loading, boarded lifting, and stretcher raising). Second: to identify whether an increased
contribution of work by the lower body (relative to the total work done by the lower body and
torso) is associated with lower trunk moments and angles. Third: to investigate if peak lower
body power, calculated using the vertical jump (CSEP, 2013) is associated with lower trunk
moments and angles.

It was hypothesized that: 1) an increased contribution of lower body work would be
associated with lower trunk angles and moments, and 2) that higher peak lower body power, as
determined via a vertical jump test, would be associated with lower trunk angles and moments.
Chapter 3

Examining the relationship between the relative contribution of lower body work and sagittal trunk angles and moments during paramedic lifting
Abstract

**Background:** Paramedic lifting often results in injury, especially in the low back. Lifting technique is often cited as a means of injury reduction; however traditional measures of lifting technique focused on initial postures assessment have yet to identify an optimal technique. Dynamic assessment of lifting technique may provide an alternative: previous research has linked an increased contribution of lower body work to a decrease in trunk moments during heavy pushing tasks. This technique has not been applied to lifting with the purpose of identifying spine-sparing strategies, and as such, the purpose of this study was to examine the relationship between the contribution of work from the lower body and peak sagittal plane trunk angles and moments during paramedic lifting.

**Methods:** Thirty-three healthy paramedics performed a series of occupational tasks. A 3D linked-segment model was then produced to compute trunk moments and angles, as well as joint power and work produced by the ankle, knee, hip, and trunk during lifting. Bilateral ankle, knee, and hip work were summed to produce a single metric of lower body work. Data analysis consisted of a series of correlations between lower body work contribution, peak lower body power, and peak sagittal trunk angles and moments.

**Results:** An increased contribution of lower body work relative to upper body was associated with a decrease in trunk angles and moments.

**Conclusion:** Measuring the relative contribution of lower body work offers an alternative means of lift technique assessment beyond traditional postural methods. The knowledge could be used by lifting coaches, who should direct their lifting training towards producing work from the lower body.
Introduction

Lifting is a demanding task, often associated with low back injuries (Frymoyer et al., 1983; Chaffin & Park, 1973). Paramedics are an occupational group commonly exposed to lifting, where 36 to 48% of all paramedic injuries are related to lifting (Hogya and Ellis, 1990; Maguire, 2014; Maguire, 2013; Ambulance Paramedics of British Columbia, 2000). When considering a typical paramedic shift paramedics will regularly lift both patients and equipment onto stretchers and into ambulances (Coffey et al. 2015). Lifting activities such as, loading a stretcher into an ambulance (Cooper & Ghassemieh, 2006), and lifting boarded patients from the ground (Lavender et al., 2000) have been shown to produce spine loads that exceed the established guidelines (Waters et al., 1993). Additionally, Prairie & Corbeil (2014) identified lifting as a concern due to the large ranges of spine motion required. Based on this information, it is not surprising that lifting is frequently associated with injury among paramedics.

Identifying ideal lifting techniques may provide an opportunity to reduce injuries through administrative controls such as lift training and education. However, there is limited consensus regarding which technique is ideal for reducing spine loads (van Dieen, Hoozemans, & Toussaint, 1999; Burgess-Limerick, 2003) when considering traditional classifications of squat, semi-squat, or stoop. However, an alternative line of inquiry explores technique by considering the body's dynamics in terms of joint power and work (Robertson et al., 2014). Using joint moment and angular velocity, joint power can be calculated, the integral of which is joint work (Robertson et al., 2014). This method has been used previously to compare the relative contribution of work from different joints between stoop and squat lifting (Hwang, Kim, & Kim, 2009), during maximum effort back squats (Flanagan, Kulik, & Salem, 2015), and how the contribution may change as lifting frequency increases (Welderbergen, et al., 1991). However,
joint power and work analyses have rarely been applied to identify optimal (body sparing) techniques in an occupational context. However, one such example exists, where Nadeau & Gagnon (1996) used a power and work analysis to identify techniques that minimized trunk moments during maximum pushing efforts. The application of a joint power and work analysis may yield insight into spine sparing lifting techniques adopted by professional lifters, like paramedics.

Higher sagittal trunk moments and greater amounts of trunk flexion have consistently been linked to an increased risk of back pain and injury in manual materials handling settings (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005). Therefore, an optimal technique would be one that minimizes a lifters exposure to these variables. Anecdotally, in the strength and conditioning sphere, it is assumed that generating power and work through the lower body during lifting is ideal for minimizing the risk of back injury during lifting. This concept aligns with the findings of Nadeau & Gagnon (1996), and provides justification for the examination of a links between the relative contribution of work from the lower body and peak sagittal plane trunk angles and moments.

This study had two main objectives. First, we aimed to determine if the contribution of lower body work (lower body work expressed relative to the total work done by the lower body and torso) was associated with peak spine moments or flexion angles. Second, we aimed to describe the peak sagittal L4/L5 moment and angles associated with three common, but demanding paramedic lifting tasks.
Methods

Participants

Paramedics were recruited from a local service using advertisements in their daily batch briefings. Only paramedics who had more than two years of work experience with the service, and who had not suffered work-related injuries in the preceding six months were eligible to participate. Thirty-three paramedics who met the inclusion criteria volunteered to participate (Table 1). The project was approved by the university’s research ethics boards (Appendix A) and all paramedics provided informed consent prior to participation (Appendix B).

Table 1. Mean participant demographic information (+/- standard deviations).

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 18)</th>
<th>Female (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>39.2 (9.0)</td>
<td>34.5 (5.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>89.8 (12.9)</td>
<td>70.2 (12.5)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.76 (0.08)</td>
<td>1.64 (0.07)</td>
</tr>
</tbody>
</table>

Note: yrs, years; kg, kilograms; m, meters; n, number of participants

Protocol

Simulated occupational tasks. Participants performed three repetitions of the following simulated paramedic lifting tasks: boarded lift (Figure 1-1), stretcher raise (Figure 1-2), stretcher load, and (Figure 1-3). The boarded lift task required participants to vertically lift a rescue mannequin on a back board from the ground to a height where the patient could be placed on a stretcher (~90 cm). The stretcher raise task required participants to raise a stretcher with a mannequin on it from a stretcher-top height of 90 cm to 110 cm. The stretcher load task required participants to lift a stretcher with a mannequin on it from a stretcher-top height of 110 cm to 125 cm. It is important to note that during stretcher loading, participants were lifting the bottom end
of the stretcher, while during stretcher raising, paramedics were lifting the top end, meaning that the handles participants grasped were different during the two tasks.

Stretcher tasks were completed using a Ferno 35X stretcher (Ferno, Wilmington, Ohio U.S.A.), whereas a Ferno EXL Scoop Stretcher (Ferno, Wilmington, Ohio, U.S.A.) was used for the boarded patient lift. Additionally, all tasks required paramedics to lift a 75 kg and 185 cm IAFF Rescue Randy manikin (Simulaids, Saugerties, New York, U.S.A.). The 75 kg weight is representative of the average patient weight lifted by paramedics (Coffey, MacPhee, & Fischer, 2015). Paramedics were instructed to perform the lift as they would in an actual emergency situation, with no specific lifting technique instructions provided. To further ensure adequate realism, the partnered lifts (boarded patient lift and the stretcher raise) were completed with a fellow paramedic assuming the partner lifting role as they would while on the job. Although partner height has been shown to affect average spine loads over the course of a lifting task, peak spine loads (which are the primary measures of interest) are unaffected (Dennis & Barrett, 2003).
Figure 1. Top: boarded lift (1), stretcher raise (2), and stretcher load (3) at the moment of lift initiation (A) and lift completion (B)

Instrumentation

All simulated occupational tasks were performed in a motion capture lab, equipped with fourteen Oqus© cameras (Qualisys: Gothenburg, Sweden) and two Bertec FP4060-05-PT force plates (Bertec: Columbus, Ohio, U.S.A.). Analog force data was converted to a digital signal and
synchronized with motion data through the Qualisys Track Manager (QTM) software, where all signals were sampled at 60 Hz. To facilitate motion tracking, 11 mm reflective markers were placed over anatomical landmarks as required to define foot, shank, and thigh segments bilaterally, in addition to the pelvis and thorax (Wu et al., 2002; 2005) (Appendix D). Additional markers fixed to rigid bodies were used for tracking the shank, thigh and pelvis segments during the dynamic lifting trials (Appendix D). Prior to initiating task performance a five-second standing static calibration trial was recorded, where participants were asked to stand upright in an anatomical position.

**Data Processing**

Marker data were visually inspected within the Qualisys QTM software. Where marker trajectory gaps were identified, gaps were filled using a third-order polynomial function in the QTM software. Trajectory and force data were then exported for further analysis using Visual3D (Version 5, C-motion, 2015).

Using the Visual 3D software, force and trajectory data were filtered using a low-pass fourth order dual-pass Butterworth filter, set at an effective cut-off frequency of 4.4 Hz, as determined through residual analysis (Appendix F) (Winter and Patla, 1997).

Once filtered, marker data were used to develop an eight-segment (right and left feet, shanks, and thighs; pelvis, and trunk) bottom-up linked-segment model following the procedures described by Robertson et al. (2014).

The kinematic model was parametrized within the Visual3D software by following these steps. First, segments were defined using the corresponding marker data. To summarize, foot, shank, and thorax segments were defined by markers placed medially and laterally on their
proximal and distal endpoints. The pelvis was defined using markers placed on the anterior and posterior superior iliac crests (ASIS & PSIS). Hip joint centers (HJC) for the thigh segments were then computed using the following formulas as described by Bell, Pedersen, & Brand (1989; 1990):

\[ \text{HJC} = (\pm 0.36 \times \text{ASIS Distance}, -0.19 \times \text{ASIS Distance}, -0.3 \times \text{ASIS Distance}) \]

**Equation 1.** Method to estimate hip joint center (HJC) adapted from Bell, Pederson, & Brand (1989; 1990).

Where the ± denotes the calculation required to estimate the right (+) and left (-) HJC and where ASIS distance is the distance between the left and right ASIS as determined using the marker data.

ISB recommendations were followed to define individual segment coordinate systems where positive X-axes projected anteriorly, positive Y-axes projected axially away from the ground, and positive Z-axes projected from left to right, laterally on the right side and medially on the left side (Wu et al., 2002; 2005)).

Joint angles were described as the orientation of the distal segment relative to the proximal segment (e.g. the orientation of the shank relative to the thigh) using a Z-Y-X decomposition. For reference, using this approach, during upright standing the thigh and shank are aligned where the corresponding knee flexion angle (shank coordinate system relative to thigh coordinate system) would be approximately 0°. However, as one flexes at the knee to squat down, the shank segment is rotated about the Z axis of the thigh, in a negative direction since the thigh Z-axis is directed from left to right. As such, these flexion angles are negative due to the ISB conventions used for the segment coordinate systems. However, to ease interpretability, we have corrected corresponding flexion angles such that flexion is positive and extension negative.
To compute segment kinetics Visual3D defaults to using data from Dempster (1955) to estimate segment anthropometrics equations described by Hanavan’s (1964) to estimate segment inertial properties. These values, in conjunction with ground reaction force data and segment kinematics, were used to compute joint moments and forces, the process for which has been described by Robertson et al. (2014).

With segment kinematics and kinetics computed, variables of interest were computed using the Visual3D software for each repetition of each task for each participant. The sagittal plane moment at the proximal end of the pelvis, approximately in line with the L4/L5 vertebrae, as well as the sagittal angle of the trunk segment were computed throughout each lifting trial. The maximum value for each measure was extracted from each trial, to provide a peak sagittal L4/L5 moment and a peak sagittal trunk angle (with respect to the pelvis segment) for each repetition of each task. These variables were chosen because of their association with the development of low back injury (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005).

Joint power, which is the product of the joint moment and the angular velocity of the two segments that comprise the joint (Equation 2) (See Appendix G for example joint moment, angular velocity, and power curves), was computed using the Visual3D software for the left and right ankles, knees, and hips. Joint power for the trunk was computed manually by multiplying the moment and the first derivative of the trunk angle. Although the software provides the capacity to perform a three-dimensional analysis, only power in the flexion-extension direction was computed for all joints. Power values in the axial and antero-posterior directions were much smaller than in the flexion-extension direction, and as such were not considered to be relevant for this analysis.
\[ P_J = \tau_J \cdot \omega_J \]

**Equation 2.** Formula used to compute joint power. \( P_J \), joint power (Watts); \( \tau_J \), joint moment (Newton metres); \( \omega_J \), joint angular velocity (radians/second).

Power values were then extracted to MATLAB, where they were integrated (Equation 3) lift initiation to lift completion to compute the work done at each joint during the lift. Lift initiation was defined as the instant the hand markers reached their minimum vertical position; and, lift completion was defined as the instant the hands reached their maximum vertical (Z) position (Figure 1).

\[ W_J = \int P_J \]

**Equation 3.** Formula used to calculate joint work (J) for each joint (ankle, hip, knee, and trunk). \( W_J \), work done by the joint; \( P_J \), joint power (W).

Joint work for the left and right ankles, knees, and hips was then summed to produce total lower body work, which has been previously validated by Flanagan and Salem (2005) (Equation 4).

\[ W_{TLB} = W_{LA} + W_{LK} + W_{LH} + W_{RA} + W_{RK} + W_{RH} \]

**Equation 4.** Formula used to calculated total lower body work done during the lifting tasks. \( W_{TLB} \), total work done by the lower body; \( W_{LA} \), work done by the left ankle (J); \( W_{LK} \), work done by the left knee (J); \( W_{LH} \), work done by the left hip (J); \( W_{RA} \), work done by the right ankle; \( W_{RK} \), work done by the right knee; \( W_{RH} \), work done by the right hip.

Lower body work and trunk work was also summed to produce total work (Equation 5).

\[ W_T = W_{Tr} + W_{TLB} \]

**Equation 5.** Formula used to calculated total work performed. \( W_T \), total work done, (J); \( W_{Tr} \), work done by the trunk (J); \( W_{TLB} \), total lower body work (J).
The percentage contribution of work done by the lower body was then computed by dividing lower body work by total work and multiplying it by 100 (Equation 6). It is acknowledged that this approach discounts contributions from the upper extremities, as discussed further in the limitations section.

\[
% \text{Cont} = \frac{W_{\text{TLB}}}{W_T} \times 100\%
\]

**Equation 6.** Formula used to calculate the percentage contribution of lower body work. % Cont, percent contribution of lower body work; \(W_{\text{TLB}}\), total lower body work (J); \(W_T\), total work (J)

**Statistical Analysis**

Peak sagittal L4/L5 moments, peak sagittal trunk angles, and the percent contribution of lower body work, were averaged across the three repetitions of each lifting task. Descriptive data including means, maximums, and minimums related to each outcome measure were calculated at the group level, and for both males and females. Data were assessed for normality and homoscedasticity prior to applying separate Pearson product moment correlations to investigate for associations between the percentage of lower body work performed and the peak sagittal L4/L5 moment; and the peak trunk angle within each lifting task. Statistical tests were performed using IBM SPSS v.20 (IBM Corp. Armonk, NY, USA), where \(p<0.05\) was used to indicate significant correlations.

**Results**

The percent contribution of lower body work was significantly correlated with both outcome measures within each lifting task (Table 2). While the size of these coefficients varied across tasks, in each, an increase in the contribution of lower body work was associated with a reduction in peak sagittal L4/L5 moment and peak sagittal trunk angle. In some trials for some
task, marker data was obscured, prohibiting the calculation of the required outcome measures. As such Table 2 also indicates the number of participants that contributed data to support each correlation. In addition, to provide a visual representation of the data scatter, Figures 2-4 illustrate the dispersion of data (moments and angles relative to % contribution of work) for each task.

**Table 2.** A summary of the correlation coefficients ($r$), significance levels ($p$), and number of participants (N) included in correlation models between the percent contribution of lower body work and the peak sagittal L4/L5 moment and peak sagittal trunk angle during the stretcher load, boarded lift, and stretcher raise tasks.

<table>
<thead>
<tr>
<th></th>
<th>Boarded Lift</th>
<th>Stretcher Raise</th>
<th>Stretcher Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>% Contr. of LBW</td>
<td>r</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-.756</td>
<td>-.552</td>
<td>-.666</td>
</tr>
<tr>
<td>$p$</td>
<td>&lt;.001</td>
<td>.003</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>N</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

Note: % Contr. of LBW, percent contribution of lower body work; M, peak sagittal L4/L5 moment; A, peak sagittal trunk angle.
Figure 2. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work and dependent measures peak sagittal L4/L5 moment (top) and peak sagittal trunk angle (bottom) recorded from paramedics performing the boarded lift task.
Figure 3. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work and dependent measures peak sagittal L4/L5 moment (top), and peak sagittal trunk angle (bottom) recorded from paramedics performing the stretcher raising task.
Figure 4. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work and dependent measures peak sagittal L4/L5 moment (top), and peak sagittal trunk angle (bottom) recorded from paramedics performing the stretcher loading task.

The boarded lifting task resulted in the largest moments and angles, and required the greatest amount of work to complete, for the entire group and across both genders (Tables 3 and 4). On average, females used a greater contribution of lower body work and were exposed to lower moments and angles than males across all three tasks.
Table 3. Mean (±standard deviation) and range (min – max) peak sagittal L4/L5 moments, and sagittal trunk angles within each task, expressed at the group level and by gender.

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Task</th>
<th>Boarded Lift</th>
<th>Stretcher Raise</th>
<th>Stretcher Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (Nm)</td>
<td>Mean (Nm)</td>
<td>Mean (Nm)</td>
</tr>
<tr>
<td>Peak Sagittal</td>
<td></td>
<td>184.25 (58.45)</td>
<td>104.81 (40.10)</td>
<td>90.95 (36.25)</td>
</tr>
<tr>
<td>L4/L5 Moment</td>
<td></td>
<td>91.87 – 302.56</td>
<td>35.62 – 181.75</td>
<td>34.41 – 156.28</td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td>224.15 (47.31)</td>
<td>117.61 (31.17)</td>
<td>113.42 (31.07)</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>153.25 – 302.56</td>
<td>55.46 – 181.75</td>
<td>55.89 – 156.28</td>
</tr>
<tr>
<td>(Nm) Males</td>
<td></td>
<td>144.34 (37.80)</td>
<td>88.80 (45.31)</td>
<td>65.23 (20.38)</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>91.87 – 228.18</td>
<td>35.62 – 149.15</td>
<td>34.41 – 97.49</td>
</tr>
<tr>
<td>(Nm) Females</td>
<td></td>
<td>58.58 (22.34)</td>
<td>21.40 (18.49)</td>
<td>20.23 (19.80)</td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td>-0.78 – 91.24</td>
<td>-15.24 – 57.04</td>
<td>-15.02 – 63.99</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>65.99 (19.12)</td>
<td>25.62 (17.40)</td>
<td>28.68 (18.00)</td>
</tr>
<tr>
<td>(°) Males</td>
<td></td>
<td>34.03 – 91.24</td>
<td>-9.56 – 52.11</td>
<td>-4.69 – 63.99</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td>50.63 (23.46)</td>
<td>16.14 (19.15)</td>
<td>10.57 (17.34)</td>
</tr>
<tr>
<td>(°) Females</td>
<td></td>
<td>-0.78 – 82.6</td>
<td>-15.24 – 57.04</td>
<td>-15.02 – 40.07</td>
</tr>
</tbody>
</table>

Note: Nm, moment; °, degree.
Table 4. Mean (±standard deviation) total work, lower body work, trunk work, and percent contribution of lower body work done by participant across the three tasks.

<table>
<thead>
<tr>
<th></th>
<th>Boarded Lift</th>
<th>Stretcher Raise</th>
<th>Stretcher Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Work (J)</strong></td>
<td>26530 (9026)</td>
<td>12618 (6152)</td>
<td>13665 (5490)</td>
</tr>
<tr>
<td><strong>Lower Body Work (J)</strong></td>
<td>20106 (6263)</td>
<td>10903 (5302)</td>
<td>13035 (4967)</td>
</tr>
<tr>
<td><strong>Trunk Work (J)</strong></td>
<td>7513 (2934)</td>
<td>2206 (1855)</td>
<td>1526 (1516)</td>
</tr>
<tr>
<td><strong>% Lower Body Work</strong></td>
<td>73% (0.09)</td>
<td>82% (0.13)</td>
<td>91% (0.12)</td>
</tr>
<tr>
<td><strong>Total Work (males, J)</strong></td>
<td>29147 (9462)</td>
<td>12280 (6868)</td>
<td>14147 (6422)</td>
</tr>
<tr>
<td><strong>Lower Body Work (males, J)</strong></td>
<td>21998 (5723)</td>
<td>10406 (5798)</td>
<td>13278 (5850)</td>
</tr>
<tr>
<td><strong>Trunk Work (males, J)</strong></td>
<td>9092 (2077)</td>
<td>2642 (1958)</td>
<td>2215 (1458)</td>
</tr>
<tr>
<td><strong>% Lower Body Work (males)</strong></td>
<td>70% (0.07)</td>
<td>78% (0.13)</td>
<td>84% (0.12)</td>
</tr>
<tr>
<td><strong>Total Work (females, J)</strong></td>
<td>22042 (6115)</td>
<td>13212 (4688)</td>
<td>12755 (2940)</td>
</tr>
<tr>
<td><strong>Lower Body Work (females, J)</strong></td>
<td>17066 (5974)</td>
<td>11727 (4331)</td>
<td>12642 (3099)</td>
</tr>
<tr>
<td><strong>Trunk Work (females, J)</strong></td>
<td>1484 (1429)</td>
<td>4976 (2819)</td>
<td>405 (750)</td>
</tr>
<tr>
<td><strong>% Lower Body Work (females)</strong></td>
<td>76% (0.10)</td>
<td>87% (0.12)</td>
<td>98% (0.06)</td>
</tr>
</tbody>
</table>

Note: Tot, average work (J) done by the lower body and trunk; LB, average work done by the lower body (ankles, knees, and hips bilaterally); Tr, average work done by the trunk; %LB, (LB/(Tr+LB))*100.

**Discussion**

The descriptive biomechanical data agrees with earlier data collected on paramedic work. Lavender et al. (2000) identified lifting a patient vertically on a backboard as the task with the greatest spine load. This dataset also identifies the boarded lift as the most demanding, eliciting the greatest peak sagittal L4/L5 moments and peak sagittal trunk angles, and also required the most total work to complete. These data also agrees with the field-work done by Prairie and Corbeil (2014), where lifting resulted in median sagittal flexion angles of 40.1° (22.1). This value was within the range of angles measured in the present study; angles of 20.23° (19.80) produced during stretcher loading, 58.58° (22.34) during boarded lifting, and 21.40° (18.49)
during stretcher raising (Table 3). It should be noted that Prairie and Corbeil (2014) found no differences in trunk angles between urgent and non-urgent lifting activities, implying that the trunk angle values observed in the non-urgent setting of the motion capture lab may be generalizable to actual work situations.

An increased contribution of lower-body work was significantly correlated with a reduction in peak sagittal L4/L5 moment and peak sagittal trunk angle. Given that higher exposures to peak sagittal L4/L5 moment and peak sagittal trunk angle are associated with the development of back injuries (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005), it appears that exposure to these mechanical factors can be reduced by generating a greater proportion of work from the lower body. This finding is similar to the result of Nadeau & Gagnon (1996), who also indicated that increasing the contribution of work done by the lower body reduced spine moments during heavy pushing tasks. This relationship has a clear mechanical explanation. Since power and work are calculated using joints moments and angular velocities, individuals who produce less work with their trunk should have lower trunk moments.

This finding may help to shed light on why previous efforts aimed at comparing stoop and squat lifts have not consistently been able to identify an ideal lifting technique, in terms of spine loading (van Dieën et al., 1999; Burgess-Limerick, 2003). When examining spine loading during a stoop or a squat lift, techniques are generally categorized by their initial static posture. Starting posture is not always indicative of motion (Zhang, Nussbaum, & Chaffin, 2000). An individual may initially assume a squat posture, but produce work primarily from the trunk depending on their movement behavior. This in turn would increase the spine moment of the individual, resulting in a lift technically classified as a squat lift, but one that results in a high
moment. Focusing on the location of work production provides an alternative method of analysis that encompasses the dynamic phase of the lift.

This knowledge has a clear practical application. Numerous administrative interventions have focused on technique as a method of reducing work related back injuries. Historically, these interventions have had mixed results (Maritimo et al., 2008). The technique training provided in these studies generally focuses on posture, rather than the relative work contribution of different body segments. The relationships demonstrated in this study could help to guide future interventions by focusing on training lifters to access power from their lower body, rather than critiquing initial starting postures. More work is needed to determine whether this relationship exists in other populations and to determine which coaching and training methods are useful to help lifters transition movement behaviors that provide for an increased contribution of work from the lower body.

These data should be interpreted in context of the following considerations. First, although the inclusion of healthy paramedics may help to identify ideal lifting technique, it also introduces a sample bias. Given the high rate of injury among paramedics, the paramedics who participated in the study were likely among the healthiest and fittest. Future research should expand inclusion criteria to examine the effects of previous injury on lifting technique, potentially by comparing the techniques of injured and uninjured paramedics. Second, it is difficult to replicate the demands of the job in a laboratory-based setting. The laboratory setting may also eliminate the pressure paramedics may feel during an actual emergency situation. The work done by Prairie and Corbeil (2014), however, indicated that paramedics’ lifting techniques may not change substantially between low pressure and high pressure situations. Lastly, the linked-segment model used did not incorporate the arms. Using ground reaction force data to
calculate arm moments requires the trunk force to be divided equally across the shoulders under the assumption that the lift is perfectly symmetrical, which may not always be the case. For the boarded lift task, the arms were fully extended for the duration of the task, and as such would not greatly contribute to the amount of work done by the upper body as the angular velocity would be minimal. For the stretcher raise and stretcher load tasks, however, there was likely some arm flexion involved, and therefore some arm work. This would lead to an overestimation of the relative contribution of lower body work.

In conclusion, paramedics whose lower bodies contributed more work to lifting experienced lower trunk angles and moments. In general, the demands quantified by this study reflect previous work done with this population, with boarded patient lifting continuing to be the greatest physical challenge. This study advances from previous stoop or squat based analyses to consider the importance of dynamics throughout the lifting activity. Additionally, the study’s findings could help guide future lifting technique interventions, where instructors can focus on teaching lifters how to access lower body power rather than focusing on posture alone.
Chapter 4

Using the vertical jump as a screening tool for sagittal trunk angles and moments during paramedic work
Abstract

**Background:** At present, there are no screening tools available to identify paramedics who are likely to possess the physical capacity necessary to lift in a spine-sparing manner. Given its association with lifting performance in other fields, the vertical jump may be one such tool. The purpose of this was to examine whether the vertical jump was a suitable tool for screening for lifters who display reduced trunk angles and moments.

**Methods:** Thirty-three healthy paramedics performed three occupational lifting tasks, as well as a vertical jump test. A 3D linked-segment model was then produced to compute trunk moments and angles during lifting. Peak lower body power was computed using vertical jump height. Data analysis consisted of a series of correlations between peak lower body power capacity, and peak sagittal trunk angles and moments.

**Results:** An increase in peak lower body power capacity was not associated with a reduction in peak trunk angles and moments experienced during commonly performed paramedic lifting tasks.

**Conclusion:** The vertical jump may not be a useful screening tool for identifying paramedics who lift in a spine-sparing manner. This could potentially be explained by the fact that measuring an individual’s maximum lower body capacity is not indicative of lifting strategy they adopt during sub-maximal lifting, or due to the fact that the jump test performed was not suitable.
Introduction

Paramedic work is physically demanding, and can be characterized by long periods of sedentary activity followed by bouts of high intensity work (Broniecki et al., 2010). As a profession, paramedics have one of highest rates of injuries among all occupational groups, 94.6/1000 workers, compared to a national average of 13.0/1000 workers (Maguire, 2014). One major cause of these injuries is muscular stress while lifting, which accounts for approximately 40% of all paramedic injuries (Maguire, 2014; Maguire, 2013). The major site of injury is the low back, which accounts for between 35 and 50% of all paramedic injuries (Hoga and Ellis, 1990; Ambulance Paramedics of British Columbia, 2000). These back injuries can be explained in part by the spine loads placed on paramedics during lifting, including loading a stretcher into an ambulance (Cooper & Ghassemieh, 2006) and lifting a patient on a backboard (Lavender et al., 2000), where each have been shown to produce spine compression and shear values that exceed the NIOSH recommended action limit (Waters et al., 1993). Lifting is also requires the greatest ranges of trunk motion (Prairie and Corbeil, 2014). Lifting is a critical task that paramedics perform, but can also be detrimental to paramedics' health.

In part to help reduce injuries, the Paramedic Association of Canada (PAC) has stated that paramedics must demonstrate adequate strength and fitness for practice (Paramedic Association of Canada, 2015). These guidelines are very general at present, with no specific standards in place. The limited descriptive data that exists indicates that paramedics possess normal levels of aerobic capacity, muscle strength, and muscle endurance (Chapman et al., 2007). However, at present, there is limited evidence to demonstrate which of these characteristics are indeed relevant. To date, the only evidence that supports this mandate indicates that an increased amount of aerobic capacity and back muscle endurance is associated
with a decrease in physiological markers of fatigue during lengthy stretcher carries (Barnekow-Bergkvist, 2004). Given the detrimental effects of lifting, it would be beneficial to identify strength and fitness related determinants of lifting performance for paramedics. This will help organizations like PAC to define what physical attributes required, enabling the development of job-specific screening tools that can help to identify paramedics who possess these attributes.

Considering the requirement to lift heavy loads, it is plausible that lower body power could be an important determinant of a paramedics lifting performance. In an Olympic lifting setting, an increase in peak lower body power has been associated with an increase in lifting performance (i.e. maximum lifting capacity during squat, snatch, and clean and jerk lifts) (Carlock et al., 2004; Hori et al., 2008). In a paramedic setting, it has been shown that paramedics who generate more work during lifting with their lower body display improved lifting performance, operationalized as a reduction in sagittal trunk moment and angle (Makhoul et al., 2015). In a manual materials handling setting, it has also been shown that an increased contribution of power and work by the lower body results in reduced spine moments during pushing tasks (Nadeau & Gagnon, 1996). Considering the importance of lower body power on lifting performance, a common vertical jump test may be a suitable predictor of paramedics’ lower body power, and ultimately their lifting performance.

The purpose of this study was to determine if lower body power, as measured using a standard vertical jump test, was associated with lower peak sagittal L4/L5 moments, or peak sagittal spine angles experienced by participants as they performed three different types of common paramedic lifting tasks. Based on previous research demonstrating the association between lower body work and these spine exposures, we hypothesized that an increase in peak lower body power would be associated with reduced trunk angles and moments.
Methods

Paramedics were recruited from a local service using advertisements in their daily batch briefings. Only paramedics who had more than two years of work experience with the service, and who had not suffered work-related injuries in the preceding six months were eligible to participate. Thirty-three paramedics who met the inclusion criteria volunteered to participate (see Table 1). The project was approved by the university’s research ethics boards and all paramedics provided informed consent prior to participation.

Table 1. Mean participant demographic information (+/- standard deviations).

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 18)</th>
<th>Female (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>39.2 (9.0)</td>
<td>34.5 (5.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>89.8 (12.9)</td>
<td>70.2 (12.5)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.76 (0.08)</td>
<td>1.64 (0.07)</td>
</tr>
</tbody>
</table>

Note: yrs, years; kg, kilograms; m, meters; n, number of participants.

Protocol

Participants performed a vertical jump test and completed three repetitions of three different simulated occupational lifting tasks. The order of exposure to the jump test and occupational simulations was randomized across participants.

Vertical jump testing. Participants' vertical jump heights were measured using the vertical jump protocol outline in the CSEP-PATH Manual (CSEP, 2013). Participants stood next to a measuring tape attached to a wall and reached overhead as high as they could with their feet still on the floor to obtain their standing reach height. Participants then bent their knees into a semi-squatted position, swung their arms backwards, jumped as high as possible, and touched the measuring tape to obtain their jumping reach height. Participants performed two vertical jumps, with the highest single value taken as their jumping reach height. The difference between
participants standing reach height and their jumping reach height was recorded as their vertical jump height.

**Simulated occupational tasks.** Participants performed three repetitions of the following simulated paramedic lifting tasks: boarded lift (Figure 1-1), stretcher raise (Figure 1-2), stretcher load, and (Figure 1-3). The boarded lift task required participants to vertically lift a rescue mannequin on a back board from the ground to a height where the patient could be placed on a stretcher (~90 cm). The stretcher raise task required participants to raise a stretcher with a mannequin on it from a stretcher-top height of 90 cm to 110 cm. The stretcher load task required participants to lift a stretcher with a mannequin on it from a stretcher-top height of 110 cm to 125 cm. It is important to note that during stretcher loading, participants were lifting the bottom end of the stretcher, while during stretcher raising, paramedics were lifting the top end, meaning that the handles participants grasped were different during the two tasks.

Stretcher tasks were completed using a Ferno 35X stretcher (Ferno, Wilmington, Ohio U.S.A.), whereas a Ferno EXL Scoop Stretcher (Ferno, Wilmington, Ohio, U.S.A.) was used for the boarded patient lift. Additionally, all tasks required paramedics to lift a 75 kg and 185 cm IAFF Rescue Randy manikin (Simulaids, Saugerties, New York., U.S.A.). The 75 kg weight is representative of the average patient weight lifted by paramedics (Coffey, MacPhee, & Fischer, 2015). Paramedics were instructed to perform the lift as they would in an actual emergency situation, with no specific lifting technique instructions provided. To further ensure adequate realism, the partnered lifts (boarded patient lift and the stretcher raise) were completed with a fellow paramedic assuming the partner lifting role. Although partner height has been shown to affect average spine loads over the course of a lifting task, peak spine loads (which are the primary measures of interest) are unaffected (Dennis & Barrett, 2003).
Instrumentation

All simulated occupational tasks were performed in a motion capture lab, equipped with fourteen Oqus© cameras (Qualisys: Gothenburg, Sweden) and two Bertec FP4060-05-PT force plates (Bertec: Columbus, Ohio, U.S.A.). Analog force data was converted to a digital signal and
synchronized with motion data through the Qualisys Track Manager (QTM) software, where all signals were sampled at 60 Hz. To facilitate motion tracking, 11 mm reflective markers were placed over anatomical landmarks as required to define foot, shank, and thigh segments bilaterally, in addition to the pelvis and thorax (Wu et al., 2002; 2005) (Appendix D). Additional markers fixed to rigid bodies were used for tracking the shank, thigh and pelvis segments during the dynamic lifting trials (Appendix D). Prior to initiating task performance a five-second standing static calibration trial was recorded, where participants were asked to stand upright in an anatomical position.

**Data Processing**

Marker data were visually inspected within the Qualisys QTM software. Where marker trajectory gaps were identified, gaps were filled using a third-order polynomial function in the QTM software. Trajectory and force data were then exported for further analysis using Visual3D (Version 5, C-motion, 2015).

Using the Visual 3D software, force and trajectory data were filtered using a low-pass fourth order dual-pass Butterworth filter, set at an effective cut-off frequency of 4.4 Hz, as determined through residual analysis (Appendix F) (Winter and Patla, 1997).

Once filtered, marker data were used to develop an eight-segment (right and left feet, shanks, and thighs; pelvis, and trunk) bottom-up linked-segment model following the procedures described by Robertson et al. (2014).

The kinematic model was parametrized within the Visual3D software by following these steps. First, segments were defined using the corresponding marker data. To summarize, foot, shank, and thorax segments were defined by markers placed medially and laterally on their
proximal and distal endpoints. The pelvis was defined using markers placed on the anterior and posterior superior iliac crests (ASIS & PSIS). Hip joint centers (HJC) for the thigh segments were then computed using the following formulas as described by Bell, Pedersen, & Brand (1989; 1990):

\[ \text{HJC} = (\pm 0.36 \times \text{ASIS\_Distance}, -0.19 \times \text{ASIS\_Distance}, 0.3 \times \text{ASIS\_Distance}) \]

**Equation 1.** Method to estimate hip joint center (HJC) adapted from Bell, Pederson, & Brand (1989; 1990).

Where the ± denotes the calculation required to estimate the right (+) and left (-) HJC and where ASIS distance is the distance between the left and right ASIS as determined using the marker data.

ISB recommendations were followed to define individual segment coordinate systems where positive X-axes projected anteriorly, positive Y-axes projected axially away from the ground, and positive Z-axes projected from left to right, laterally on the right side and medially on the left side (Wu et al., 2002; 2005)).

Joint angles were described as the orientation of the distal segment relative to the proximal segment (e.g. the orientation of the shank relative to the thigh) using a Z-Y-X decomposition. For reference, using this approach, during upright standing the thigh and shank are aligned where the corresponding knee flexion angle (shank coordinate system relative to thigh coordinate system) would be approximately 0°. However, as one flexes at the knee to squat down, the shank segment is rotated about the Z axis of the thigh, in a negative direction since the thigh Z-axis is directed from left to right. As such, these flexion angles are negative due to the ISB conventions used for the segment coordinate systems. However, to ease interpretability, we have corrected corresponding flexion angles such that flexion is positive and extension negative.
To compute segment kinetics Visual3D defaults to using data from Dempster (1955) to estimate segment anthropometrics equations described by Hanavan’s (1964) to estimate segment inertial properties. These values, in conjunction with ground reaction force data and segment kinematics, were used to compute joint moments and forces, the process for which has been described by Robertson et al. (2014).

With segment kinematics and kinetics computed, variables of interest were computed using the Visual3D software for each repetition of each task for each participant. The sagittal plane moment at the proximal end of the pelvis, approximately in line with the L4/L5 vertebrae, as well as the sagittal angle of the trunk segment were computed throughout each lifting trial. The maximum value for each measure was extracted from each trial, to provide a peak sagittal L4/L5 moment and a peak sagittal trunk angle (with respect to the pelvis segment) for each repetition of each task. These variables were chosen because of their association with the development of low back injury (Marras et al., 1993; Norman et al., 1998; Wrigley et al., 2005).

Peak lower body power was then calculated from vertical jump height, using the following equation:

\[
\text{Peak Power} = 60.7 \times (\text{jump height [cm]} + 45.3 \times (\text{body mass [kg]}) - 2055
\]

**Equation 2.** Sayers’ equation to calculate peak lower body power (Sayers et al., 1999).

Note: cm, centimeters; kg, kilograms.

**Statistical Analysis**

Peak sagittal L4/L5 moments and peak sagittal trunk angle were averaged across the three repetitions of each lifting task to give one moment and angle per lifting task, per participant. Descriptive data including means, maximums, and minimums related to each
outcome measure were calculated at the group level, and for males and females. Data were assessed for normality and homoscedasticity prior to applying separate Pearson product moment correlations to investigate for associations between the percentage of lower body work performed and the peak sagittal L4/L5 moment and the peak sagittal trunk angle within each lifting task. Statistical tests were performed using IBM SPSS v.20 (IBM Corp. Armonk, NY, USA), where $p<0.05$ was used to indicate significant correlations.

**Results**

The boarded lifting task resulted in the largest moments and angles, for the entire group and across both genders (Table 2). On average, females were exposed to lower trunk angles and moments than males. On average, males were able to produce a greater amount of peak lower body power (Table 3).
Table 2. Mean (±standard deviation) and range (min – max) peak sagittal L4/L5 moments and sagittal trunk angles within each task, expressed at the group level and by gender.

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Task</th>
<th>Group Level</th>
<th>Task</th>
<th>Task</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Sagittal L4/L5 Moment (Nm)</td>
<td>Boarded Lift</td>
<td>184.25 (58.45)</td>
<td>104.81 (40.10)</td>
<td>90.95 (36.25)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>91.87 – 302.56</td>
<td>35.62 – 181.75</td>
<td>34.41 – 156.28</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>Mean</td>
<td>224.15 (47.31)</td>
<td>117.61 (31.17)</td>
<td>113.42 (31.07)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>153.25 – 302.56</td>
<td>55.46 – 181.75</td>
<td>55.89 – 156.28</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>Mean</td>
<td>144.34 (37.80)</td>
<td>88.80 (45.31)</td>
<td>65.23 (20.38)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>91.87 – 228.18</td>
<td>35.62 – 149.15</td>
<td>34.41 – 97.49</td>
</tr>
<tr>
<td>Peak Sagittal Trunk Angle (°)</td>
<td>Boarded Lift</td>
<td>58.58 (22.34)</td>
<td>21.40 (18.49)</td>
<td>20.23 (19.80)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>-0.78 – 91.24</td>
<td>-15.24 – 57.04</td>
<td>-15.02 – 63.99</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>Mean</td>
<td>65.9929 (19.12)</td>
<td>25.62 (17.40)</td>
<td>28.68 (18.00)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>34.03 – 91.24</td>
<td>-9.56 – 52.11</td>
<td>-4.69 – 63.99</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>Mean</td>
<td>50.63 (23.46)</td>
<td>16.14 (19.15)</td>
<td>10.57 (17.34)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>-0.78 – 82.6</td>
<td>-15.24 – 57.04</td>
<td>-15.02 – 40.07</td>
</tr>
</tbody>
</table>

Note: Nm, moment; °, degree.

Table 3. Peak lower body power in Watts derived using the Sayers (1999) equation (± standard deviation).

<table>
<thead>
<tr>
<th>Power</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3965 (1006)</td>
</tr>
<tr>
<td>Range</td>
<td>1815 – 6122</td>
</tr>
<tr>
<td>Mean (males)</td>
<td>4675 (664)</td>
</tr>
<tr>
<td>Range (males)</td>
<td>3624 – 6122</td>
</tr>
<tr>
<td>Mean (females)</td>
<td>3112 (595)</td>
</tr>
<tr>
<td>Range (females)</td>
<td>1815 – 3987</td>
</tr>
</tbody>
</table>

In general, peak lower body power (W) was only significantly associated with peak sagittal L4/L5 moment during boarded lift task, where an increase in peak lower body power was
associated with an increase in peak sagittal L4/L5 moment. Peak lower body power was not associated with peak sagittal L4/L5 moment during the stretcher raise and stretcher load task, or peak sagittal trunk angle (Table 4) during any task.

**Table 4.** Correlation coefficients ($r$), significance levels ($p$), and number of subjects (N) between peak lower body power and peak sagittal L4/L5 moment, and peak sagittal trunk angle during the stretcher load, boarded lift, and stretcher raise tasks.

<table>
<thead>
<tr>
<th></th>
<th>Boarded Lift</th>
<th></th>
<th>Stretcher Raise</th>
<th></th>
<th>Stretcher Load</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M A</td>
<td></td>
<td>M A</td>
<td></td>
<td>M A</td>
<td></td>
</tr>
<tr>
<td><strong>Lower Body Power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Watts)</td>
<td>$r$</td>
<td>-.495</td>
<td>-.261</td>
<td>-.068</td>
<td>.474</td>
<td>-.261</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>.005</td>
<td>.430</td>
<td>.171</td>
<td>.735</td>
<td>.009</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>30</td>
<td>29</td>
<td>29</td>
<td>27</td>
<td>29</td>
</tr>
</tbody>
</table>

Note: M, moment (Newton-Metres); A, angle (degrees).

**Discussion**

Higher peak lower body power capacity was not associated with lower trunk moments or angles during lifting. There was one significant positive correlations between peak lower body power and peak sagittal L4/L5 moment, meaning that as peak lower body power increased, so did the spine moment. This is likely the product of body weight, rather than technique. On average, male participants had higher body weight than females. An increase in body weight drives an increase in ground reaction force, which generally means that spine moments also increase with body weight. Male participants could also produce more peak lower body power, on average, than females. The differences between the two groups likely created an artificial trend (See Appendix H for moment and power data distributions by gender). Gender differences were not expected, and the study was underpowered to run statistics on males and females separately.
This lack of significant correlations deviates from other literature where the vertical jump has been reported as an effective predictor of performance (Carlock et al., 2014; Hori et al., 2008). In these studies peak lower body power calculated from a vertical jump, using the Sayers equation (Sayers et al., 1999), was positively correlated with maximum lifting capacity. Carlock et al. (2014) found moderate to strong correlations between peak lower body power and one-repetition squat, snatch, and clean-and-jerk maximums among lifters training at the Olympic level. This trend was also demonstrated among semi-professional Australian Rules Football players, where significant correlations were found between barbell lift strength (front squat and power clean) and vertical jump power (Hori et al., 2008). In this context, individuals who were able to produce more peak lower body power during a vertical jump task were also able to produce more power during lifting.

There is one major difference between the present study and previous studies that linked peak lower body power to lifting performance: the present study was focused on predicting lifting behavior rather than maximal lifting capacity. Calculating peak lower body power from a vertical jump score offers a measure of an individual’s maximum lower body capacity. Although lifting using an increased contribution of lower body work has been shown to be spine sparing (Makhoul et al., 2015), this is the result of individuals using their lower body power for lifting. As such, measuring maximum lower body capacity may not be appropriate for predicting lifting strategies during sub-maximal lifting.

Another possible explanation for the lack of significant associations is the actual jump test employed in the present study. In general, there are two common methods used to for testing vertical jump: the counter-movement jump, where individuals start in a standing position and make a downward movement with an arm swing before starting to push off, and the squat jump,
where participants start in a squatted position before pushing off (Bobbert et al., 1996; Harman et al., 1990). In the present study, the counter-movement jump was used, which may not be as representative of lifting. Paramedic lifting does not incorporate a counter movement or an arm swing, where a squat jump may have been a better alternative.

Additionally, the present study’s participants had varying degrees of familiarity with the counter-movement jump. Given that both the counter-movement and the arm swing have been shown to increase the amount of power produced during jumping (Harman et al., 1990), it could be that participants who were more familiar with the test were able to produce more power using the counter-movement and the arm swing, rather than as a result of their lower body power capability. Regardless of the mechanism, the counter-movement jump is not likely an appropriate screening tool to identify paramedics’ that are likely to lift with more spine sparing mechanics.

These data should be interpreted in context of the following considerations. First, although the inclusion of healthy paramedics may help to identify ideal lifting technique, it also could have introduced a sample bias. Given the high rate of injury among paramedics, the paramedics who participated in the study were likely among the healthiest and fittest, which could impact lower body power production depending on the type of injury previously sustained. Future research should expand inclusion criteria to examine the effects of previous injury on lifting technique. Second, the sample size for this study was quite small; larger scale studies should be conducted to validate the generalizability of these results.

In conclusion, peak lower body power as calculated from the vertical jump was not correlated to peak sagittal L4/L5 moments and peak sagittal trunk angles during paramedic lifting tasks, despite the fact that an increased contribution of work by the lower body was associated with a reduction in these factors (Makhoul et al., 2015). This could be due to
differences in movement strategies between the counter-movement jump and lifting, or between inexperienced and experienced jumpers. Future research could examine the squat jump as a method of testing the relationship between lower body power and spinal loading.
Chapter 5

General Discussion

This study explored for biomechanical determinates of safer lifting technique, where lower trunk moments and less trunk flexion were considered as indicators of safety based on their association with back injuries in a manual materials handling setting. The overarching hypothesis was that an increased contribution of work and power by the lower body would be associated with lower trunk moments and less trunk flexion. This idea originates from perspectives gained by experienced coaches in the strength and conditioning sphere, which is that producing power from the lower body is safer for the spine during lifting, as opposed to producing power from the trunk. The work of Nadeau & Gagnon (1996) provided empirical evidence for this idea’s efficacy in an occupationally relevant context. They demonstrated that an increased contribution of work and power by the lower body resulted in decreased trunk moments (a more spine sparing technique) during pushing tasks. Joint power analysis is not novel, and has been used since the 1980s (Robertson & Winter, 1980); however it has not yet been applied to lifting to determine if an increased contribution of work from the lower body during lifting is spine sparing, despite the positive results produced during heavy pushing tasks (Nadeau & Gagnon, 1996). Filling this void in the body of lifting literature may provide a lens with which to examine lifting technique beyond postural assessments, which at present, have not found an ideal technique (van Dieën et al., 1999).

The main challenge with assessing the dynamics of lifting (power and work), however, is the equipment and expertise required to perform it. It is not practical for paramedic safety officers or other clinical practitioners to calculate the power and work contribution of the lower body when screening lifters. As such, a simpler screening tool may be better. The vertical jump
presented a plausible screening tool to achieve this requirement for simplicity. It was assumed that individuals with greater lower body power would be more likely to do more work with their lower body, which would then be associated with reduced spine moments and angles. This was not the case, however, as peak lower body power (measured during a vertical jump test) was not associated with trunk angles or moments, and was also not associated with the contribution of lower body work (Appendix H, Table 1). It would seem that just because an individual has a greater capacity to produce peak lower body power does not mean they will apply it to lifting.

Despite this lack of association, the study itself still possessed a number of strengths. First, the tasks that were selected were the result of extensive discussion and research, using paramedics’ expertise to create simulations that were as realistic as possible: including a physical demands description and a survey filled out by a local paramedic service to identify tasks that are performed frequently by paramedics and are also physically demanding (OPPAT, 2015). Once the tasks were selected, active-duty paramedics were invited to help develop the protocol by demonstrating how the tasks would be performed on actual patients and while using their standard equipment. Photographs and video information were captured during these pilot sessions, and measurements were taken of a standard ambulance loading platform used by paramedics, where this information was used to inform the mock-ups in the lab. Second, the equipment used during the simulated tasks is currently used during active service, which means paramedics were comfortable working with it. Third, the equipment used to capture motion and force data was advanced from previous studies investigation of the biomechanics of paramedic work (Lavender et al., 2000; Cooper & Ghassemieh, 2006); reflective marker data allows three-dimensional data to be collected with a high degree of accuracy. Additionally, the sample population was made up of individuals who had been healthy for the previous six months. The
benefit of this is that it provided the study with a population of paramedics who may be more physically competent, and as such provided insight into the physical capacities of healthier paramedics.

The study did have limitations, however. Despite the usefulness of including only healthy paramedics, it also may have introduced a sample bias, where only the most physically competent were eligible to participate. As such, it is not clear how previous injury would affect the physical capacity of paramedics. Second, the low-pressure environment of the laboratory may have affected movement strategies as well, although this is not certain based on the results of Prairie and Corbeil (2014), as previously discussed in the manuscript (Chapter 3, discussion section). The biomechanical model itself also may have limitations: segment masses were computed using total body weight and Dempster’s anthropometric data (Dempster, 1955), while moment of inertia and center of gravity values are calculated using Hanavan’s (1964) model. The uses of different models generally result in changes in these values (Pearsall & Costigan, 1999; Rao, Amaratini, Berton, & Favier, 2006). The impact of these changes varies somewhat in the literature, with some authors reporting changes in joints moments of approximately 1% (Pearsall & Costigan, 1999) and other reporting changes of up to 20% (Rao et al., 2006). As such, future researchers should be cautious about comparing their data to the present data set, depending on which model they use to calculate segment masses, moments of inertia and centers of gravity.

Future research could build on this research while addressing the limitations. First, it would be important to expand the inclusion criteria for another cross-sectional studies so that participants who had sustained an injury more recently than six months could be included in the study; these participants would have to have been cleared for active duty, however. It would also be important to record these injuries and examine whether or not they were associated with the
contribution of lower body work. This additional cross-sectional study could also assess other
generic fitness measures to see whether or not they are associated with trunk angles and
moments, and the contribution of lower body work; potentially a squat jump, as previously
mentioned in the short communication (Chapter 4, discussion section).

If a greater contribution of lower body power and work remains associated with a
reduction in trunk moments and angles among a larger sample of paramedics (including a greater
range of physical health and previous injuries), then a longitudinal study could be undertaken.
This study could examine a number of different measures, depending on the relationships
uncovered by other cross-sectional studies. If, for example, a screening tool is found that is
highly associated with both the contribution of lower body power and work as well as trunk
angles and moments, then the study could be relatively straightforward: a cohort of paramedics
could be tested regularly using this hypothetical screening tool, and the rate of back injury due to
lifting could be recorded. A receiver operator characteristic curve could then be used to establish
the ideal score required for this screening tool that most strongly predicts injury risk, without
including large proportions of false-positives and false-negatives (high sensitivity and
specificity). This screening tool could then be used to identify paramedics who may require
additional strength training or coaching to help protect them from injury.

If a suitable screening tool cannot be identified, then the study would require a different
methodology. Once again, a cohort of paramedics could be followed and their rates of back
injury could be recorded. Their lifting technique however, would have to be monitored in order
to identify their respective contribution of lower body power and work. This could be done by
quantifying their lifting dynamics using motion capture and force plate systems at regular
intervals, similar to the present study. Alternatively, if a series of electrogoniometers could be
worn by paramedics on the job, similar to the work of Prairie and Corbeil (2014), but for the entire body, the contribution of lower body power and work could be calculated while paramedics are on the job. This could be achieved by estimating changes in segmental energy, as described and validated by de Looze et al. (1992). Using this approach the energy content of a rigid segment is calculated as the sum of its potential, translational kinetic and rotational kinetic energy. Segment masses would also be required to calculate this, which could either be measured at the outset of the measurement period, or approximated using anthropometric values. These studies could provide new insights into injury prevention and lifting technique.

I will now conclude with a brief discussion of my own personal growth over the course of this two-year study period. I began this program with very limited knowledge of actual biomechanics; my knowledge of movement analysis came from a coaching setting in both strength and conditioning as well as general athletics. My main objective was to learn to describe movement quantitatively, to provide objective feedback for athletes. I can say with certainty that this is an area where I have expanded my horizons enormously. The power and work analysis is an area I find especially exciting; it has the potential to provide athletes with objective measures of where they are experiencing movement inefficiencies.

I have also gained a much deeper appreciation for scientific theory and being able to identify well-crafted studies. This is especially valuable to me; there are often many conflicting claims that are made, especially in the strength and conditioning sphere. I feel as though now I have the capacity to identify studies that actually demonstrate what they set out to, and identify flaws in methodology that result in statements being presented as facts to be nothing more than claims.
References


Dennis, GJ., Barrett, RS. Spinal loads during two-person team lifting, effect of matched versus unmatched standing height. Ergonomics, 32(1), 25 – 38

de Looze, MP., Bussman, JBJ., Kingma, I., Toussaint, HM. Different methods to estimate total power and its components during lifting. Journal of Biomechanics, 25(9), 1089 – 1095.


Appendix A
Ethics Approval

August 26, 2014

Dr. Steven Fischer
Assistant Professor School of Kinesiology and Health Studies
Queen's University
28 Division Street
Kingston, ON, K7L 3N6

Dear Dr. Fischer:

RE: Amendment for your study entitled: GPHE-161-13 Evaluating human performance when completing simulated occupational tasks; ROMEO# 6011647 Thank you for submitting your amendment requesting the following changes:

1) To modify the simulated tasks to represent those common to paramedic work;

2) To add additional strength and fitness tasks within the protocol to assess participant’s functional capability to carry out paramedic work tasks;

3) To change the participant pool to include current paramedics, or those currently enrolled in a paramedic training program;

4) To add Dr. Kathryn Sinden, Postdoctoral Fellow, to the research team.


By this letter you have ethics clearance for these changes. Good luck with your research.

Sincerely,

Joan Stevenson, Ph.D.
Chair General Research Ethics Board c.: Dr. Pat Costigan, and Dr. Kathryn Sinden, Co-investigators

Mr. Paul Makhoul, Ms. Elizabeth Price, and Mr. Brendan Coffey, Research Assistants
Appendix B
Letter of Information and Consent Forms

Letter of Information
Evaluating human performance when completing simulated occupational tasks

This research is being conducted by Dr. Steven Fischer and Dr. Kathryn Sindén in the School of Kinesiology and Health Studies at Queen’s University in Kingston, Ontario.

What is this study about? The purpose of this research is to measure indicators of human performance before, and while you complete the simulated tasks as outlined below. Millions of Canadians spend 40+ hours per week at work completing a variety of occupational tasks, a small sample of which you are going to simulate today. However, in the workplace it is difficult to measure indicators of human performance and we are often left to guess how workers might move or activate their muscles to complete a work task. Or, if we aim to improve their workplace conditions, it is difficult to know how a potential change in the workplace (moving a work surface or adding additional equipment for example) might impact on their performance. For that reason, you are being asked to participate in this study where you will complete simulated versions of occupational tasks while we use high-fidelity measurement tools and techniques to measure your performance. We use this information to help us better estimate how workers are likely to perform these techniques in industry, since we are unable to measure them directly on the shop floor.

What simulated tasks will I be asked to complete? In this study, you will be asked to complete a short survey, a series of tasks design to help us evaluate your functional capability, and a series of simulated common paramedic tasks. The brief survey will be used to help us learn more about your perspective of the current workplace organizational policies and procedures. The strength and fitness tasks will include: bi-manual hand dexterity and grip strength, core muscle endurance, hip flexibility, functional movement quality, aerobic fitness and general fitness (push-ups, balance, jump test); where your performance on these tasks will be used to establish your underlying functional capability and level of fitness. The simulated paramedic tasks will include a: vertical patient transfer, lateral patient transfer, unloaded stairchair ascent, loaded stairchair decent, loaded stretcher load into ambulance, loaded stretcher manipulation task, and an equipment carrying tasks. All loaded activities will be completed by simulating the weight of a patient using a 165 lb. rescue manikin.

Specific Task Descriptions – Functional Capability Tasks
1) **Pegboard Task** – This task will require you to place pegs into pre-defined holes as quickly as possible. Your performance is measured as your time to completion.

2) **Grip Strength** – This task will require you to grip a handle that can measure your grip force. You will be asked to squeeze the handle as hard as you can to indicate your maximum grip strength. Performance is measured as the peak force generated during the squeezing task.

3) **Push-Up Task** – This task will require you to complete as many push-ups as possible within the pre-defined criteria indicated by the researcher. Performance is measured by counting the total number of push-ups completed.

4) **Vertical Jump Task** – This task will require you to jump as high as you can. Your maximum jump height is recorded. Performance is estimated using an equation that combines your weight and maximum jump height.

5) **One-Leg Stance Task** – This task will require you to balance on one-leg according to the pre-defined criteria indicated by the researcher. Performance is measured as your maximum balance time.

6) **Core Endurance Task** – This task will require you to maintain each of five different postures for as long as you can: a V-sit, left and right side bridge, front plank, and back extension position. Performance in each posture is indicated by the maximum hold (endurance) time.

7) **Hip Flexibility Task** – This task will require you to lie on a clinic table while the researcher passively measures your range of motion in 6 different positions. Performance is measured using a goniometer, where the maximum passive range of motion is recorded.

8) **Functional Movement** – This task will require you to complete seven different functional movements (i.e. squat, hurdle step, etc.) that are designed to allow the researcher to assess your movement quality potential. Performance is indicated by the researcher subjectively scoring your movements using pre-defined criteria.

9) **Aerobic Fitness** – This task will require you to cycle on an ergometer (a stationary bike). During this test the intensity of exercise increases gradually until you are physically unable to continue exercising because the intensity is either too high or too uncomfortable. The test will begin with the exercise intensity being very light and easy. After a few minutes the exercise intensity will gradually and continuously increase until you are unable to continue because of fatigue, or until you wish to stop. During this test you will be required to wear a nose-clip (to prevent you from breathing through your nose) and a rubber mouthpiece (similar to breathing through a snorkel or diving mask). This will enable us to measure the volume of air that you breathe in and out, and measure the gas concentration in that air. You may experience some initial discomfort from wearing the nose-clip and mouthpiece. You will also be required to wear a heart rate monitor around your chest during all tests.

**Specific Task Descriptions – Paramedic Tasks**

For all of the simulated paramedic occupational tasks, paramedics will be instructed to perform the tasks as they would in an actual emergency situation.
1) **Vertical patient transfer** – a 165 lb rescue mannequin lying in a supine position will be lifted by two paramedics from the ground to a stretcher. Participants will perform both of the roles associated with this lift, first by lifting the upper body, and then by lifting the lower body. Participants will perform this lift raw (with no stabilization board), and boarded (with the rescue mannequin on a spine and then scoop board).

2) **Lateral patient transfer** – a 165 lb rescue mannequin lying in a supine position will be lifted by two paramedics from a stretcher to a hospital gurney. Participants will perform both of the roles associated with this lift, first by lifting the upper body, and then by lifting the lower body. Participants will perform this lift raw (with no stabilization board), and boarded (with the rescue mannequin on a spine board and then a scoop board).

3) **Stair chair ascent** – an empty stair chair will be carried up a flight of six steps (step rise, run, and width) by a single paramedic.

4) **Stair chair descent** – a 185 lb rescue mannequin strapped to a stair chair will be lowered down a flight of six steps by two paramedics. Participants will perform both roles associated with this lift, either supporting the bottom of the stair chair, or the top.

5) **Stretcher unloading** – Participants load a stretcher with a 185 lb rescue mannequin and the appropriate patient monitors on it onto a platform of similar dimensions to the back of an ambulance (height: 30”, width: 51”).

6) **Stretcher manipulation** – Participants will maneuver an unloaded stretcher and a stretcher loaded with a 185 lb rescue mannequin for a distance of up to 50 m.

7) **Equipment handling** – Participants will pick up, walk with, and lower, up to three different paramedic equipment bags.

What measures of human performance will be used? All human performance measures used in the Biomechanics and Ergonomics Lab are conducted using standard operating procedures that are based on leading practices and that have been approved by the Queen’s General Ethics Review Board. We are happy to provide you with a copy of these standardized procedures upon request if you would like more information; however, a brief description of each is provided below. Only those procedures indicated by an ‘X’ in the check box will be applied in this study.

- **Motion Capture using Qualisys**: In biomechanics and ergonomics, researchers and clinicians use motion data to study and observe human performance. The system quantifies movements exactly by tracking the locations of reflective markers that will be placed on your body to represent the underlying boney landmarks of interest.

- **Video and Still Image Recording**: Video and still images are used in both biomechanics and ergonomics to help researchers, clinicians and coaches visually evaluate movement performance. Video and still image recordings will only be obtained if you choose to provide your consent to do so at the end of this package. As indicated in the consent form below your images will be retained and that it may be possible, yet unlikely, that you may be recognizable from those images.
Goniometers: Goniometers measure the angle between adjacent segments or limbs. These angles can be measured passively by the experimenter at static moments in time using a clinical grade plastic handheld goniometer. Alternatively, angles can be monitored continuously over time by affixing an electro-goniometer over the joint of interest. The type of goniometer we will be using in this study is circled below:

- Passive Goniometer
- Active Goniometer

Force data: Force plates and multi-axis load cells will be used to measure the forces that you are able to apply as they interact with the objects in the lab environment. The force plates, similar to a bathroom weigh scale will measure the forces that you transmit to the ground. The multi-axis load cells are embedded within the handles and objects you will interact with as you complete these simulated activities.

Is my participation voluntary? Yes. You should not feel obliged to answer any questions or perform a movement that you find objectionable or that makes you feel uncomfortable. You may also withdraw at any time with no effect on your standing in school. If you choose to withdraw, please announce to the researcher that you no longer want to continue. At that point, any instrumentation will be removed and you will be free to exit. In addition, all electronic data related to your participation will be deleted and any hard-copy data will be shredded.

What will happen to my responses? We will keep your data and responses confidential. All of your data and responses will be stored using an alphanumeric code known only to the experimenters. In fact, our lab manages all participants’ data using a standard operating procedure that we are happy to show you have any more concern. In addition, the data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should you be interested, you are entitled to a copy of the findings.

What are the risks associated with my participation? All exercise and simulated work task activities carry a small risk of personal injury. Should any such injury occur during your participation in this study you will be initially cared for by the study administrators, all of whom are certified in first aid. Should further assistance be required you will be taken to the university health centre/hospital or emergency as required.

Will I be compensated for my participation? No, you will not be compensated. However, your willingness to volunteer to participate is greatly appreciated!

What if I have concerns? Any questions about study participation may be directed to the principle investigators, Dr. Steven Fischer at steve.fischer@queensu.ca or Dr. Kathryn Sinden kathryn.sinden@queensu.ca. Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081. Please note that you may also keep this letter of information if you choose.
Again, thank you. Your interest in participating in this research study is greatly appreciated.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies.
Consent Form

Evaluating human performance when completing simulated occupational tasks

Name (please print clearly): ____________________________________________

1. I have read the Letter of Information and have had any questions answered to my satisfaction.

2. I understand that I will be participating in the study called “Evaluating human performance when completing simulated occupational tasks”. I understand that this means that I will be asked to complete the simulated occupational activities as outlined in the letter of information.

3. I understand that my participation in this study is voluntary and I may withdraw at any time.

4. I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only experimenters in the Biomechanics and Ergonomics Laboratory will have access to this area. The data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should I be interested, I am entitled to a copy of the findings.

5. I am aware that if I have any questions, concerns, or complaints, I may contact the principle investigators, Dr. Steven Fischer at steve.fischer@queensu.ca or Dr. Kathryn Sinden at Kathryn.sinden@queensu.ca; or the Chair of the General Research Ethics Board at Queen’s University at chair.GREB@queensu.ca or by phone 613-533-6081.

I have read the above statements and freely consent to participate in this research:

Signature: ________________________________

Date: ________________________________
Consent to Use Digital Images in Teaching, Presentations, and Publications

Sometimes certain images clearly show a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I agree to allow digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name and that any facial features will not be discernible.

I am aware that I may withdraw this consent at any time without penalty. If consent is withdrawn, I ask that all digital images of myself be erased and removed from storage.

I am aware that if I have any comments or concerns resulting from my participation in this study, I may contact Dr. Steve Fischer; steve.fischer@queensu.ca or 613-533-6000 extension 75210 or I may contact the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.

Signature: ______________________________________

Name of Participant (Printed) ___________________________________

Dated at Kingston, Ontario: ___________________________________

I wish to receive a summary of the results obtained from this study

Please provide you e-mail address in the space below if you would like the research team to e-mail you a summary of the results obtained from this project. We greatly appreciate your willingness to participate in this research.

E-mail address: ________________________________________________
Appendix C
Participant Demographics Form

Gender_______

Age: _____     Date of Birth: ___/___/___

(DD/MM/YYYY)

Height: _____ ft/inch or cm

Weight: _____ kg or lbs

Number of years as a Paramedic: _________

Rank/Job Title: _________________________________________________________________

Paramedic Service Location: _____________________________________________________
Appendix D

Marker Set

Table 1. Calibration and tracking marker locations and their palpation techniques for the reflective marker set used in this project to build the 3D linked segment model.

<table>
<thead>
<tr>
<th>Location</th>
<th>Palpation Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calibration</strong></td>
<td></td>
</tr>
<tr>
<td>C7 Vertebrae</td>
<td>The is C7 is found at the protrusion that appears when participants tuck their chin to their chest.</td>
</tr>
<tr>
<td>Suprasternal Notch</td>
<td>The suprasternal notch is found at the depression directly between the clavicles.</td>
</tr>
<tr>
<td>Xiphoid Process</td>
<td>The xiphoid process is found at the depression in the center of the rib cage at the base of the sternum.</td>
</tr>
<tr>
<td>T8 Vertebrae</td>
<td>The T8 vertebrae is found at the midpoint between the base of the left and right scapulae when the humeri are externally rotated.</td>
</tr>
<tr>
<td>Anterior Superior Iliac Spine</td>
<td>The left and right iliac crests are found by palpating for the ridge on the anterior aspect of the pelvis</td>
</tr>
<tr>
<td>Posterior Superior Iliac Spine</td>
<td>The left and right greater trochanters are found by palpating for the ridges on the posterior aspect of the pelvis</td>
</tr>
<tr>
<td>Femoral Epicondyles</td>
<td>The left and right medial and lateral epicondyles are found by palpating for the protrusions that appear at the distal end of the femurs when participants flex and extend their knees</td>
</tr>
<tr>
<td>Malleoli</td>
<td>The medial and lateral malleoli markers are placed at the most medial and lateral aspects of the malleoli.</td>
</tr>
<tr>
<td>First Metatarsal</td>
<td>The first metatarsal markers are placed at the most medial aspect of the first metatarsal.</td>
</tr>
<tr>
<td>Fifth Metatarsal</td>
<td>The fifth metatarsal markers are placed at the most lateral aspect of the fifth metatarsal.</td>
</tr>
<tr>
<td><strong>Tracking Markers</strong></td>
<td></td>
</tr>
<tr>
<td>Rigid Body - Low Back</td>
<td>The rigid body on the low back is placed approximately halfway between the midpoint of the iliac crests and the T8 vertebrae.</td>
</tr>
<tr>
<td>Rigid Body - Pelvis</td>
<td>The rigid body on the pelvis is placed at the midpoint of the most posterior aspects of the gluteus maximus muscles.</td>
</tr>
<tr>
<td>Rigid Body - Thigh</td>
<td>The rigid bodies on the left and right thighs are placed approximately halfway between the greater trochanter and the epicondyles of the knee.</td>
</tr>
<tr>
<td>Rigid Body - Shank</td>
<td>The rigid body on the left and right shanks are placed</td>
</tr>
</tbody>
</table>
approximately halfway between the epicondyles of the knee and the malleoli of the ankle.

Calcaneus
The calcaneus marker is placed on the most posterior aspect of the heel.

Fifth Metatarsal - Base
The base of the fifth metatarsal is found by palpating for the depression that appears when participants raise onto the balls of their feet.

Second Finger - Base
The marker on the base of the second finger is placed on the most lateral aspect of the finger.

*Note: the markers on the C7 vertebrae, suprasternal notch, xiphoid process, and T8 vertebrae are used for both calibration and tracking.

Figure 1. Locations of calibration markers.
Appendix E
Force Plate Location

To locate the force plates, a probe was created with a virtual marker at its tip. This was achieved by fixing four reflective markers to a small piece (5x5 cm) of thermoplastic with a screw attached to the end. A small virtual marker was then created at the tip of the screw, and a series of motion trials were captured. A 6DOF rigid body was then created with the four fixed markers on the thermoplastic as the reference markers, and the small marker at the tip of the screw was turned into a virtual marker.

Prior to data collection, five one-second trials were captured: two with the tip of the screw touching the positive Y-axis, then the positive X-axis, then the top of the plate. The marker position data for these trials was then passed through a function in MATLAB that created vectors in the X-Y plane to establish the X and Y coordinate locations of the force plate corners. The Z-location of the force plate was determined from the height of the tip during the fifth trial where the tip is pressed onto the top of the force plate.
Appendix F
Residual Analysis

The residual analysis was performed by repeatedly passing data through a dual-pass first order Butterworth filter, data with incrementally increasing filter cut-off levels (starting at 0 Hz and increasing by increments of 0.1 to a maximum of 10 Hz). For each cut-off level, the root mean squared (RMS) of the filtered signal and raw signal was taken. The RMS was then plotted against the cut-off frequency. To determine the filter setting, a line was drawn that runs parallel to the linear portion (the point at which the slope approached zero; in this case a slop of 0.02) of the curve from the curve to the Y-axis. From this point on the Y-axis, a horizontal line was drawn to the curve. From this point on the curve, a vertical line was drawn to the X-axis to give the effective cut-off frequency, which will eliminate the most amount of noise possible while minimizing the amount of signal lost (Winter, 2005).

This analysis was run on all trajectory data contained in three random trials of five random participants. The MATLAB script was written such that only the highest effective cut-off frequency was retained from all the trajectories in order to avoid losing data from higher frequency motions. The highest number produced from all the trials by the random participants was retained as the cut-off frequency.
Appendix G

Power Analysis Processing Steps

An example of the joint moment, angular velocity, and power curves for the left ankle (Figure 1), knee (Figure 2), and hip (Figure 3) during boarded lifting that would be used to calculate the contribution of work can be seen below.
Figure 1. Left ankle moment, angular velocity, and power during boarded lifting.
Note: Nm, Newton Metres; degs/s, degrees per second; W, Watts.
Figure 1. Left knee moment, angular velocity, and power during boarded lifting.
Note: Nm, Newton Metres; deg/s, degrees per second; W, Watts.
Figure 1. Left hip moment, angular velocity, and power during boarded lifting.
Note: Nm, Newton Metres; degs/s, degrees per second; W, Watts.
Appendix H

Correlation Data Distributions

The distribution of data used for the correlations between the percent contribution of lower body work, as well as peak lower body power capacity, and peak sagittal L4/L5 moment, and peak sagittal trunk angle for the Stretcher load (Figure 1), Boarded Lift (Figure 2), and Stretcher Raise (Figure 3) can be seen below. The distribution of data for the correlations between the contribution of lower body work and peak lower body power (Figure 4) can also be seen. Correlation coefficients and significance levels can also be seen for the relationship between lower body work contribution and peak lower body power (Table 1).
Figure 1. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work (left column) and Peak Lower Body Power Capacity (right column) and dependent measures peak sagittal L4/L5 moment (top) and peak sagittal trunk angle (bottom) recorded from paramedics performing the boarded lift task. Blue diamonds represent female participants, red squares represent male participants.
Figure 2. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work (left column) and Peak Lower Body Power Capacity (right column) and dependent measures peak sagittal L4/L5 moment (top) and peak sagittal trunk angle (bottom) recorded from paramedics performing the stretcher raise task. Blue diamonds represent female participants, red squares represent male participants.
Figure 3. Scatter plots illustrating the dispersion of data when considering the independent measures Percent Contribution of Lower Body Work (left column) and Peak Lower Body Power Capacity (right column) and dependent measures peak sagittal L4/L5 moment (top) and peak sagittal trunk angle (bottom) recorded from paramedics performing the stretcher load task. Blue diamonds represent female participants, red squares represent male participants.
Figure 4. Scatter plots illustrating the dispersion of data when considering the independent measures Peak Lower Body Power peak and dependent measure Percent Contribution of Lower Body Work recorded from paramedic performing a boarded lift (top-left), stretcher raise (top-right), and stretcher load (bottom). Blue diamonds represent female participants, red squares represent male participants. 
Note: % Cont. of LBW, percent contribution of lower body work; W, Watts.
Table 1. Correlation coefficients ($r$), significance levels ($p$), and number of subjects (N) between the percent contribution of lower body work during stretcher load, boarded lift, and stretcher raise tasks, and peak lower body power.

<table>
<thead>
<tr>
<th></th>
<th>Stretcher Load</th>
<th>Boarded Lift</th>
<th>Stretcher Raise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Contr. of LBW</td>
<td>% Contr. of LBW</td>
<td>% Contr. of LBW</td>
</tr>
<tr>
<td>Peak $r$</td>
<td>-.291</td>
<td>-.277</td>
<td>-.337</td>
</tr>
<tr>
<td>LBP (W) $p$</td>
<td>.133</td>
<td>.170</td>
<td>.092</td>
</tr>
<tr>
<td>$N$</td>
<td>28</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

Note: Peak LBP, peak lower body power in Watts; % contr. Of LBW, percent contribution of lower body work.