The Efficacy of a Lifting Strap as an Ergonomic Intervention for EMS Providers: Does it make it easier to raise a Patient from Supine Lying Posture to Upright Sitting Posture?

Thesis

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Abstract

Previous investigations have shown that musculoskeletal injuries among Emergency Medical Service (EMS) providers are prevalent. A combination of awkward postures, high force demands, and environmental factors increase the physical demands in EMS tasks and the risk of injury. This study was designed to evaluate whether the postures and biomechanical loads experienced when raising a patient from the supine posture to the upright sitting posture (raising task) could be reduced through the use of an ergonomic intervention, specifically, the use of a strap, placed under the patient's torso, and long enough that emergency medical service (EMS) providers can perform the patient raising task in an upright standing posture. In this study, 15 participants performed this raising task with the strap or using a traditional method (without the strap) wherein the EMS provider grasps the patient's shoulder. These tasks were performed in an open area, a restricted space simulating a hallway setting, and in a bathtub. Torso and knee postures, along with EMG data from the back and arms were collected and analyzed. Analysis of postural data implied a significant amelioration of postural concerns. The muscle activation increased in the biceps muscle with the strap compared to the traditional method, while the EMG response from the latissimus dorsi muscle was reduced when the strap was used. However, the EMG activity of the erector spinae muscle increased when the strap was used, possibly to the flexion relaxation phenomenon and the associated loading of passive tissues due to the extreme torso flexion observed when using the traditional method. Perceived effort assessments found that most participants thought it was at least a little easier to perform the tasks with the strap within each environmental setting. Therefore, the intervention of using a strap in the raising task could be recommended to the EMS providers.

Key words: emergency medical service (EMS), intervention, raising, supine, sitting, posture, EMG.

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Special gratitude to Dr. Steve Lavender, my advisor, for all kinds of generous help and suggestions not only about achieving this project but also throughout this two-year program. His professionalism, enthusiasm, and sense of humor would inspire me forever. I am grateful to Dr. Carolyn Sommerich, one of my female role models, for her contribution to this study, as she always does, guiding me to dive deeper into the questions. I would like to thank all my beloved friends in the Orthopaedic Ergonomics Laboratory, Chunyi Sun, Xueke Wang, Ardiyanto, Noura Amini Pay, and Vivek Ramachandran for their sharing resources and experience during every phase of the study, as well as a thousand times mutual encouragement. Great respect to all the participants who devoted their time to make this research happened. Last but not least, I would like to thank my supportive and open-minded parents from the bottom of my heart for always having my back. And I would like to thank my dear friends, as they are my shield and sword along the way of fight.

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Fields of Study

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Chapter 1. Introduction

Persona

A two-person team of paramedics, Jerry and Frank, are responding to a call in which Bob, a 43-year-old male weighing around 82 kg has fallen in the bathtub and cannot get up. Upon their arrival, the paramedics see that space around the bathtub is extremely limited, and the patient is lying in the bathtub. To make the situation more challenging, the patient is wet and slippery. After checking the patient's vital signs, Jerry determines that the patient is not in a life-threatening situation, but they must move him out of the bathroom and prepare him for transport. Jerry and Frank decide to utilize some lifting equipment, a vest-like device that essentially puts handles on the patient. But to do so, they have to wrap the lifting device around the patient's torso, which requires the patient first to be raised from a supine to a seated position. This requires that Jerry to enter the tub, stand between the patient's legs, and pull the patient up with an action coordinated with Frank. For both of them, this initial patient handling task has them working in a very stooped posture in order to be able to grasp the patient at the shoulders. The patient has recently dislocated one of his shoulders, so pulling on the patient's arms is not possible with this patient and is generally not recommended for most patients (injury risk to patient's shoulders). During the raising process, Jerry feels a lot of tension in his back muscles. Once the patient is upright, the team is able to apply the lifting device and move the patient from the tub to the stair chair for transport. After this shift, Jerry still finds his back is increasingly aching. He suspects a relapse of a prior back muscle strain because of that raising exertion. If only there was a better way to perform this initial patient handling task…

FFPs' and Caregivers' Dilemma

Emergency medical service (EMS) providers, who are often firefighter/paramedics (FFPs) are the populations suffering a high risk of work-related musculoskeletal disorders (MSD). In 2017, 12,240 out of 25,835 total firefighter injuries occurred at non-fire emergencies. Amongst all injuries, strain, sprain, and muscular pain were the most prevalent, which consisted 58% of injuries related to non-fire emergency injuries, and 53% of total firefighter injuries in 2017 (Haynes & Molis, 2018). It was reported that between 2001 and 2011, over half of the work-related diagnosed injury claims from EMS workers who were working in the private ambulance service in Ohio were back sprains or strains (Reichard et al., 2018).

For firefighters in the U.S. between 2003 and 2014, 36 percent of the injuries treated in emergency departments were related to patient care (Marsh, Gwilliam, Konda, Tiesman, & Fahy, 2018). The result from the research on lower back health issues amongst 334 EMS providers in Switzerland indicated that 67% of research participants had at least one day of lower-back symptoms during the 12 months before the investigation (Arial, Benoît, & Wild, 2014). In summary, all reports have shown a high injury risk in EMS workers, but the factors behind these work-related injuries are complicated. In the Occupational Outlook Handbook, published by the Bureau of Labor Statistics (U.S.

Department of Labor), claimed that EMS technicians and paramedics was one of the occupations with the highest rates of injuries and illnesses, which partially due to the fact that they were easily exposed to substantial kneeling, bending, and lifting postures during the patient care and the patient handling (Bureau of Labor Statistics, U.S. Department of Labor, 2019).

Risk Factors

From July 2010 through June 2014, the occurrence of full-time EMS workers treated injuries related to body motion, which included overexertion, awkward postures, and repetitive movement, was 2.6 per 100 full-time equivalent EMS workers. Within these body motion related injuries, estimated 90 percent occurred during transferring, carrying, and lifting tasks, 31 percent occurred during twisting, and 22 percent was due to the awkward posture and movement. The weighted estimates EMS provider injuries treated in emergency departments caused by loss of balance was 14,000, at a rate of 1.4 per full-time equivalent EMS workers (Reichard, Marsh, Tonozzi, Konda, & Gormley, 2017).

Awkward Working Postures

When FFPs were laterally transiting a patient from a bed to a stretcher, the FFP who was on the bed may be in a kneeling posture (Lavender, Conrad, Reichelt, T. Meyer, & Johnson, 2000a). This task was among the top ten strenuous work activities performed by FFPs (Conrad, Lavender, Reichelt, & Meyer, 2000). The Lumbar Motion Monitor logistic regression model used by Lavender et al. (2000b) reinforced the finding that kneeling posture was riskier than standing for the FFPs on the bed during lateral transfers. More generally speaking, working in a kneeling posture limits the biomechanical contributions to the lifting. In the recent EMS job risk index study, it was found factors of lifting and holding awkward postures, such as forward bending and transverse plane rotation, were likely to increase the risk index in general (Larouche, Bellemare, Prairie, Hegg-Deloye, & Corbeil, 2019). The EMS providers motion assessment conducted by Gentzler et al. (2010) disclosed the high health risk aroused by the awkward postures as well. To attain low spinal compression loads and torso muscle activation, Schultz et al. (1982) suggested working with the torso upright, and the arms close to the body. This can be difficult to do during patient handling activities.

Overexertion

Lifting a patient with one or two EMS providers was believed as one of the top factors responsible for firefighter work-related injury (Dropkin, Moline, Power, & Kim, 2015). Data from the U.S. National Center for Health Statistics showing obesity trends (Hales, Carroll, Fryar, & Ogden, 2017) will enhance the patient handling challenges faced by FFPs. Reichard et al. (2017) study indicated that during July 2010 to June 2014, half of the respondents mentioned in the injury description about injuries took place while lifting a patient depicting that the patient was “heavy, overweight, or obese”. Some research has already considered the potential for interventions aimed at easing the physical demands when lifting heavier patients within their homes (Lavender et al., 2020).

Other Potential Risk Factors

Lavender and Sommerich (2017), through focus groups with FFPs, identified several difficult patient handling situations encountered by FFPs, including lifting or assisting patients in confined spaces, for example, in a hallway, or when the patient is in a bedroom and in a narrow space between the wall and bed, or in a bathroom when the patient is between the toilet and bathtub, the toilet and the wall, or in the bathtub. Additionally, other factors such as patient sensitivity due to the injury or other issues, the difficulty to grab patients if they were wet and slippery, or significant clutter in the patient's home environment, would increase the challenge for the FFPs (Lavender & Sommerich, 2017). Trunk muscle activation and spinal loading would be expected to increase due to the slippery floor surfaces as reported by Lavender et al. (2007) during pulling tasks. The focus groups conducted by Lavender and Sommerich (2017) also identified potential ergonomic interventions that could be used in these situations. However, the efficacy of these potential approaches still needs to be demonstrated

Limitations of Previous Research

While prior studies have investigated the efficacy of ergonomic intervention devices that potentially aid FFPs when laterally transferring lifting, and transporting patients (Lavender et al., 2020; Lavender et al, 2007a,b,c), none have looked specifically at the demands and possible interventions for raising a supine patient to a seated posture. This is often the first step in the patient handling process, as the patient is often moved from the floor to a stair chair for transport.

Purpose of the Investigation

The purpose of this study was to assess the biomechanical loads experienced when raising a patient from the supine lying posture to the upright sitting posture and to test the value of a relatively simple intervention, namely a strap under the torso. The strap would be long enough to allow the EMS providers to be in an upright standing posture while performing this task. Our prior study (Lavender and Sommerich, 2017) identified a relatively simple method for positioning a strap under the patient, however, the benefit of using the strap has not been determined.   It was hypothesized that using a strap to raise the patient' torso from a supine posture to an upright sitting posture would improve the EMS worker's trunk posture and reduce the physical demands on the muscles when performing these patient torso raising tasks.

Chapter 2. Method

Experimental Design

This investigation was designed to evaluate the biomechanical efficacy of an emergency medical service (EMS) intervention, the use of a strap to pull up patients from a supine position to an upright sitting posture. The work method was the primary independent variable which consisted of two levels: a traditional method in which the patient handlers grasp the patient's shoulders and an alternative method, in which a strap positioned around the participant's back is pulled by patient handlers. These work methods were evaluated in three environmental settings, which included raising a patient in an open area, in a constrained space such as a hallway, and in a bathtub. As mentioned previously, EMS work could happen in all kinds of environmental settings. These environments simulated a sufficient space for the EMS providers in which to work, a restricted narrow space, and an extremely constrained space. Each combination of work method and environmental condition was repeated three times. Therefore, there were (3 environmental settings × 2 methods × 3 repetitions) 18 lifts performed in total for each study participant.

Figure 1 illustrates the settings and methods in the six combined conditions. Each experimental session started with the open environment so that participants had a chance to become familiar with the task in the least constrained condition. The sequence of the hallway and bathtub environments was randomized for each participant. Within each

(a1) the traditional method in the open environment (the figure does not include the assistant at the patient's left side)

(a2) the strap method in the open environment

(b1) the traditional method in the hallway (the figure does not include the assistant at the patient's left side)

(b2) the strap method in the hallway

(c1) the traditional method in the bathtub

(c2) the strap method in the bathtub

Figure 1 Environmental settings and methods demonstration. The participant is standing on the patient's right side.

environment, the sequence of strap versus the conventional method was randomized for each participant.

Participants

Fifteen participants without EMS experience, thirteen male and two females, were recruited in this study. The mean age was 21.9 years (range 19 to 33 years). Mean height and weight were 178.6 cm (165-187 cm) and 75.7 kg (63-91 kg). Participants were without a history of back surgery or limiting clinical conditions, and free from back, shoulder, arm, and knee pain for the three months before their participation.

Three actor-patients, two males and one female were recruited for the study. All weighed between 64 and 68 kg. Since the raising task required two people, one of the investigators served as the second EMS provider and assisted the participant with the patient raising tasks while positioned at the patient's left side and provided consistent raising technique instruction across participants.

Apparatus

Participants were bilaterally instrumented with six bipolar surface electromyographic (EMG) electrodes (Bagnoli Desktop System, Delsys, Inc., Natick, MA, USA) to attain muscle activities from biceps, latissimus dorsi, and erector spinae, as EMG was proved to be a reliable dependent variable in measuring lower back activities (Ahern, Follick, Council, & Laser-Wolston, 1986). EMG data were sampled at 900 Hz with a bandpass filter of 20 to 450 Hz. Postural data were collected via a motion capture system (Flock of Birds, Ascension Technologies). Motion capture data were sampled at 60 Hz. Posture and EMG data were collected using an integrated data acquisition system (The Motion MonitorTM, Innsport, Chicago, IL, USA).

Procedures

All participants were presented with an IRB approved informed consent document upon their arrival at the laboratory. They were briefly introduced to experiment content, possible risks, and participants' rights, and given time to review the document. After signing the informed consent document, surface EMG electrodes were placed bilaterally over the biceps, latissimus dorsi, and erector spinae muscles. After confirming the quality of the EMG data, resting data were collected with the participant standing in an upright neutral posture. Participants then performed a series of maximal voluntary exertion activities that were designed to elicit a maximal EMG signal from each muscle. During maximum exertion tests, participants were asked to pull on an isometric strength testing apparatus as hard as they could without hurting themselves and maintain the exertion for 5 seconds. Videos and hands-on demonstration were used to instruct the participants. Figure 2 illustrates the postures used when attaining the maximum exertions. For the bicep muscles, participants were asked to hold a handle, which was set at the standing elbow level, with a supinated palm, and 90 degrees of elbow flexion, and pull the handle upward by attempting to flex the elbow further. The activity was performed separately for the left and the right bicep muscles. Testing began with one side, then switched to the other side. Each side was tested twice with a rest period of two minutes between the trials for a specific arm. For the erector spinae muscles, participants were then instructed to pull upwards on a handle positioned at knee height with both hands using their back muscles rather than using their leg or arm muscles. The activity was repeated twice with about one minute between trials. For the latissimus dorsi muscles, participants were instructed to pull two handles, adjusted to the participants' elbow level, posteriorly while bracing either foot against the pillar of the exertion apparatus (Figure 2). The participants then repeated the same activity with the other foot on the pillar.

(a) Biceps (Two times each side) (b) Erector spinae (Two times) (c) Latissimus dorsi (Once per side)

Figure 2 Demonstration of the maximum exertion tests

Following the collection of the MVC data, magnetic motion capture sensors (Flock of BirdsTM) were attached to selected body segments to capture postural data. Sensors were placed on the head, over T12 and S1 vertebrae, on the upper arms, lower arms, thighs, and shanks using a combination of straps and tape. After the digital model was developed by the system, a neutral position was sampled in which the subject was instructed to stand straight, look straight ahead, and arms down at the side with thumbs pointing forward.

During the lifting task, participants were asked to raise the patient from a supine lying position to a seated upright position in an open environment, in a simulated constrained area (hallway), and in a bathtub using both the traditional method and the strap. The strap was a polypropylene lifting strap, that was 284.5 cm long, 7.6 cm wide. It had a 363 kg lifting capacity (A.A.C. Forearm Forklift Inc., Baldwin Park, CA). It was positioned under the patient just below the axillae and supported the patient's upper back when the strap ends were separately pulled by the participant and the assisting person. Instruction, including oral tutorial and presentation slides containing pictures, description texts, and videos, was provided before each condition. In each condition, practice trials were performed prior to the data collection trials so the participants were familiar with how the task should be performed.

Due to space constraints within each environmental setting, the participant's initial position was varied for each setting and method combination. In all conditions, the participants were on the right side of the patient, and the assistant was positioned on the patient's left side. In the open area scenario, participants using the traditional method were instructed to kneel on their right leg along the patient's right side, such that their left foot was positioned next to the patient's elbow. The participants then reached forward to the patient’s right shoulder and grasped the top of the patient’s shoulder with their right hand while their left hand supported and pulled from behind the shoulder. When asked to use the strap method, participants were asked to stand with their left leg forward such that their left foot was next to the patient’s hip, and they were asked to have their right foot at about the patient’s knee level. Participants were also instructed to slightly bend their knees and lean forward a little. In the simulated hallway environment, the patient was assumed to be lying against a wall. The participants had to place their right foot between the patient’s legs and left foot by the patient’s right side at hip level. Without the strap, the participant assumed a stooped posture when reaching for the patient’s shoulder. With the strap in the hallway condition, the participant’s feet were in the same position as without the strap. In the bathtub environment, participants were assumed to be standing in the tub and against the wall. Room for standing was more restricted than in the hallway. It was problematic for the EMS worker’s left foot to be at the patient’s hip level, especially if the patient was heavier or with the potential problems of the limited space in the bathtub. In this condition, therefore, participants were required to stand between the patient’s legs, having their feet together to pull up the patient in both the traditional method and the strap conditions.

In both the strap and the traditional method conditions, participants coordinated the raising procedure by counting down from ‘3’ prior to initiating the lifting activity so as to coordinate their actions with those of the assistant. The simulated patient was instructed not to assist during the procedure. A pillow was provided to reduce the patient’s discomfort of lying on a hard surface.

Each lifting condition was repeated three times with a one to two minute rest period between each trial. Upon completion of all the tasks, participants were asked to compare the level of effort required when using the strap method as compared with using the traditional method for each environmental setting using a subjective rating survey. The rating scale was “much harder”, “harder”, “a little harder”, “about the same”, “a little easier”, “easier”, and “a little easier”, which followed the rating scale used by Lavender et al. (2020) in a biomechanical evaluation research of several ergonomic intervention devices with EMS providers. After all the rating questions were answered by participants, researchers would then ask them to further explain why they made the decision. Total participation time for each participant was up to 90 minutes.

Data Analysis

Raw EMG data were pre-processed by preset built-in notch filters through The Motion MonitorTM system to eliminate possible interference from the electromagnetic motion capture system. Six notch filters were set at 60 Hz, 120 Hz, 180 Hz, 240 Hz, 300 Hz, and 360 Hz. Nevertheless, some of the participants showed artificial RMS EMG data pattern from their bilateral latissimus dorsi with this pre-set. Thus, 40 Hz high pass filters were added on all participants’ latissimus dorsi EMG data to consistently offset the artifacts (De Luca, Donald Gilmore, Kuznetsov, & Roy, 2010). Root mean square (RMS) values were obtained from the raw EMG signals with a 100ms time constant (Farfán, Politti, & Felice, 2010).

The RMS EMG data of each subject were normalized relative to maximal and resting values (Mirka, 1991). After normalization, the 90th percentile EMG values of the period during which the participant was raising the patient's torso was selected, using a customized MATLAB program. The starting point and ending point of the task trials were defined according to the movement of the left wrist sensor in both the horizontal and vertical axes. Likewise, postural changes between the neutral baseline values and maximum postural change in each trial were obtained through a similar MATLAB program. One thing that is worthy of attention, when one is bending the torso forward, the pelvis would be rotating forward simultaneously causing a probable increment in torso flexion. Therefore, sacrum flexion (SCFL) was also measured in this study. Since spine flexion and pelvis forward rotation are not necessarily reaching the peak values at the same time, torso flexion (TFL), the real-time sum of spine flexion and sacrum flexion values, was calculated in The Motion MonitorTM system.

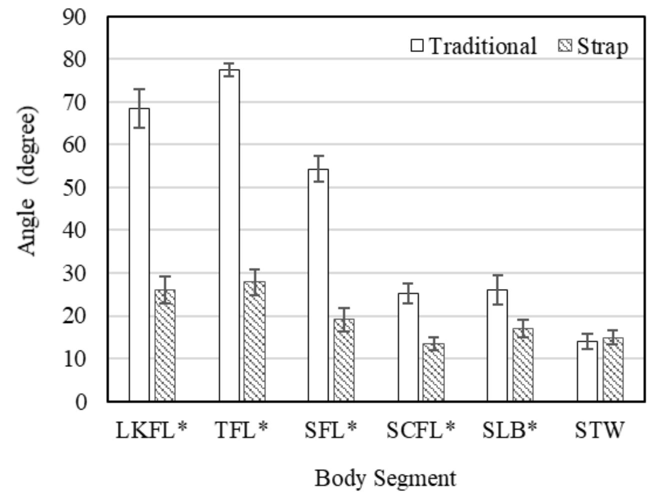
Auto-programmed graphs of EMG data and kinematic postural data were saved separately for data verification. After the normalized 90th percentile value for each trial was obtained, all the EMG and kinematic data graphs were manually reviewed to confirm the data quality and where artifacts existed, contaminated values were removed from the analysis. Given that specific hand placements on the strap were not controlled and relative amount of force used between the two hands with both methods could vary across participants, the maximum value within each bilateral muscle group was selected for each trial and represented the value used in the analysis of the biceps, latissimus dorsi, and erector spinae activity.

An analysis of postural data revealed that some of the postural measures were not normally distributed. Thus, a nonparametric method, Wilcoxon signed rank test, was used to perform the statistical analysis to evaluate the postural difference between raising methods within each environmental setting (Shott, 1990). On the other hand, the EMG data were more normally distributed, so an ANOVA model, blocked on subjects, was used to evaluate differences between methods within each setting. Statistics analysis was conducted using SAS software (Version 9.4).

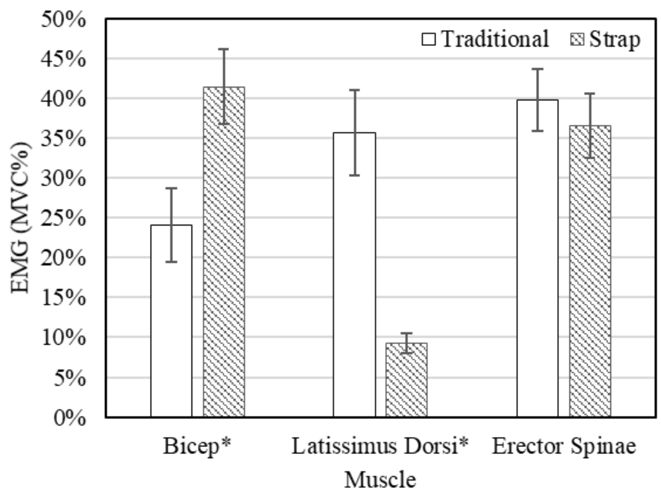
Chapter 3. Result

Open Environment

Figure 3a shows the differences in the postural measures as a function of the method used within the open environment. There were statistically significant reductions in left knee flexion (LKFL), torso flexion (TFL), spine flexion (SFL), sacrum flexion (SCFL) and spine lateral bend (SLB) when using strap method in comparison to the traditional method (Table 1). One thing should be kept in mind is that in the open environment, participants had their right knees on the floor and the mean value of left knee flexion was 68 deg. Torso flexion with the strap was reduced to 28 deg from 77 deg with the traditional method in this environment. Furthermore, a 9 degree reduction in spine lateral bend was observed when using the strap (Figure 3a). Table 2 shows a summary of the statistical outcomes for the EMG data. The latissimus dorsi activity was reduced from 36 percent MVC with the traditional method to 9 percent MVC when using the strap, in the open environment (Figure 3b). The EMG response of the erector spinae muscle showed a small and non-significant decrease from 40 percent MVC to 37 percent MVC when the strap was used. On the contrary, the biceps muscle activity increased from 24 percent MVC, when the traditional method was used, to 41 percent MVC when the strap was used.



(a)



(b)

Figure 3 Postural data and EMG data across 15 participants in the open environment environmental setting. Chart (a) presents the postural data, and the abbreviation respectively stands for left knee flexion (LKFL), torso flexion (TFL), spine flexion (SFL), sacrum flexion (SCFL), spine lateral bending (SLB), spine twisting (STW). Chart (b) displays the EMG MVC data. Error indicators present the positive and the negative error around the means. Asterisk sign (*) represents a statistical significance between the traditional method and the strap method is observed.

Hallway Environment

In the hallway environment, relative to the traditional method, the strap method reduced the left knee flexion from 46 degrees to 28 degrees. The torso flexion was reduced from 100 degrees to 33 degrees and the spine lateral bending was reduced from 27 to 13 degrees when using the strap (Figure 4a).

Figure 4 shows, in the constrained hallway environment, that the peak biceps muscle activity rose from 13 to 31 percent MVC and the erector spinae increased from 20 to 37 percent MVC. However, the latissimus dorsi activity decreased by more than half, from 24 percent to 11 percent MVC with the strap compared to the traditional method.

Bathtub Environment

When it comes to raising up the patient in a bathtub, there was a 24 degree decrease in left knee flexion (LKFL) and a 47 degree decrease in torso flexion (TFL) when using the strap compared to the traditional method. There was also a statistically significant 6 degree reduction in the lateral spine bending (SLB) when the strap was used (Figure 5a).

When using the strap in the bathtub, the peak biceps muscle activity increased to 23 percent MVC, versus the 13 percent MVC observed with the traditional method. Similar to the hallway condition, the erector spinae response also increased from 19 percent MVC with the traditional method to 35 percent MVC when using the strap. However, the latissimus dorsi decreased from 26 percent MVC with the traditional method to 13 percent MVC when using the strap (Figure 5b).

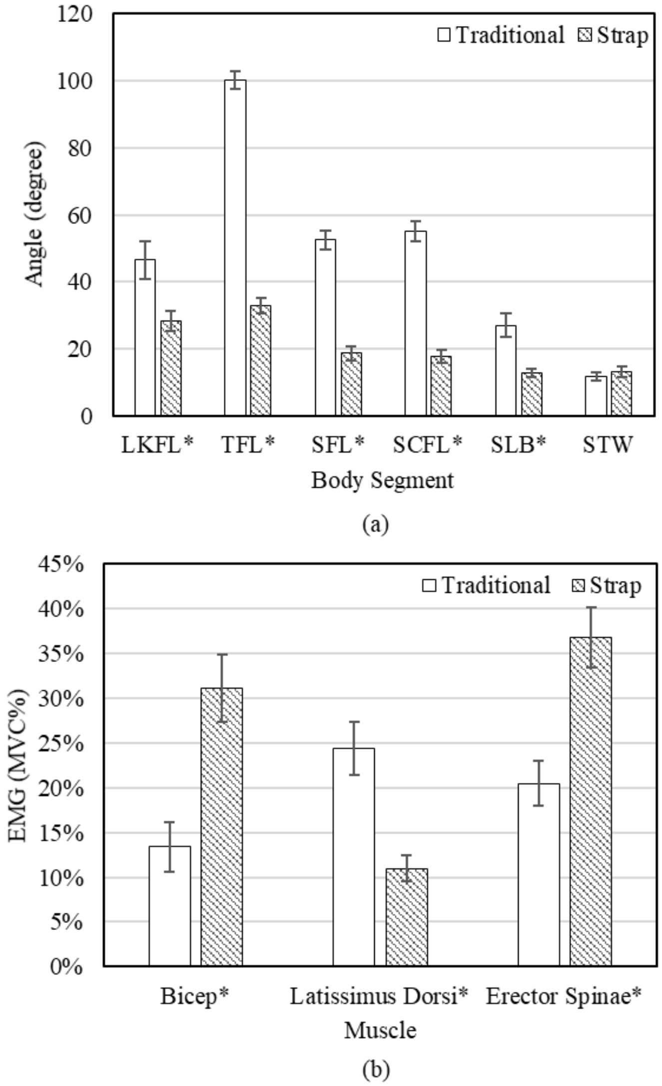


Figure 4 Postural data and EMG data across 15 participants in the hallway environmental setting. Chart (a) presents the postural data, and the abbreviation respectively stands for left knee flexion (LKFL), torso flexion (TFL), spine flexion (SFL), sacrum flexion (SCFL), spine lateral bending (SLB), spine twisting (STW). Chart (b) displays the EMG MVC data. Error indicators present the positive and the negative error around the means. Asterisk sign (*) represents a statistical significance between the traditional method and the strap method is observed.

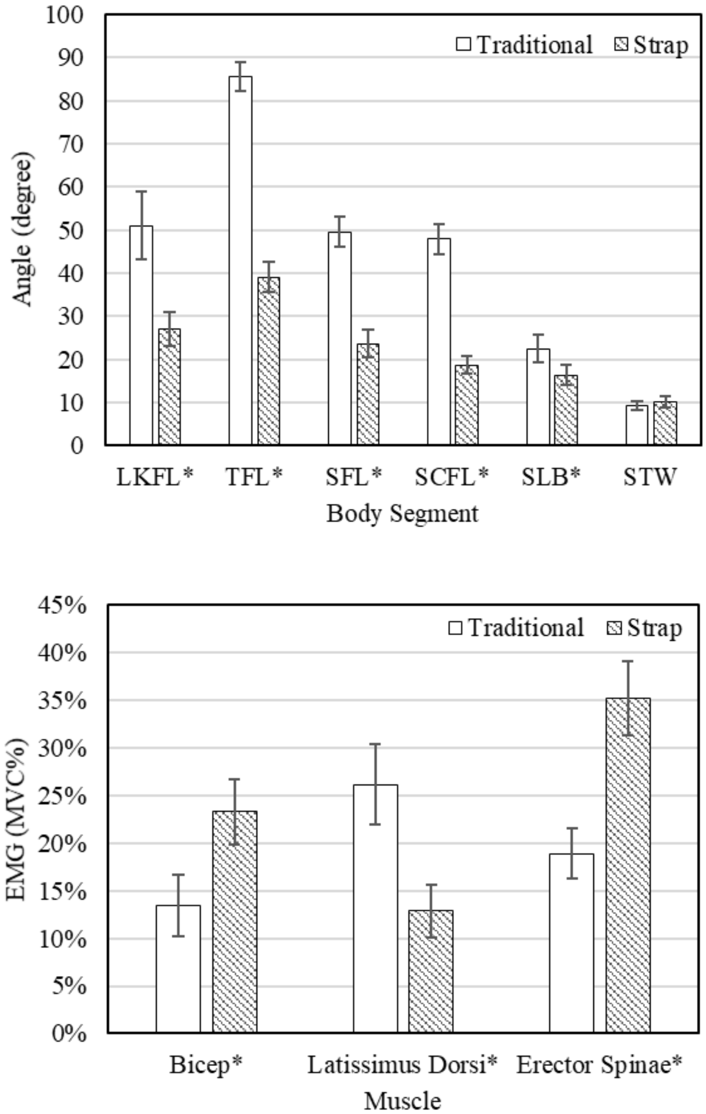


Figure 5 Postural data and EMG data across 15 participants in the bathtub environmental setting. Chart (a) presents the postural data, and the abbreviation respectively stands for left knee flexion (LKFL), torso flexion (TFL), spine flexion (SFL), sacrum flexion (SCFL), spine lateral bending (SLB), spine twisting (STW). Chart (b) displays the EMG MVC data. Error indicators present the positive and the negative error around the means. Asterisk sign (*) represents a statistical significance between the traditional method and the strap method is observed.

Environment	LKFL	TFL	SFL	SCFL	SLB	STW
Open Environment	<.0001	<.0001	<.0001	0.0004	0.0084	0.6387
Hallway	0.0004	<.0001	<.0001	<.0001	0.0004	0.3591
Bathtub	0.0001	<.0001	0.0001	<.0001	0.0479	0.9341

Table 1 P-values of Wilcoxon Signed Rank Test between two methods for the postural Data

Environment	Biceps	Latissimus Dorsi	Erector Spinae
Open Area	0.0018	0.0002	0.505
Hallway	0.0003	0.0007	0.0018
Bathtub	0.0131	0.015	0.002

Table 2 P-values of ANOVA between two methods for the EMG data

Subjective Ratings

Figure 6 summarizes the subjective rating responses from the study participants. The ratings show the participants' assessment regarding the relative effort required to use of the strap relative to the traditional method within each environmental setting.

In the open environment, 13 out of 15 participants found it at least a little easier when using the strap; while the remaining two participants did not feel there was a difference between two methods. Of the positive responses, 3 indicated it was "much easier" option, 3 responses indicated it was easier, and 7 responses indicated it was "a little easier" to complete the task with the strap. A common perception of all participants in this setting was that it was easy to do the job because of the enough space that they could either stand or kneel. Plus, some thought it was not difficult to kneel and pull in this scenario, as there was enough space to support kneeling posture. One of the participants specially pointed out that even though it was not demanding to kneel, the use of the strap removed the requirement to kneeling, and he preferred not to kneel. Another participant mentioned a similar idea, as well. The perceived benefit of the strap that getting rid of bending down and entailing a shorter range of motion over distance drove this participant to mark "much easier" for all environmental settings.

As shown in Figure 6, among those who held positive opinions on the strap method for the hallway environment, almost half of them noted that it was "much easier" than using the traditional method, five saw it "easier", and two believed that it was "a little easier". They felt that due to the movement constraints, the strap made it easier to perform the task, as it eliminated awkward bending when reaching over the patient. In the bathtub environment, two-thirds of the participants felt using the strap was "much easier" when the space for leg placement was further limited in the bathtub. Another four participants indicated it was "easier" to use the strap than the traditional method.

There were three participants who mentioned that they did not feel as stable when reaching forward in the bathtub as they were in the other environmental settings or found it hard to bend forward; thus, two rated the strap method as "easier" and one rated the strap method as "much easier" for each environmental setting, due to the better sense of balance with the strap compared to the traditional method. There was an interesting comment from one participant who said that the shoulder grabbing method was a little uncomfortable and challenging in the bathtub because one had to squeeze the left hand into the gap between the patient's shoulder and the bathtub. He would prefer his hand not to be squeezed before the trial started, and his hand would be possibly smashed onto the bathtub if the attempt failed while his left hand was still protecting the patient on the back of the shoulder.

However, not all participants endorsed a sense of ease with the strap. One participant found it was "a little harder" with the strap in the open environment and the hallway, and then he said it was "harder" in the bathtub. He stated that in the standpoint of exertion efficiency, he felt easier to find the lever point for using his strength to pull up the patient rather than using the strap

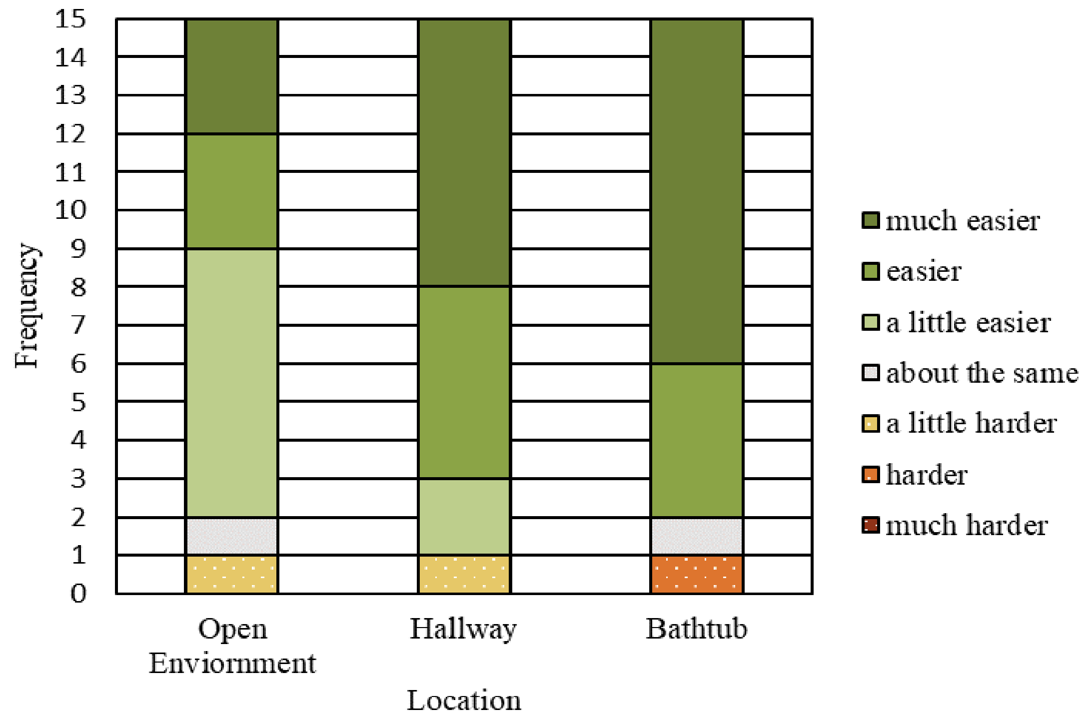


Figure 6 Subjective rating survey result. The survey questioned the participants the level of effort about the strap method comparing to the traditional method within each environmental setting.

Chapter 4. Discussion

Summary

Overall, the hypothesis of this study that the strap method could improve posture when raising a patient from a lying down position to a sitting position was supported. While the hypothesis regarding the reduction in muscle activities was partially supported as the results indicated there were trade-offs between muscle groups when the strap was used.

Postural Data

The change of posture between two methods was significant, based on the postural data analysis result, as the torso forward flexion (sagittal plane), lateral bending (frontal plane) and the left knee flexion decreased. Previous studies have illustrated the negative effect of kneeling, moderate trunk flexion, and sustaining awkward postures on musculoskeletal health and safety. When working with external loads, lifting weights, for example, the negative effect would be exacerbated (Larouche et al., 2019; Lavender et al., 2000b; Schultz et al., 1982; Marras et al., 1995; Prairie & Corbeil, 2014; Keyserling et al. 1992). Therefore, the current study provides evidence that the use of the strap could achieve a positive effect by improving the posture.

EMG Data.

Overall, the EMG results indicate there was a trade-off between biceps and erector spinae versus the latissimus dorsi muscle groups for the raising task when the strap was used. Compared to the traditional method, the strap method involved a posture closer to an upright standing position, while using the traditional method, the participant's trunk was nearly in full flexion and was parallel to the floor. Compared to the traditional method, the strap method switched the upper body motion from bending forward, pulling and lifting to a two-hand pulling motion. While participants were shifting the weight backward, they tended to curl their arms to further lift the patient's torso upward. Thus, the biceps activation with the strap was greater than that observed with the traditional method, while the latissimus dorsi activation was less than the traditional method across all environmental settings. The muscle activities of biceps and latissimus dorsi were comparatively consistent across the three settings.

However, when using the traditional method, the magnitude of the erector spinae EMG activity was considerably lower than when the trunk flexion was deeper in the more constrained spaces while in the standing posture. Considering the extreme torso flexion angles participants adopted, it is possible that a substantial portion of the spine loads was placed on the spine's passive supporting tissues, consistent with the spine flexion-relaxation-phenomenon (Floyd et al., 1951).

Floyd et al. (1951) demonstrated the phenomenon that erectors spinae potentially relaxed if the spine is fully flexed. The study found that erector spinae EMG signal muted when participants were fully bending their torso and reaching to the ground without being influenced by moderate knee flexion while bending. EMG activation would resume with knee extension and the torso gradually raising. Intervertebral ligaments, instead of erectors spinae, were believed taking over the load, supporting the torso moment, and constraining extreme flexion. Bailey (1960) defined this phenomenon of erector spinae silence found with extreme trunk flexion as the flexion-relaxation phenomenon (FRP). Further research facilitated with both EMG measuring muscle activation and biomechanical model predicting internal force substantiated those findings about flexion-relaxation phenomenon (Schultz, Haderspeck-Grib, Sinkora, & Warwick, 1985). They also pointed out that torso flexion substantially increased the load on the spine, as resistive forces can be generated through both active and passive tissues. Similarly, Dolan et al. (1994) validated the function of the passive tissues in her spine model. McGrill and Kippers (1994) illustrated that the biomechanical model of transferring load within lumbar muscles and passive tissue during flexion relaxation phenomenon was happening. They found that even though the extensor muscles were seemingly silent when looking at EMG, muscles still generated elastic forces to support the full flexion; even with small amount of load in the hands, there would be a considerable load on the intervertebral discs that might be close to NIOSH low back compression limit.

Many factors potentially influence the occurrence of the FRP, for example, the flexibility of the individual (Shin et al., 2004) affects the degree of torso flexion angle one needs before the flexion-relaxation phenomenon begins to occur. Chen et al. (2018) also showed that erector spinae EMG activation was significantly higher for people with higher flexibility when torso flexion reached 75 degrees and 90 degrees, respectively. Generally, to supplement the evidence of the benefit of relieving the risk LBD in terms of reducing the lower back loading, other in vivo research methods could be applied. Intra-abdominal pressure (IAP), for example, was believed as a valuable measure of response from musculoskeletal system towards lifting tasks (Marras et al., 1995). Besides, models that estimate the compression force and shear force on lumbar could be used to measure the spinal loads during extreme spine flexion. Nonetheless, overall, the strap method was perceived to be easier by participants in all scenarios relative to the traditional method. The more the scenario was restricted, the higher proportion of participants expressed the opinion that the task was much easier with the strap method.

Limitations

There are some limitations that could be addressed in future research. Participants of the study were all inexperienced with regards to patient handling tasks. This meant that they were not able to provide professional suggestions regarding strap use from an EMS worker perspective. Based on daily work experience, real EMS providers might feel different about the ergonomic intervention devices. The ergonomic intervention usage compliance would be influenced by the caregiving culture, management, and the relevant time increase due to the engagement of the intervention devices (Daynard et al., 2001). Furthermore, as inexperienced participants could have experienced different biomechanical loads than those of experienced workers.

Another limitation was the weight of the simulated patients. It is normal for FFPs to work with heavier patients, even overweight patients, than the “standard” patient used in this study. However, the designed frequency of raising exertion in this study was once per minute, which was much higher than what would be encountered in the real-life EMS work environment. Therefore, it was easier for the participants to be fatigue. Thus, with non-professional participants in this study, the weights of the “standard” patients were limited to values that participants could work with through all the experimental conditions.

From an experimental control viewpoint, instructions were given to all participants in a consistent manner, but the adaption to the strap was still relatively diverse. The initial expectation of the strap method was to encourage participants to utilize their legs to shift their weight thereby augmenting the muscle force required to raise the patient, rather than lifting with their torso, or lifting with their arm muscles. However, it was inevitable that there was variability in movement strategies across participants within the strap conditions. For example, some participants used more knee motion and lifted the strap by extending their legs, some stood and used their arms to raise the patient, and some participants tended to lean back. Researchers reminded participants who were bending too much with the strap to stand more upright and use their shift their whole body when using the strap. Further work could explore these differences between these "leg-assist" and "torso-assist" strategies. This could be a valuable reference when establishing training protocols. However, there was not enough statistical power to comprehensively analyze this phenomenon in the current dataset. Different strategy adoption would be more likely to happen if the strap was introduced to EMS workers without proper training.

The current study did show some of the apparent ergonomic advantages of using the strap, which as Weiler et al. (2012) pointed out is one of the key factors that affect EMS providers adopting an ergonomic intervention. Thus, it is worth considering the degree to which different strategies of the strap use affect the ergonomic advantage in future studies.

Chapter 5. Conclusion

The research evaluated the efficacy of the lifting strap comparing to the traditional manual method for raising a supine patient to a sitting position in three simulated common EMS work environment settings. Adopting the strap method in each environment could remarkably mitigate the trunk forward flexion, lateral bending, and kneeling postures while raising the patient to a sitting position. It should be recognized that these postures may still be required when inserting the strap, but when this is done, the external forces acting on the body are much smaller than when raising the patient. Likewise, there was a substantial decrement in the latissimus dorsi activations which given the body's muscle architecture, should reduce biomechanical loads on the spine. These benefits come at the expense of increased biceps use and the apparent increase in spine loading from the erector spinae. However, in the constrained conditions, such as the hallway and the bathtub scenario, the lower erector spine EMG response using the traditional method, might be due to the flexion relaxation phenomenon (FRP) in which passive tissues are loaded which in turn biomechanically loads intervertebral disc tissues. Hence, the benefit of the strap could not be seen in terms of the erector spinae EMG diminishment, thus leaving the question open as to the net biomechanical effect on spine tissues. Nonetheless, the conspicuous posture improvement and participants' preference for the strap in all scenarios, especially in the restricted scenarios, suggest the strap intervention has utility in EMS work environments.

In summary, it appears that the strap would be an appropriate intervention for the intended task of raising patients from supine lying posture to seated position. Whereas the bilateral erector spinae EMG data did not support the hypothesis that the strap is valuable regarding reducing the possibility of lower back loading, due to the potential confounding with the flexion relaxation phenomenon. Further in-vivo studies using biomechanical modeling of the lower back are recommended. Further, professional opinions from firefighters and paramedics on the strap method in these simulated settings remained unexplored, which deserves an investigation in the future as well.

Bibliography

Ahern, D. K., Follick, M. J., Council, J. R., & Laser-Wolston, N. (1986). Reliability of lumbar paravertebral EMG assessment in chronic low back pain. *Archives of Physical Medicine and Rehabilitation*, *67*(10), 762–765. https://doi.org/10.1016/0003-9993(86)90014-6

Arial, M., Benoît, D., & Wild, P. (2014). Exploring implicit preventive strategies in prehospital emergency workers: A novel approach for preventing back problems. *Applied Ergonomics*, *45*(4), 1003–1009. https://doi.org/10.1016/j.apergo.2013.12.005

Bailey, H. (1960). *Physical Signs in Clinical Surgery* (Thirteenth). Bristol: John Wright & Sons Ltd.

Bureau of Labor Statistics, United States Department of Labor. (2019). OCCUPATIONAL OUTLOOK HANDBOOK. https://doi.org/10.2105/ajph.48.9.1282-a

Chen, Y. L., Lin, W. C., Liao, Y. H., & Lin, C. J. (2018). Effect of individual flexibility and knee posture on the lumbar curvature and back muscle flexion-relaxation phenomenon. *International Journal of Industrial Ergonomics*, *68*(September 2017), 82–88. https://doi.org/10.1016/j.ergon.2018.06.009

Conrad, K. M., Lavender, S. A., Reichelt, P. A., & Meyer, F. T. (2000). Initiating an ergonomic analysis: a process for jobs with highly variable tasks. *AAOHN Journal*, *48*(9), 423–429. https://doi.org/10.1177/216507990004800903

Daynard, D., Yassi, A., Cooper, J. E., Tate, R., Norman, R., & Wells, R. (2001). Biomechanical analysis of peak and cumulative spinal loads during simulated patient-handling activities: A substudy of a randomized controlled trial to prevent lift and transfer injury of health care workers. *Applied Ergonomics*, *32*(3), 199–214. https://doi.org/10.1016/S0003-6870(00)00070-3

De Luca, C. J., Donald Gilmore, L., Kuznetsov, M., & Roy, S. H. (2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *Journal of Biomechanics*, *43*(8), 1573–1579. https://doi.org/10.1016/j.jbiomech.2010.01.027

Dropkin, J., Moline, J., Power, P. M., & Kim, H. (2015). A qualitative study of health problems, risk factors, and prevention among Emergency Medical Service workers. *Work*, *52*(4), 935–951. https://doi.org/10.3233/WOR-152139

Dolan, P., Mannion, A. F., & Adams, M. A. (1994). Passive tissues help the back muscles to generate extensor moments during lifting. *Journal of Biomechanics*, *27*(8), 1077–1085. https://doi.org/10.1016/0021-9290(94)90224-0

Farfán, F. D., Politti, J. C., & Felice, C. J. (2010). Evaluation of EMG processing techniques using Information Theory. *Biomedical Engineering Online*, *9*, 72. https://doi.org/10.1186/1475-925X-9-72

Floyd, W. F., & Silver, P. H. S. (1951). Function of Erector Spinae in Flexion of the Trunk. *The Lancet*, *257*(6647), 133–134. https://doi.org/10.1016/S0140-6736(51)91212-3

Gentzler, M., & Stader, S. (2010). Posture stress on firefighters and emergency medical technicians (EMTs) associated with repetitive reaching, bending, lifting, and pulling tasks. *Work*, *37*(3), 227–239. https://doi.org/10.3233/WOR-2010-1075

Haynes, H. J. G., & Molis, J. L. (2018). United States firefighter injuries – 2017, (November), 1–35. Retrieved from https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics/Fire-service/osFFInjuries.pdf

Hales, C. M., Carroll, M. D., Fryar, C. D., & Ogden, C. L. (2017). Prevalence of Obesity Among Adults and Youth: United States, 2015–2016. NCHS data brief, no 288. Hyattsville, MD: National Center for Health Statistics. *NCHS Data Brief, No 288. Hyattsville, MD: National Center for Health Statistics.*, (288), 2015–2016. Retrieved from https://www.cdc.gov/nchs/products/databriefs/db288.htm

Keyserling, W. M., Brouwer, M., & Silverstcin, B. A. (1992). A checklist for evaluating ergonomic risk factors resulting from awkward postures of the legs, trunk and neck. *International Journal of Industrial Ergonomics*, *9*, 283–301. https://doi.org/10.1016/0169-8141(92)90062-5

Larouche, D., Bellemare, M., Prairie, J., Hegg-Deloye, S., & Corbeil, P. (2019). Overall risk index for patient transfers in total assistance mode executed by emergency medical technician-paramedics in real work situations. *Applied Ergonomics*, *74*(August 2018), 177–185. https://doi.org/10.1016/j.apergo.2018.08.029

Lavender, S. A., Conrad, K. M., Reichelt, P. A., T. Meyer, F., & Johnson, P. W. (2000a). Biomechanical analyses of paramedics simulating frequently performed strenuous work task. *Applied Ergonomics*, *31*(1), 167–177. https://doi.org/10.1016/S0003-6870(99)00027-7

Lavender, S. A., Conrad, K. M., Reichelt, P. A., T. Meyer, F., & Johnson, P. W. (2000b). Postural analysis of paramedics simulating frequently performed strenuous work tasks. *Applied Ergonomics*, *31*(1), 45–57. https://doi.org/10.1016/S0003-6870(99)00027-7

Lavender, S. A., Chen, S.-H., Li, Y.-C., & Andersson, G. B. J. (2007). Trunk Muscle Use during Pulling Tasks: Effects of a Lifting Belt and Footing Conditions. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *40*(1), 159–172. https://doi.org/10.1518/001872098779480631

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Gacki-Smith, J., & Kohok, A. K. (2007a). Designing ergonomic interventions for EMS workers, Part I: Transporting patients down the stairs. *Applied Ergonomics*, *38*(1), 71–81. https://doi.org/10.1016/j.apergo.2005.12.005

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Kohok, A. K., & Gacki-Smith, J. (2007b). Designing ergonomic interventions for EMS workers-part II: Lateral transfers. *Applied Ergonomics*, *38*(2), 227–236. https://doi.org/10.1016/j.apergo.2006.02.005

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Kohok, A. K., & Gacki-Smith, J. (2007c). Designing ergonomic interventions for emergency medical services workers-part III: Bed to stairchair transfers. *Applied Ergonomics*, *38*(5), 581–589. https://doi.org/10.1016/j.apergo.2006.08.002

Lavender, S. A., & Sommerich, C. M. (2017). Preventing firefighter injuries when handling obsese patients: Understanding the patient handling scenarios. *Proceedings of the Human Factors and Ergonomics Society*, *2017-Octob*(2), 1015–1016. https://doi.org/10.1177/1541931213601736

Lavender, S. A., Sommerich, C. M., Bigelow, S., Weston, E. B., Seagren, K., Pay, N. A., … Marras, W. S. (2020). A biomechanical evaluation of potential ergonomic solutions for use by firefighter and EMS providers when lifting heavy patients in their homes. *Applied Ergonomics*, *82*, 102910. https://doi.org/10.1016/J.APERGO.2019.102910

Marras, W. S., Lavender, S. A., Leurgans, S. E., Fathallah, F. A., Ferguson, S. A., Allread, W. G., & Rajulu, S. L. (1995). Biomechanical risk factors for occupationally related low back disorders. *Ergonomics*, *38*(2), 377–410. https://doi.org/10.1080/00140139508925111

Marsh, S. M., Gwilliam, M., Konda, S., Tiesman, H. M. ., & Fahy, R. (2018). Nonfatal Injuries to Firefighters Treated in U.S. Emergency Departments, 2003–2014. *American Journal of Preventive Medicine*, *55*(3), 353–360. https://doi.org/10.1016/j.amepre.2018.04.051

McGill, S. M., & Kippers, V. (1994). Transfer of loads between lumbar tissues during the flexion-relaxation phenomenon. *Spine*, *19*(19), 2190–2196.

https://doi.org/10.1097/00007632-199410000-00013

Mirka, G. A. (1991). The quantification of EMG normalization error. *Ergonomics*, *34*(3), 343–352. https://doi.org/10.1080/00140139108967318

Prairie, J., & Corbeil, P. (2014). Paramedics on the job: Dynamic trunk motion assessment at the workplace. *Applied Ergonomics*, *45*(4), 895–903. https://doi.org/10.1016/j.apergo.2013.11.006

Reichard, A. A., Marsh, S. M., Tonozzi, T. R., Konda, S., & Gormley, M. A. (2017). Occupational Injuries and Exposures among Emergency Medical Services Workers. *Prehospital Emergency Care*, *21*(4), 420–431. https://doi.org/10.1080/10903127.2016.1274350

Reichard, A. A., Al-Tarawneh, I. S., Konda, S., Wei, C., Wurzelbacher, S. J., Meyers, A. R., … Robins, D. C. (2018). Workers' compensation injury claims among workers in the private ambulance services industry—Ohio, 2001–2011. *American Journal of Industrial Medicine*, *61*(12), 986–996. https://doi.org/10.1002/ajim.22917

Schultz, A. B., Haderspeck-Grib, K., Sinkora, G., & Warwick, D. N. (1985). Quantitative studies of the flexion-relaxation phenomenon in the back muscles. *Journal of Orthopaedic Research*, *3*(2), 189–197. https://doi.org/10.1002/jor.1100030208

Shin, G., Shu, Y., Li, Z., Jiang, Z., & Mirka, G. (2004). Influence of knee angle and individual flexibility on the flexion-relaxation response of the low back musculature. *Journal of Electromyography and Kinesiology*, *14*(4), 485–494. https://doi.org/10.1016/j.jelekin.2003.12.001

Shott, S. (1990). *Statistics for Health Professionals*. Saunders. Retrieved from https://books.google.com/books?id=1jkQAQAAMAAJ

Schultz, A., Andersson, G. B., Ortengren, R., Bjork, R., & Nordin, M. (1982). Analysis and quantitative myoelectric measurements of loads on the lumbar spine when holding weights in standing postures. *Spine*, *7*(4), 390–397. https://doi.org/10.1097/00007632-198207000-00009

Weiler, M. R., Lavender, S. A., Mac Crawford, J., Reichelt, P. A., Conrad, K. M., & Browne, M. W. (2012). Identification of factors that affect the adoption of an ergonomic intervention among Emergency Medical Service workers. *ERGONOMICS*. https://doi.org/10.1080/00140139.2012.714474