Applied Ergonomics 82 (2020) 102910

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

A biomechanical evaluation of potential ergonomic solutions for use by firefighter and EMS providers when lifting heavy patients in their homes

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ARTICLE INFO

Keywords:
Firefighter
EMS
Ergonomics
Patient handling
Injury prevention

ABSTRACT

Firefighters and EMS providers continue to be challenged when lifting heavy patients in their homes. This study investigated the biomechanical efficacy of four devices that could be used by two-person teams when lifting patients from the floor, from a reclining chair, or from a Simulated Inflatable Seat at chair height. Fourteen firefighter-paramedics, working in two-person teams, were instrumented with motion capture and electromyographic sensors. The Binder Lift™, the Simple Strap, and the Slip Preventer were used to lift patient actors, and were compared to current lifting methods. Postural data and the peak dynamic spine shear forces at the L5/S1 level were reduced when using the Simple Strap, the Binder Lift, and the Simulated Inflatable Seat. The Slip Preventer reduced spine flexion when the Binder Lift was not used. In summary, the tested devices can potentially reduce the biomechanical loads experienced by EMS providers as they lift and move patients.

1. Introduction

1.1. Fire service and emergency medical responder injuries, risk factors, and costs

In an analysis of fire service injuries, Haynes and Molis (2017) noted that the overall number of injuries experienced by firefighters in the United States has been declining for the past 20 years. Yet, in 2016 there were still an estimated 62,085 injuries; 12,780 of these injuries occurred during non-fire emergencies. From 1981 to 1997, the number of non-fire emergency injuries increased by 31%, largely due to the 294% increase in the number of non-fire emergency response calls received. While the number of fire ground injuries has shown a steady decline over the last 20 years, the number of injuries at non-fire emergencies has remained between 12,000 and 16,000 and shows no pattern of decline. Sprains, strains, and muscular pain account for 60% of the injuries suffered by firefighters while performing non-fire emergency tasks, such as EMS and other rescue operations (Haynes and Molis, 2017). Their findings are consistent with others who have reported overexertion activities as the typical cause of musculoskeletal injuries in fire and emergency medical services (EMS) services, with the back and shoulders being the major body parts affected (U.S. Bureau of Labor Statistics (BLS), 2013; Dropkin et al., 2015; Maguire et al., 2005; Poplin et al., 2012). BLS data for 2017 show the incident rate for back injuries in emergency medical technicians and paramedics working in private industry was among the 10 highest occupations (Table R97, BLS, 2017). Where the specific source of the lost time injury was a patient, incidence rates for emergency medical technicians were 105 cases per 10,000 full time equivalent (Table R99, BLS, 2017).

Injury risks associated with patient-handling are compounded by the obesity epidemic in the US. About one-third of American adults are classified as overweight ($25 < \text{BMI} < 29.9$), and about 40% are obese ($\text{BMI} \geq 30$) (National Center for Health Statistics, 2017). With obesity comes a host of medical conditions, some of which increase the need for emergency responder intervention, including hypertension (34.3% prevalence) and diabetes (11.1% prevalence), as well as cancer and heart disease. In addition to weight, body shape and medical conditions that heighten pain or limit mobility contribute to the physical challenge of handling obese patients (Cowley and Leggett, 2010). Characteristics of the patient's home, including narrow hallways and stairways, add to

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https://doi.org/10.1016/j.apergo.2019.102910
Received 26 March 2019; Received in revised form 19 July 2019; Accepted 29 July 2019
Available online 07 August 2019
0003-6870/

the physical stress and difficulties of handling these patients. Johnson (2006) described various types of injuries to firefighter/paramedics in the Mason City (Iowa) Fire Department that were associated specifically with handling bariatric patients: “injury records have included falls, back injuries, upper extremity strains and crush injuries … Falls were commonly caused by loss of balance and loss of control of the patient, causing over-compensation by the rescuer.”

Injuries to firefighters and emergency medical service personnel are costly (Tri Data Corporation, 2005). In examining the extent and cost associated with musculoskeletal injuries across a number of fire departments and years, researchers found that overexertion-related injuries were associated with high worker compensation costs (Walton et al., 2003), and frequently involve the back. In addition to these monetary costs, Johnson (2006) expressed concern for “a deleterious effect on future staffing of the department”, which is consistent with ongoing challenges of smaller fire service operations to retain and recruit personnel (Meyer, 2003). Thus, prevalence, cost, and disability associated with work-related musculoskeletal injuries among firefighters, as well as the association between patient-handling activities and injury, and the increasing weight of patients, all support the need for further analysis and development of control measures.

Focus groups with firefighters (FFs), organized for the purpose of discussing challenges experienced when handling heavy patients, revealed that patients were frequently found in a bathroom (Lavender and Sommerich, 2017). These bathroom patient handling situations included patients in the tub or shower, patients that were wedged between the toilet and wall (or tub), or patients lying on the bathroom floor. Another common situation was finding the patient in a bedroom, having fallen between the bed and a wall or a heavy piece of furniture (e.g. dresser). In sum, these discussions indicated that FFs need to lift these patients in restricted spaces, which severely limits the number of FFs that can assist in these efforts. In addition to medical emergencies, many of the calls the participants described were requests for fall assistance, where the patient needed to be lifted from their current location, but transport to a medical facility was not required.

After discussing these commonly encountered situations, focus group participants engaged in a brainstorming process where they were asked to ideate potential ergonomic solutions that could be used to facilitate their patient handling tasks. As was learned through conversations with FFs and as explained by Johnson (2006), the only equipment that FFs commonly utilize to handle obese patients is a special reinforced tarp with handles and standard equipment including their backboard, Stokes basket, ropes, and assorted hardware. Bariatric equipment is available, but it is in the form of higher weight-capacity cots and winch systems on some ambulance vehicles. However, this equipment does not address the patient handling activities that occur from the point in time when the patient is encountered in the home to when the patient is placed on the cot. Administrative controls are often relied on for these handling activities. For example it is recommended that patients who weigh more than 136 kg should not be moved by fewer than four providers and that a safety officer should oversee the operation (Augustine, 2012), however the space constraints described above limit the effectiveness of such guidelines.

1.2. Intervention needs and solution ideation

Prior focus groups (Lavender et al., 2007) discussed how difficult it is to get hold of people when trying to lift them from the floor. Multiple participants in these focus groups explained that many of their patients have shoulder issues (i.e. weakness, pain, etc.) that preclude lifting them by or underneath the patient's arms. In the brainstorming process that was included in the focus group research, many of the participants suggested ideas for devices that essentially put handles on the patient so that the FF could securely grasp the patient during the lifting process. Based on these discussions, a device was developed based on earlier work (Lavender et al., 2007), which is referred to as “The Simple Strap”. This device is a long strap with one buckle that can be used to create a simple lifting sling for the patient, and in so doing, essentially provides handles on the patient for the FFs to use when lifting the patient. The strap goes under the thighs, under the arms and around the upper back, which is where the buckle is located (Fig. 1a and 1b). This device was designed to lift patients in a seated posture from the floor or from a piece of furniture to a different seated location, for example a stairchair. An alternative device is a commercially produced product, the Binder Lift™. This device wraps around the torso below the arms and has multiple handles that can be used for lifting the patient (Fig. 1c). The device has three belts around the torso. In addition, there are two leg straps, however, these were not used in the current study given that in many situations it would be difficult to get these in position and our firefighter participants suggested they would likely not be used. This device can be used to lift a person to a standing position or up to a seated position on a chair.

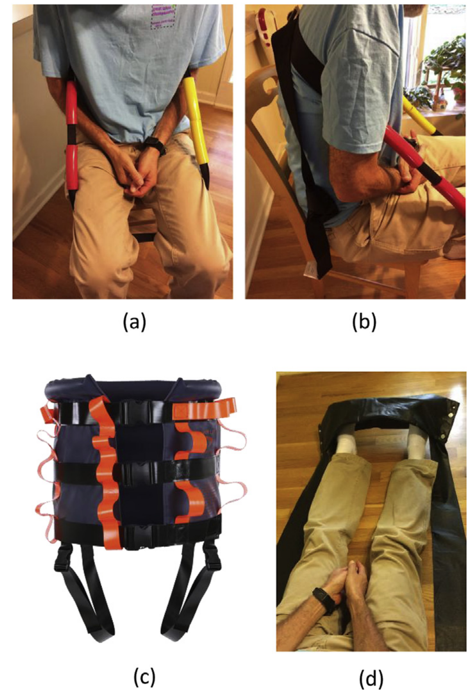

Fig. 1. The interventions tested included the Simple Strap shown from the front (a) and side (b), The Binder Lift (c), and the Slip Preventer (d).

The focus group participants also described a situation they commonly experience when lifting patients from the floor to a standing position wherein the patient's feet slide across the floor, thus making it difficult to get the patient to a standing position. To address this issue, a device called the “Slip Preventer” was developed to hold the patient's feet in position, preventing the feet from sliding forward/away while the patient is lifted. The device consists of two long straps attached to a fabric pouch that is placed over patient's toes (Fig. 1d). The long straps, made of a tacky material that produces a high coefficient of friction when placed on the floor and stood upon, are laid on each side of the patient. When EMS personnel lift the patient they each stand on one of the long straps, thereby preventing the patient's sliding motion.

1.3. Validation study

The next step was to investigate the biomechanical validity of these ergonomic solutions when used in patient lifting tasks that simulated the most common and physically stressful conditions described by the focus group participants. Two lifting tasks were assessed in this study. The first task to be investigated was lifting patients seated on the floor or from chair level to a stairchair. Consistent with task description information provided by the focus group participants, the patients were lifted from a reclining chair ('recliner'), from a constrained space that simulated a bathroom floor, and from a surface at chair level that simulated lifting from an inflated seat device (e.g., Manger ELK Lifting Cushion, a device designed to raise a patient seated on the floor to a height of 56 cm off the floor through inflation of a stack of 50 cm × 50 cm "air mattresses"). In each of these tasks the patient was lifted to a stairchair by two FFs along with a third individual (research team member) assisting the EMS providers by positioning the stairchair behind the patient as instructed by the FFs. Specifically, this part of the study tested the following hypotheses:

1. Spinal loading will be reduced when lifting the patient to the stairchair from a recliner, a chair height simulated inflatable device, or the bathroom floor when using the Binder Lift or the Simple Strap, relative to the spinal loads incurred when EMS providers use their usual lifting techniques in these situations.
2. Spinal loading will be reduced when a team of two EMS providers position themselves with on one on each side of the patient rather than one behind (to lift torso) and in front of the patient (to lift legs).

The second lifting task evaluated in this study involved lifting the patient from the floor to a standing position with and without the Binder Lift and with and without the use of the Slip Preventer. This part of the study tested the following hypotheses:

1. Spinal loading will be reduced when EMS providers use the Slip Preventer to prevent the patient from sliding while the patient is being lifted from the floor to a standing posture.
2. Spinal loading will be reduced when a Binder Lift is used by EMS providers when raising a patient from the floor to a standing posture.
3. Spinal loading will be reduced when the Binder Lift and the Slip Preventer are used by EMS providers in combination as compared with using either of the devices individually.

2. Methods

2.1. Experimental design

The first lifting task investigated two independent variables: the lifting scenario (lifting the patient to a stairchair from the bathroom floor, lifting from a recliner, and lifting from a simulated inflated seat) and the equipment used (No Equipment, the Binder Lift, and the Simple Strap). The second lifting task investigated two independent variables: the use of Binder Lift versus no lift equipment, and the use of the Slip Preventer versus no slip prevention device. A repeated measures experimental design was used for both tasks in which each FF participant performed each lifting condition. Two samples of each lifting condition were obtained. Thus, 18 lifts were performed for the first task (3 scenarios x 3 equipment conditions x 2 repetitions) and 8 lifts were performed for the second task (2 lifting equipment conditions x 2 slip preventer conditions x 2 repetitions). Within each lifting scenario, the sequence of equipment use was randomized. Likewise, in the second lifting task, the sequence of the four combinations of slip preventer and Binder lift use was randomized for each teams of FF participants.

2.2. Participants

Fourteen professional FFs (13 male, 1 female) were recruited to participate in these experiments, with two FFs attending each data collection session. These tasks are typically performed by a minimum of two FFs (in the US most medic trucks have two FFs assigned to them). These participants had between 4 and 27 years of experience as firefighters (average = 14.5 years). The mean height and weight of these participants was 1.78 m and 91 kg, respectively. Three different individuals served as the simulated patient, their weights ranged from 91 to 103 kg. Each team of FF worked with the same simulated patient for all conditions.

2.3. Instrumentation

Electromyographic (or EMG) data were sampled at 1000 Hz using bipolar surface electrodes and either a wireless Trigno system (Delsys, Natick, MA, USA) (one subject) or a wired Motion Lab Systems MA300-XIV system (Motion Lab Systems, Baton Rouge, LA, USA) (the other subject). Each participant was instrumented with five pairs of electrodes to bilaterally sample muscle activity data from the erector spinae, latissimus dorsi, external oblique, internal oblique, and rectus abdominus muscles. Kinematics for both subjects were recorded via a 42-camera Prime 41 OptiTrack optical motion capture system (NaturalPoint, Corvallis, OR, USA) at a 120 Hz sampling rate; the accuracy of this system has been validated to be less than 200 μm in 97% of the capture volume (Aurand et al., 2017), and use of all 42 cameras helped prevent marker occlusion. During model calibration (performed separately for each subject), ground reaction forces were recorded at 1000 Hz from a 6090-15 six-axis force plate (Bertec, Worthington, OH, USA). All signals were synchronized with a data acquisition board (USB-6225, National Instruments, Austin, TX, USA).

2.4. Procedures

Each participant signed an IRB-approved consent document upon arrival at the study site. After taking several anthropometric measures (stature, mass, width and depth of the torso at the xiphoid and navel, circumference of the torso at the navel) that are used to scale the biomechanical model to each subject, each subject was outfitted with both surface electrodes on the aforementioned torso muscles and motion capture markers. Consistent with Mirka and Marras (1993), the erector spinae electrodes were placed approximately 4 cm lateral to the midline of spine at the L3 level; the latissimus dorsi electrodes were placed over the most lateral portion of the muscle at the T9 level; the external oblique electrodes were positioned approximately 10 cm from the midline of the abdomen and 4 cm above the ilium at 45° to the midline of the abdomen; the internal oblique electrodes were placed posteriorly, 4 cm above ilium, in the lumbar triangle and at a 45° angle relative to the midline of the spine; and the rectus abdominus electrodes were placed 3 cm from the midline of the abdomen, and 2 cm above the umbilicus. Motion capture markers (41) were placed onto the body of each subject consistent with a marker set predetermined by OptiTrack's motion capture software; redundancy markers were also added to the forearm and leg of each subject in order to fill gaps in marker data from marker occlusion.

After being instrumented with electrodes and motion capture markers each participant performed a series of calibration exercises (sagittal and lateral bending) standing on a force plate while holding a 9.07 kg medicine ball. Data collected during these exercises were used to calibrate the biomechanical model (Hwang et al., 2016a) for each participant and tune the model to his/her muscle response (Dufour et al., 2013). This model calibration technique reverse-engineers individual muscle parameters and other relationships (force-length, force-velocity) for each subject without the use of maximum voluntary contractions (MVCs) for EMG normalization.

Prior to performing each patient handling task, the firefighter teams were shown a training video, prepared by the research team, for each ergonomic solution and then they practiced the task prior to data collection. These videos showed a FF positioned on each side of the patient (Fig. 2). When working in the simulated bathroom space, some participants (n = 6) claimed their normal technique involved one FF lifting the torso from behind and one FF lifting the legs. In these situation we used the torso position as the no equipment (control) condition. Another four participants showed us both the front/back and the side

Fig. 2. The lifting situations and independent variables investigated in the first and second lifting tasks.

lifting techniques in the bathroom. This allowed us to perform a secondary analysis of the effect of lifting position. In the second lifting task, when the Slip Preventer was not used, the patients, who were wearing only socks on their feet, were instructed to let their feet slide forward if the lift trajectory created a horizontal force. Once the data collection process was initiated, the team of firefighters coordinated the timing of their activities, as they would do in actual patient handling situations. There was a 1 min rest period between the performance of each activity. At the completion of each lifting task, the FFs were asked to subjectively rate the relative effort required to use each lifting relative to how they typically perform the task. In all tasks, the patient actors were instructed by the investigators to follow instructions provided by the FFs but not to assist the FFs in the lifting process.

2.5. Data analysis

Kinematic data were collected at a sampling frequency of 120 Hz using the 42 camera system. Marker trajectories were filtered with a low pass filter using a cutoff frequency of 6 Hz. Motion capture provided the location and orientation of each body segment expressed in quaternions, while a custom Matlab script calculated and expressed relative differences (i.e., joint angles) between body segments via Euler angles. The kinetic (force plate) data were low pass filtered at 10 Hz. EMG signals were notch filtered at 60 Hz and its aliases and band-pass filtered between 30 Hz and 450 Hz. The signals were then rectified and smoothed using a fourth order low pass filter with a cutoff frequency of 1.59 Hz (4th-order Butterworth, chosen from a time constant of 100 ms).

Each participant's EMG data were used to compute muscle forces based upon the data collected during the initial calibration exercises. For each condition tested, arm, leg, and back postures were determined from the motion capture system. The EMG and kinematic data were used in a subject-specific biologically-assisted 3D dynamic spine model that has been developed in the Biodynamics Laboratory at The Ohio State University (Hwang et al., 2016a, 2016b; Knapik and Marras, 2009, Granata and Marras, 1995). In the model, geometric relationships between the power producing muscles of the trunk are represented based on previous MRI studies which have quantitatively documented the torso architecture, cross-sectional area, lines of action, as well as the mechanical advantage of these muscles for both males and females at each vertebral level from T8 to S1 (Jorgensen et al., 2001; Marras et al., 2001). Ten trunk muscle equivalent vectors (approximating trunk anatomy and mechanics) are governed by (surface) EMG recording inputs. Processed EMG data and calibrated muscle strength values are combined with muscle size, length and contraction velocity to determine muscle force magnitudes. The model computes the time varying spine compression force at each vertebral level and shear forces acting on each of the intervertebral discs within the lumbar spine, as well as the time varying muscle forces. Once the compression force and the lateral and anterior shear forces were obtained, peak values during each task were extracted from the data stream for analysis; the highest compression on the spine occurred at L4/L5 and the highest shear loading occurred at L5/S1. Likewise, peak spine flexion values were also extracted from the time varying data stream.

For each lifting task, the peak values were analyzed using analyses of variance (ANOVA) procedures where the effects of the independent variables (defined by the equipment used and the scenario in which it was used) were analyzed. Each participant was treated as a fixed blocking factor to control for the extraneous variance between participants in this within-participants study design even though they worked in two-person teams.

3. Results

Simple Strap and Binder Lift Evaluations When Lifting Patients from a Simulated Inflated Seat, from a Recliner, and from the Floor in the Bathroom.

When lifting the patient from the recliner, there were statistically significant differences in spine anterior shear loading, the torso flexion and torso lateral flexion when using the Binder Lift and the Simple strap (Table 1). The anterior shear force was reduced by 22 percent when using the Binder Lift, and by 53 percent using the Simple Strap (Fig. 3a) relative to the no equipment condition. Fig. 3b shows the within subject changes in the peak anterior shear loading with the Binder Lift and the Simple Strap. For these same lifts, Fig. 3c shows the simple strap reduced torso flexion by 17° (32 percent) and Fig. 3d shows the within subject changes. As for the lateral bending, the Binder lift resulted in

Table 1
Summary of the p-values and corresponding effect sizes for tests involving the simple strap and the Binder Lift devices.

Location of Lift	Measures	p-value	Effect Size (Eta-Squared)
Recliner	L4/5 Compression	NS	–
	L5/S1 Shear	< .001	.52
	L5/S1 Lateral Shear	NS	–
	Torso Flexion Angle	< .001	.50
	Torso Axial Rotation	NS	–
	Torso Lateral Flexion	.031	.23
Inflatable Seat	L4/5 Compression	NS	–
	L5/S1 Shear	.013	.17
	L5/S1 Lateral Shear	NS	–
	Torso Flexion Angle	< .001	.45
	Torso Axial Rotation	NS	–
	Torso Lateral Flexion	NS	–
Bathroom Floor	L4/5 Compression	NS	–
	L5/S1 Shear	.017	.27
	L5/S1 Lateral Shear	NS	–
	Torso Flexion Angle	NS	–
	Torso Axial Rotation	NS	–
	Torso Lateral Flexion	NS	–

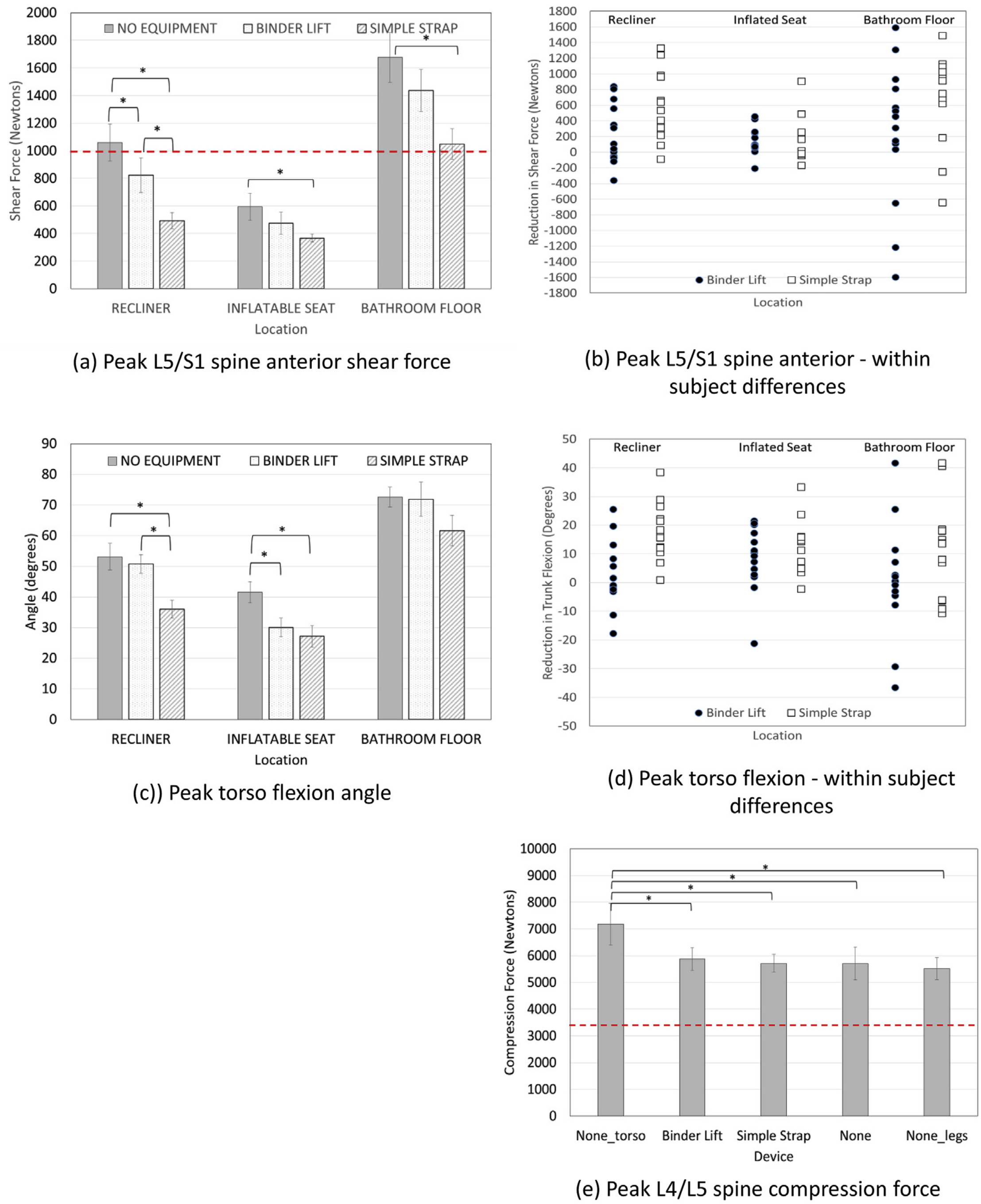

Fig. 3. The average of the peak L5/S1 spine anterior shear forces as a function of equipment used and the location (a), and the within subject differences due to the Binder lift and the Simple Strap at each location (b). The means of peak torso flexion as a function of the lifting device used and the location where the patient lift originated (c) and the within subject differences due to the equipment used. The dashed lines in (a and e) indicates the recommended 1000 N shear force limit and 3400 N compression limit (NIOSH), respectively. The bottom figure (c) shows the peak L4/L5 spine compression forces when lifting with the devices, without a device and the FFPs on each side of the patient ("None") and when the FFPs chose to have one individual lift the torso and the other lift the patient's legs ("None_torso" and"None_legs") (* = p < 0.05). Error bars represent one standard error of the mean.

significantly more lateral bending than the simple strap, although neither were statistically different from the no equipment condition.

When lifting from the simulated inflated seat, the Simple Strap significantly reduced the L5/S1 anterior shear by 38 percent relative to the no equipment condition. The Binder Lift reduced the anterior shear force by 20 percent, however, this was not statistically different from the no equipment condition (Figures 3a and b). In addition, both the Simple Strap and the Binder Lift significantly reduced the trunk flexion by 35 and 28 percent, respectively as compared with the no equipment condition (Fig. 3c and d).

While lifting the patient in the bathroom, there was significant device effect for the anterior shear (Table 1). In this condition, use of the simple strap significantly reduced the anterior shear force by 37 percent relative to no equipment condition (Fig. 3a and b). Use of the Binder Lift reduced the anterior shear by 14 percent, although this was not statistically different from the no equipment condition. There were no significant changes in any of the other measures in the bathroom environment.

An evaluation of the FF suggested alternative technique, where the patient in the bathroom is lifted with one FF behind the patient, lifting

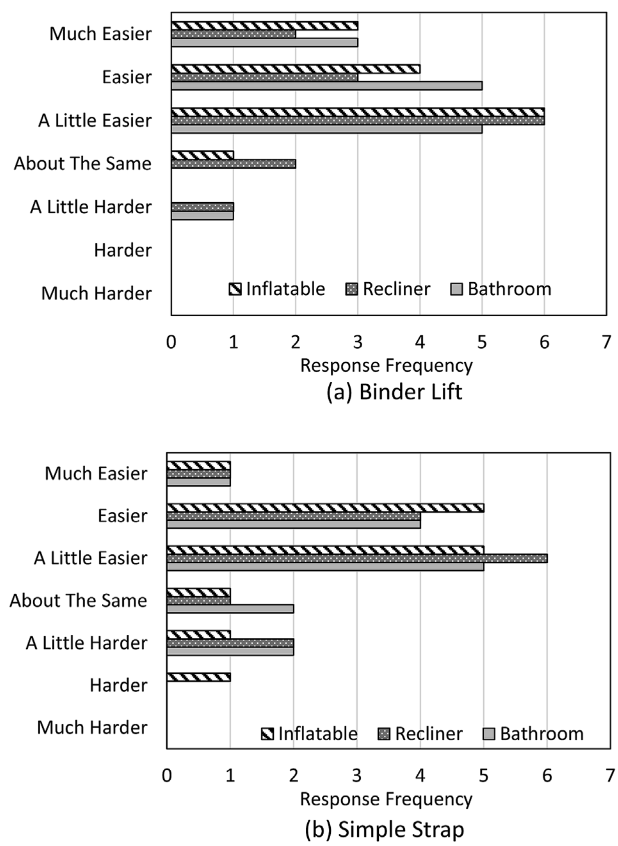

Fig. 4. Subject ratings of the relative effort required to lift the patient from the bathroom floor, recliner, and simulated inflatable seat while using the Binder Lift (a) and the SimpleStrap (b) relative to the participant's conventional methods without equipment.

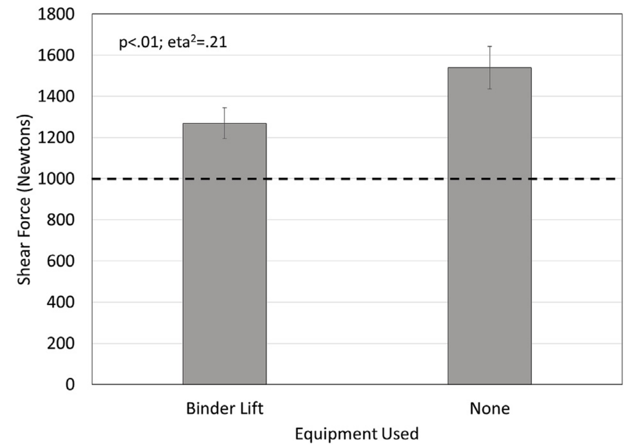

Fig. 5. Peak L5/S1 anterior shear force at the L5/S1 disc when raising a patient seated on the floor to a standing position. The dashed line is the recommend shear force limit of 1000 N. Error bars represent one standard error of the mean.

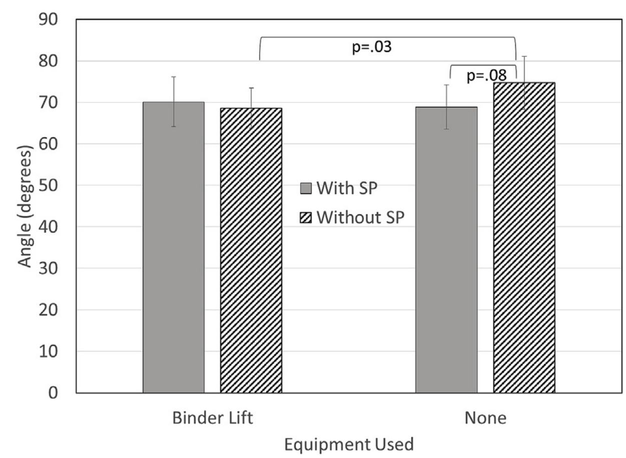

Fig. 6. Lift device use by Slip Preventer (SP) use interaction effect on the spine flexion angle. Error bars represent one standard error of the mean.

the patient's torso, and the second FF lifting the legs, indicated that the FF lifting the torso experienced significantly higher compressive loading on the spine ($p < .001$, $eta^2 = 0.38$) when compared with the conditions where the FFs were on each side of the patient, with or without a lifting device. Relative to the one-on-each-side condition without any lifting device, the spine compression force was 26 percent higher on the torso-lifting FF (Fig. 3e). The peak spine compression force did not differ across the remaining lifting conditions (Binder Lift, Simple Strap, and the FFs lifting from the side with no additional equipment).

The data from the subjective evaluation of the effort required to perform the lifting tasks using the Binder Lift and the Simple Strap relative to the normally used method are shown in Fig. 4. Most participants reported the Binder Lift was at least a little easier to use than the conventional approach. This was particularly true for the bathroom and simulated inflated seat conditions. Overall, the Simple Strap was rated positively with regards to reducing effort, although two of the 14 participants did indicate that this device made the task “a little harder” in the bathroom and with the recliner. Likewise two of the participants indicated that lifting from the simulated inflated device was more difficult when using the Simple Strap.

3.1. Slip preventer and Binder Lift

Fig. 5 shows that the Binder Lift reduced the anterior shear force by 18 percent when lifting the patient from the floor ($p < .01$; $eta^2 = 0.21$). Use of the slip preventer did not reduce the calculated spinal loads. However, there was a marginally significant interaction effect between device use and slip preventer use for the peak torso flexion angle ($p = 0.053$, $eta^2 = 0.11$). Fig. 6 shows that when the Binder Lift was used there was no difference in the trunk flexion angle between slip preventer conditions. However, without the Binder Lift, using their normal lifting techniques, the participants reduced their torso flexion by approximately 6° when using the Slip Preventer. This may be due to the FF participants positioning themselves differently relative to the patient. Without the slip preventer, participants tended to position themselves so they had one of their feet blocking the patient's feet, in order to prevent the slip. Using the Binder Lift without the Slip Preventer also resulted in a 6° decrease in the torso flexion. This is likely the case because when the Binder Lift was used, the handles on the device provided a way to grasp the patient without bending as far. This may also be why the anterior shear load was reduced when using the Binder Lift.

Subjective data assessing whether the lifting was easier with the Slip Preventer and when the Slip Preventer was used in combination with the Binder Lift are shown in Fig. 7. Eight of the 14 participants indicated the lifting task was “a little easier” or “easier” with the Slip Preventer. Four participants thought it was about the same and two participants thought the task was a little harder with the Slip Preventer. When the Slip Preventer was used with the Binder Lift, with the exception of one participant who reported the effort was “about the same”, the remaining 13 participants reported the task to be easier, with eight of them indicating it was “much easier”. Note that the perceived effort for the Binder Lift by itself was not assessed in this task, but was assessed in the prior lifting task (Fig. 4).

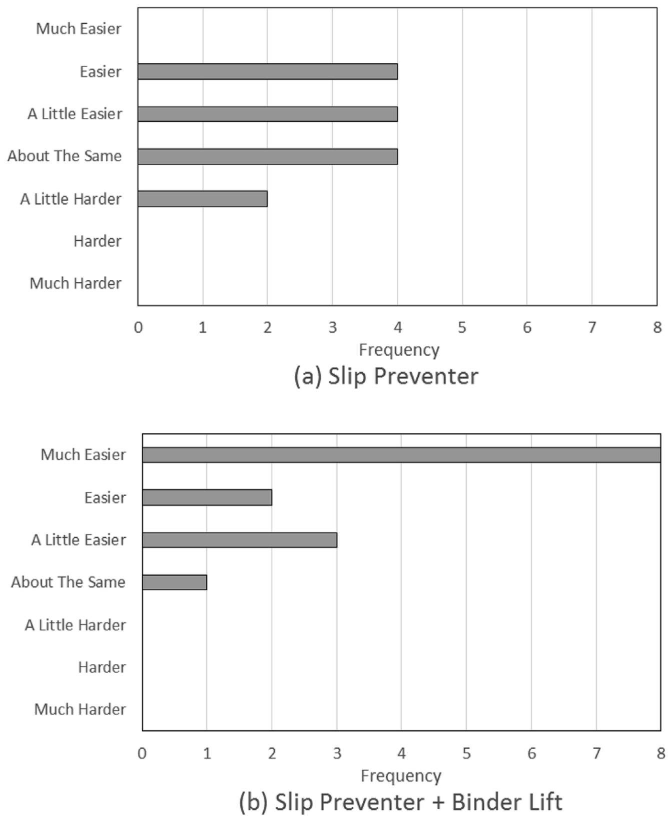

Fig. 7. Frequency of responses to two questions which asked FFPs about the relative ease or difficulty of lifting a patient using the Slip Preventer by itself, and using the combination of the SlipPreventer and Binder Lift, compared to their normal way of lifting patients whose feet can slip.

A secondary comparison was used to assess the effects of the simulated inflated seat. Data from the floor lifts, without the Slip Preventer, were compared to the data from the lifts from the simulated inflated seat both with and without the Binder Lift. The results from the ANOVA show that the spine compression ($p < .001$, $eta^2 = 0.32$), anterior shear force ($p < .001$, $eta^2 = 0.71$) and the torso flexion angle ($p < .001$, $eta^2 = 0.69$) were reduced when moving a patient from the simulated inflated seat to the stairchair as compared to moving the patient from the floor to the stairchair. Fig. 8 shows that the peak spine compression, anterior shear, and spine flexion were reduced by 26, 61, and 44 percent, respectively.

4. Discussion

The data presented here show that lifting patients from the floor or from a recliner can lead to significant spinal loading, even with the moderate weight actor-patients who volunteered for this study. Both the Binder Lift and the Simple Strap showed reductions in spinal anterior shear loads relative to the performance of these tasks without additional equipment. It is interesting to note that subjective assessment data (Fig. 4) more strongly favored the use of the Binder Lift, while the biomechanical data tended to favor the Simple Strap for the sampled lifting tasks. Importantly, the biomechanical data also showed that even without the additional equipment, FFs should be discouraged from having one FF lift the torso while the other lifts the legs. Clearly, there may be environmental conditions that justify this approach, however, when this is not the case, having a FF on each side of the patient is a significantly better approach in terms of the spinal compression values.

The second lifting task involved lifting the patient from the floor to a standing position. The collected data support the hypothesis that Binder Lift reduces FF spinal loads when raising a patient from the floor to a standing posture relative to not using the equipment. Essentially the Binder Lift, by putting handles on the patient, required less spinal flexion when initially grasping the patient, thereby reducing the anterior shear force during the lifting task. When the Binder Lift was used, it was easier for the FFs to lift the patient with a more vertical trajectory thus negating the need for the Slip Preventer. Without the Binder Lift, the patients were brought to their feet by more of a combined lifting and forward (from the patient's perspective) motion. The forward motion was constrained with the Slip Preventer, which resulted in a trend in reduced spinal flexion. Interestingly, while a little over half (8/14) of the participants felt the Slip Preventer by itself made the task easier, when used in combination with the Binder Lift all but one of the participants thought the lifting task was easier (13/14), and a little over half of the sample (8/14) indicated the task was "much easier".

To some, the Binder Lift may look like an oversized gait belt. There have been a number of studies that have investigated the use of gait belts during patient handling tasks (Hignett et al., 2003). Benevolo et al. (1993) reported that a gait belt used by two caregivers was rated as less stressful by the caregiver participants and rated more secure and comfortable by patients, relative to handling without a gait belt. However, Nelson et al. (2009), indicate that the gait belt, for chair level transfers, should only be used when the patient is able to "partially bear weight", "position/reposition their feet on the floor", and "achieve independent sitting balance". The Binder Lift, by making contact with much more of the torso, may be able to overcome these use constraints, because the torso is lifted and stabilized as a unit when using this device. The Simple Strap requires even less control on the part of the

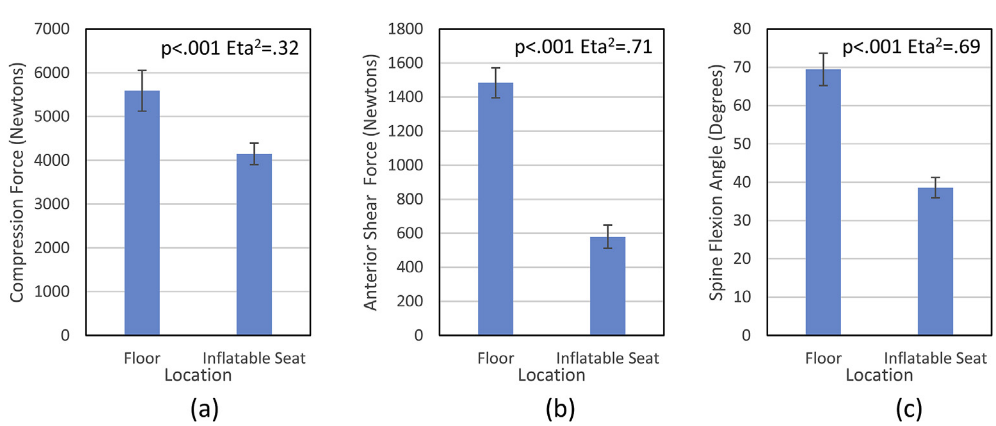

Fig. 8. The peak L4/L5 spine compression force (a), peak L5/S1 anterior shear force (b), and the torso forward flexion angle (c) when lifting the patient from the floor versus lifting the patient from the simulated inflatable seat. Error bars represent one standard error of the mean.

patient, because the legs are lifted along with the rest of the body.

When it comes to lifting obese patients from the floor, Boatright (2002) advocated for the use of inflatable air bags to raise the patient and facilitate lateral patient transfers. While not the primary purpose of the current study, the data comparing the lifts from the floor with the lifts from the simulated inflated seat at chair level strongly support the use of this type of equipment to perform the most strenuous part of the lifting task (lifting from floor level). These findings are consistent with Larouche et al. (2019) who, based on their analysis of field observations, reported that the transfers of patients sitting on a raised surface were less physically demanding than when lifting patients from the ground. Independent of the lifting device used, when the actor-patients in the current study (mass of 91–103 kg) were lifted from the simulated inflated seat the shear loads were below the 1000 N limit advocated in the ergonomics literature (Gallagher and Marras, 2012). However, what was not addressed in the current study was the additional task of repositioning the patient on to an inflatable device. It should be noted that both the Binder Lift and the Simple Strap could be used to facilitate this additional step in the process.

While many advocate for the use of powered lifting equipment (Hignett et al., 2003; Nelson et al., 2009) for patient handling tasks in institutional environments, these approaches are typically not feasible for FFs when working in patient's homes. These environments are typically space constrained and FFs report there is limited room on their trucks for this type of equipment (Lavender et al., 2007). The previous focus groups emphasized the need for patient handling equipment that is easily transported to scene and easy to set up.

There are a few limitations to this study that should be acknowledged. First, while this study evaluated equipment that could potentially assist FFs when handling obese individuals, the tests were conducted with actor-patients that weighed only 91–103 kg. Thus, the effectiveness of this equipment with significantly heavier individuals was not demonstrated due to subject safety and fatigue concerns. Second, all participants indicated that they would often have extra assistance with very heavy patients, which may partially alleviate this prior limitation where there is space for more people to contribute to the lifting task in a substantial way. But as we learned in our prior focus groups (Lavender et al., 2007), many of the more memorable lifting tasks participants recounted occurred in relatively tight spaces that limited the amount of assistance that could be provided. A third limitation of the study was that while the FFs were briefly trained on how to use the tested devices, they were relatively inexperienced in their use. Unfortunately we were not able to schedule practice sessions ahead of time with these FF participants, and there was concern regarding their overall lifting exposure during the scheduled experimental session that limited the practice opportunities. Thus, the presented findings are from participants with limited experience using the tested equipment. One might expect the findings would be even stronger with more FF experience. A fourth limitation of this study is that the technique used by the fire firefighter in the no additional equipment conditions was not standardized. There were variations across teams in exactly how these tasks were performed, but that variability is important when determining if the metrics used in this study could be expected to improve as these types of tasks are performed in the real world. The change score charts indicate that in a small number of instances there were not improvements relative to their normally selected methods. And finally, this work was primarily focused on spinal loads. It is possible that improvements in the spine biomechanical loads could have resulted in increased biomechanical loads in other body segments and joints, for example the shoulders. This should be addressed in future studies.

In summary, the results of this study support the use of devices that effectively put handles on the patients as they have the potential to substantially reduce biomechanical loads during the lifting process. The data from conditions involving the simulated inflated seat also suggests there would be value in using equipment that mechanically raises patients from the floor to chair level. Future studies should focus on how useful and useable these types of devices are in daily EMS operations.

Acknowledgement

This research was financially supported by the Ohio Bureau of Workers' Compensation's Ohio Occupational Safety and Health Research Program.

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