ELSEVIER

Applied Ergonomics 31 (2000) 45–57

APPLIED ERGONOMICS

www.elsevier.com/locate/apergo

Postural analysis of paramedics simulating frequently performed strenuous work tasks

Steven A. Lavender[a,*], Karen M. Conrad[b], Paul A. Reichelt[b], Fred T. Meyer[b], Paul W. Johnson[b]

[a]*Department of Orthopedic Surgery, Rush-Presbyterian-St. Luke's Medical Center, Chicago, IL 60612 USA*
[b]*College of Nursing, University of Illinois at Chicago, Chicago, IL, USA*

Received 2 October 1997; accepted 31 January 1999

Abstract

Paramedics who perform emergency rescue functions are highly susceptible to musculoskeletal injuries. Through an interview and survey process firefighters, many of whom are cross-trained paramedics in a consortium of 14 suburban fire departments, identified and rated tasks that were perceived to be both strenuous *and* frequently performed. The objective of the current study was to describe the working postures and the forces applied as firefighter/paramedics (FF/Ps) simulated specific roles within the following tasks identified by the survey: (1) transferring a patient from a bed to a stretcher using bedsheets, (2) transferring a patient from the ambulance stretcher to a hospital gurney, (3) carrying a victim down a set of stairs and around a landing using a stairchair, (4) carrying a victim down a set of stairs and around a landing using a backboard, and (5) carrying a victim down a set of stairs using a stretcher. Ten two-person teams of FF/Ps participated and were videotaped to obtain postural data for the upper and lower extremities as they performed each role in the simulated two-person tasks. Trunk postures were obtained using *lumbar motion monitors*. Static hand forces were estimated using a hand-held dynamometer at the most physically demanding points for each role within each task. The postural and force data were averaged across subjects performing identical roles to quantify the postures assumed by the FF/Ps at the most strenuous moments during task performance. Based on these analyses we concluded that: (1) when transferring victims from a bed to a stretcher the FF/P on the bed was able to maintain an upright and more stable posture by standing as opposed to kneeling, (2) an interface board should be used to reduce the frictional forces when transferring victims from a bed to a stretcher or from a stretcher to a gurney, thereby reducing the need to lift the victim with flexed torsos and /or shoulders, and (3) equipment and training that encourages the FF/P in the leader role to walk facing forward during victim transport, especially when descending stairs, potentially results in safer transit. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Ergonomics; Back injuries; LBP; Paramedic; Firefighter; Fire service

1. Introduction

Firefighters and emergency rescue personnel are required to engage in heavy lifting and material handling activities in nearly every call they receive. Epidemiological studies have repeatedly linked heavy lifting and material handling with the occurrence of low back disorders (Andersson, 1997). Similarly, in emergency medical technicians and paramedics, whose primary job function includes lifting and transporting patients, high back injury rates have been documented (Hogya and Ellis, 1990).

To date most of the injury prevention efforts in the fire service have focussed on strength testing and physical conditioning (Cady et al., 1979; Reichelt and Conrad, 1995). The rationale behind strength and endurance testing and training is that if individuals do not have adequate strength or endurance to perform the task, the potential for musculoskeletal injury and disability is significantly elevated (Chaffin, 1979; Doolittle and Kaiyala, 1986). However, while most of the firefighters sampled by Ellam et al. (1994) reported they were as fit or more fit than the average man, one-third or more were estimated to be overweight. Others have found that flexibility training had no effect on the incidence of musculoskeletal injury in firefighters, although it did significantly reduce the lost time associated with injuries when they occurred (Hilyer et al., 1990).

* Corresponding author. Fax: 312-942-2101.
E-mail address: slavende@rush.edu (S.A. Lavender)

0003-6870/00/$ - see front matter
PII: S0003-6870(99)00027-7

The application of ergonomic design to fire service tasks, including emergency rescue tasks, has made little progress. Some truck design characteristics have been published (LeCuyer, 1994), although as stated by Matticks et al. (1992): "… firefighting represents a task that is difficult to design and control. Therefore a greater emphasis must be placed on worker selection and education or training" (p. 233). Thus, the application of engineering controls to fire service tasks has been met with significant skepticism. In large part this is due to the enormous variation found in emergency situations and due to the fact that, unlike most industrial jobs, the environment in which the exposure to ergonomic risk factors occurs is always changing and often on private property. The same can be said about emergency rescue tasks performed by paramedics.

However, by restricting the domain of the current study to the less studied emergency rescue tasks, it was hypothesized that there are many common elements that can be found across these tasks that may lend themselves to ergonomic interventions. For example, Doormaal et al. (1995), using the Work and Health Questionnaire (WHQ), reported that ambulance drivers and nurses perceived that "getting a patient" was a strenuous task. In fact, these authors found the largest spine loads predicted with biomechanical analyses of simulated emergency response tasks occurred when lifting a patient from the ground to a stretcher. Similarly Conrad et al. (1997) identified, by means of personal interview and an extensive survey, the most *frequently performed strenuous* emergency rescue tasks encountered by the firefighting crews performing paramedic functions (FF/Ps) in a sample of suburban fire districts. These tasks included:

1. transferring a patient from a bed to a stretcher using a bedsheet,
2. transferring a patient from the stretcher to a hospital gurney using a bedsheet,
3. lifting and transporting a patient down the stairs and around a landing using a backboard,
4. transporting a patient down a straight set of stairs using a stretcher,
5. transporting a patient down the stairs and around a landing using a stairchair.

Within each task there were two roles. For example, in the task of transferring the patient from the bed to a stretcher (task number 1) the following roles were identified in the initial interviews and validated in the survey as being commonly used:

Role A: Standing on the far side of the stretcher and pulling/sliding the patient toward yourself using the underlying bedsheet.

Role B: Kneeling or standing on the bed and assisting the patient transfer by lifting the underlying bedsheet.

Once the set of frequently performed strenuous tasks and roles within those tasks were identified, the next step in the process of designing suitable ergonomic interventions is the development of task analyses. In ergonomics, task analyses are used to identify which specific steps when performing a task expose a worker to ergonomic risk factors and the magnitude of that exposure. Therefore, the objective of this paper is to describe the tasks in terms of the roles played, the postures assumed, and the exertions performed by trained FF/Ps while completing the most frequently performed strenuous tasks.

2. Methods

2.1. Approach

A set of simulated emergency rescue tasks was developed under the guidance of members from a consortium of suburban fire departments. The tasks identified via the survey were modeled such that the data collection requirements could be met while maintaining a close resemblance to the generic situations encountered by the FF/Ps. Data collection requirements included an open stairway for videotaping, a 90° (or greater) turn near the bottom of the stairs (landing) that was followed by additional steps, an open staging area at the top of the stairs that afforded adequate space for videotaping, and open space to simulate the bed to stretcher and stretcher to gurney transfer tasks.

2.2. Subjects

Ten teams of two experienced FF/Ps were recruited from 7 suburban fire departments to participate in this study. The 20 volunteers, 17 male and 3 female were cross-trained as firefighters and paramedics. Eighteen of the 20 worked full time for their respective departments. Two individuals came from a volunteer fire department. The mean height and weight of these individuals was 1.79 m (range: 1.60–1.93 m) and 87 kg (range: 57–118 kg), respectively. Each team's participation ranged from two to two and a half hours. Prior to participating the paramedics were briefed as to the tasks they would perform and signed an informed consent form.

2.3. Apparatus

The stairway at the simulation site was considerably wider than that found in a typical residence. A rope was used to create an artificial "wall" one meter from the railing on the open side of the stairs. The rope was tied such that it was approximately one meter above the stairs and did not present a trip hazard. Each step had a 180 mm rise and a 305 mm run. In all there were 19 steps including the landing which required a 90° turn.

A conventional double bed, 1.93 m long, 1.52 m wide, 0.53 m high, was used to simulate the bed to stretcher transfer. The stretcher to gurney transfer was simulated by transferring the victim from one stretcher to another while the stretchers were in their raised positions (0.92 m from the floor).

The victim was a practice dummy used by one of the local fire departments. The weight of the dummy was 471 N (48 kg). This would be similar to handling a small female victim. While this is not representative of the entire population, we were continually reminded that heavier victims are typically handled by more than two people. Moreover, to prevent fatigue we had to balance the weight carried versus the number of carries that were required during our testing protocol.

Each team of paramedics brought their own equipment to use during the testing. This included a stretcher, backboard, stairchair, and straps necessary to secure the dummy to these transport tools. The variation in the weight of the backboards across departments, 62–71 N (mean = 69 N), largely depended upon how many straps were attached to the board. Stretchers varied between 303 and 401 N (mean = 368 N). Stairchairs showed the most variation between departments. Weights ranged between 80 and 107 N (mean = 94 N). The height of the chairs ranged between 0.94 and 1.37 m while the handle height varied between 0.82 and 1.30 m. It should be noted that approximately half of the paramedics elected not to use the handles on the stairchair during the testing procedure and grasped the chair at the top of the seat back. Two teams performed lifts with a slat-stretcher which weighed 71 N.

Two teams demonstrated the transport of the victim using a "slat-stretcher". This piece of equipment weighs the same as a backboard and is constructed out of canvas with two meter wood strips sewn into the fabric. This provides the carrier with longitudinal stiffness and lateral flexibility. Fabric handles, sewn into the canvas, allow the paramedics to carry the slatstretcher with one hand when necessary.

Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of the team of subjects. Trunk positions were determined with the Lumbar Motion Monitor (LMM) manufactured by Chattanooga Group, Inc. (Chattanooga, TN). This device measures the motion in the lumbar and thoracic sections of spine. The accuracy of the LMM has been previously reported (Marras and Fatallah, 1992). Connections between the LMMs and the computers used for data collection were made through a long wire and via a radio link.

2.4. Procedures

Upon arrival each member of the team was instrumented with a LMM. The radio transmitter was provided to the LMM of the team member who volunteered to take on the transport tasks descending the stairs in reverse (walking backwards while carrying the victim). Pieces of masking tape were placed over the ankles, the lateral side of each knee, the greater trochanters, the acromium processes, the mid-line of the elbow, and the mid-point of the wrist breath dimension. These were used in quantifying body postures from the videotapes.

The data collection started with the bed to stretcher transfer, followed by the stretcher to gurney transfer, and concluded with the three stair decent tasks. The sequence of the stair decent tasks with the stretcher, stairchair, and backboard was randomized for each team. Each task was repeated three times. Two teams indicated that they would never transport a victim down the stairs using a stretcher. Instead, these teams frequently used a piece of equipment called a slat-stretcher. Therefore, for one of these teams the slat-stretcher was substituted for the conventional stretcher and analyzed separately. The second team familiar with the slat-stretcher volunteered to perform extra trials so more data could be obtained with this piece of equipment. Teams were allowed to select their own method for completing the task so long as the roles were consistent with those identified via the survey (Conrad et al., 1997). Observed variations consisted of standing on the bed rather than kneeling during the patient transfer tasks, and different arm postures used by the person descending the stairs backwards during the transport tasks.

Hand forces were measured using a hand-held dynamometer (Wagner Instruments, model FDV 100). For the bed to stretcher and the stretcher to gurney tasks, the peak dynamometer readings were obtained as the force was slowly increased to overcome the frictional forces. Since the hand forces were not evenly distributed between the two roles in the victim transport task, hand forces were determined for each role. Once the distribution of forces was known for the backboard and stretcher, these forces were adjusted to accommodate the variation in each team's equipment.

2.5. Task analysis process

The tasks were broken down by subtask as shown in Table 1. Further, each subtask contained the two roles identified from the interviews and surveys (Conrad et al., 1997). The videotapes were reviewed to obtain bi-planer postural data for the shoulders, and sagittal plane motion for all articulations except the torso. The torso postural data were obtained from the LMMs. For most subtasks, the reported postures were obtained from the most physically strenuous point in the performance of each individual subtask. For example, postures were analyzed as the subjects initiated lifting the backboard from the floor, and when the victim was just being accelerated towards the stretcher in the bed to stretcher transfer task. In some

Table 1
Transport tasks performed during simulation

Transport tast	Lift at top of stairs	Begin stair decent	Carry victim on stairs	Carry victim through landing
Stairchair		X	X	X
Backboard	X	X	X	X
Stretcher		X	X	
Slat-stretcher	X	X	X	X

Note: All tasks, with the exception of the slat-stretcher transport task, were identified based on interview and survey data.

of the transport subtasks (e.g., mid-stairs), the trunk and arm postures were essentially static thereby allowing the postures to be analyzed when the camera view was optimized. The averaged leg postures shown in the following section were more affected by the decision on where to freeze-frame the videotape for analysis.

Once the postural data were obtained from each team these data were then averaged across all teams employing similar work methods. Where method variations could be identified these subgroups were averaged separately, although, it should be noted that there were typically a small number of observations in these subgroups ($n = 1$ to 3). Averaged data were used to construct figures for the postural analysis. The figures were scaled using the average anthropometry presented by Marras and Kim (1993) and values obtained from other published sources (Webb Associates, 1978).

3. Results

3.1. Bed to stretcher task

Figs. 1a and b show the two roles defined for the bed to stretcher task. One paramedic stands on the floor and reaches across the stretcher (stretcher width 0.56 m) to grasp the sheet and pull the victim onto the stretcher. The other paramedic assists by kneeling or standing on the bed and lifting the victim with the sheet.

For the individual in the pull role, the measured applied force was 268 N. This force, while having a strong horizontal component, must also contain enough of a vertical component to assist the victim over the stretcher – bed interface and reduce the frictional force. This task required the pulling FF/P to work in a stooped posture at the point when the greatest force would be exerted. Trunk flexion angles averaged 54° (sd = 20) at the initiation of the motion. The lower extremities were also used to prevent the stretcher from moving, thereby limiting the postures that could have been adopted during the patient transfer.

The FF/P positioned on the bed provides a lifting force to reduce the frictional force encountered by his or her partner and assist the victim over the bed–stretcher interface. Kneeling on the bed, while providing stability to the FF/P's initial posture, does not allow for easy movement. As a result, most of these individuals completed the transfer with outstretched arms and significant forward spine flexion (49°, sd = 18). This posture would create

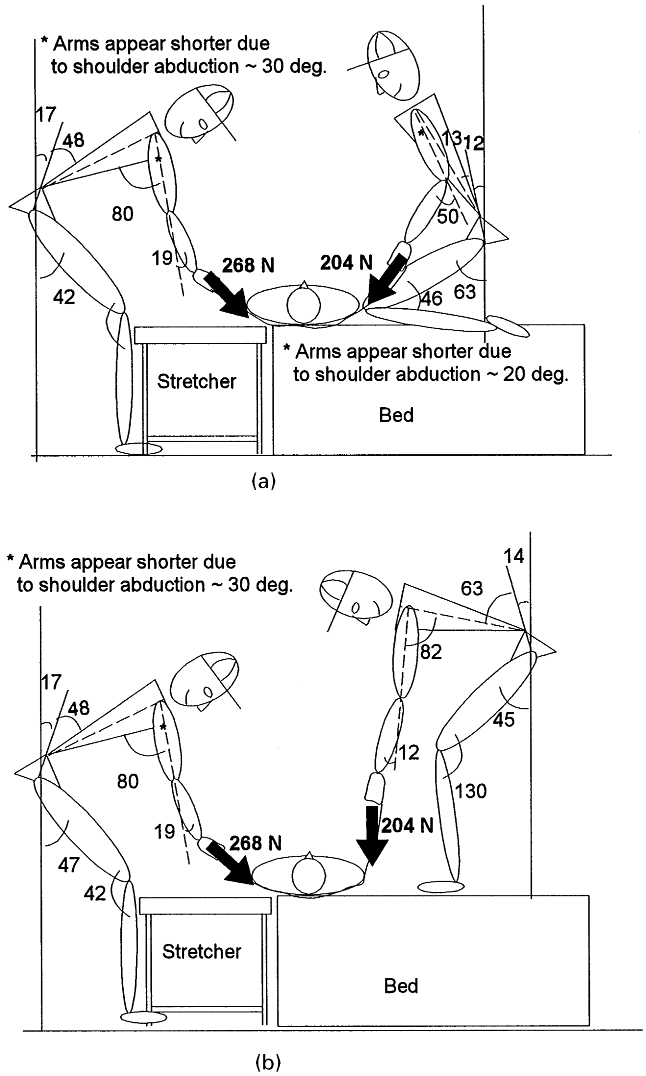

Fig. 1. The bed to stretcher task using the kneeling (a) and the standing (b) methods.

a large moment (torque) acting on the spine. Three FF/Ps performed the simulation by standing on the bed. By standing the FF/Ps could potentially exert more of the lifting force with their legs while maintaining mobility, and hence, achieve shorter reach distances at the completion of the transfer. However, the transfer task was still initiated with a significant amount of forward bending as the FF/P typically grasped the sheet near the victim. Fig. 2 shows some representative observations obtained as FF/Ps in the bed role completed the two methods. Note the difference in the reach distance. While standing appears beneficial in a static analysis, the FF/Ps' stability

Fig. 2. Video images showing differences between kneeling and stooped postures as exertions by the paramedic on the bed are completed.

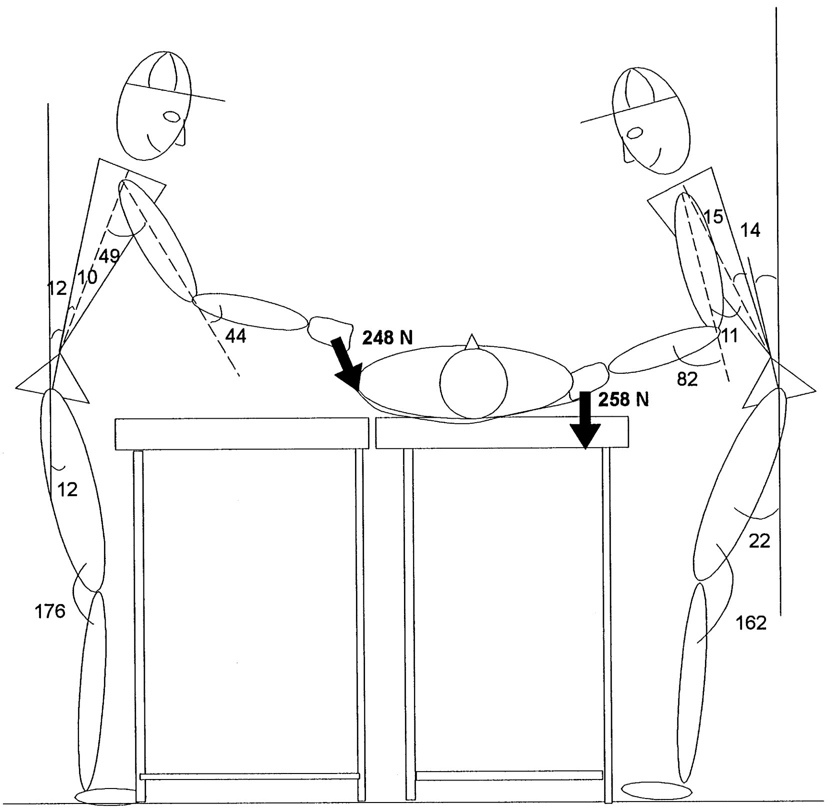

Fig. 3. The stretcher to gurney transfer task. The paramedic on the left in this figure lifts and pulls the patient. The paramedic on the right assists by lifting.

may be compromised due to the mattress underfoot. Time should be taken to achieve a stable stance before the initial lift.

3.2. Stretcher to hospital gurney

This task is the least strenuous of the tasks simulated, however, it is performed on nearly every emergency medical service run. This task requires the victim to be lifted or slid from one surface to the other (Fig. 3). One paramedic in the "pull" role lifts and/or slides the victim toward the gurney and toward his or her torso. The other paramedic in the "push" role primarily lifts the victim to reduce the frictional force.

In most cases the exertion was coordinated by the two FF/Ps by a synchronizing count. This is particularly important as it reduces the likelihood that one individual will endure more of the load than anticipated. The forces measured with the dynamometer as the 467 N dummy was moved were 248 N for the individual pulling and 258 N for the individual lifting. These were the peak force values captured during a slow transfer. Faster transfers would require larger forces to be applied. Likewise, a heavier patient would result in larger forces. FF/Ps reported during interviews that the availability of assistance from hospital staff could not be relied upon, however, if hospital staff are available they will generally assist in patient transfer.

The postures shown in Fig. 3 represent the average postures found at the point the transfer is initiated. For the pull role, the trunk flexion derived from pelvic rotation and spine flexion was 22° (sd = 8.7) and the arms were outstretched. In the push role the initial posture was even slightly more stooped. This enabled the pushing paramedic to lift more with their backs rather than relying on arm and shoulder strengths.

The LMM detected lateral bending in some individuals in the pull role at the end of the exertion. This supplemental motion occurred as the lower extremities were transferred onto the gurney. Usually this was not accompanied by any foot movement. FF/P's should be encouraged to align themselves with the lower extremities prior to this component of the lifting task, thereby eliminating the trunk lateral bending component.

3.3. Transport down stairs using a backboard

This task comprises a series of subtasks. First, the victim on the board was lifted from the floor to waist level ("initial lift"). Next, after a short carry, the FF/Ps reached the stairs and initiated their decent ("begin stairs"). Once on the stairs the decent subtask continued ("mid-stairs") until the landing was reached. At this point postures changed as the backboard was carried through the 90° turn ("landing"). The two roles were defined as the "leader" and "follower" roles. The leader lifted the end of the backboard with the victim's feet and carried the board while walking backwards down the stairs. The follower carried the end with the victim's head and walked forwards down the stairs.

Fig. 4a shows the most extreme postures, averaged across the ten teams, observed during the initial lift. The FF/Ps in either role approached the task by straddling the end of the backboard. The trunk was essentially

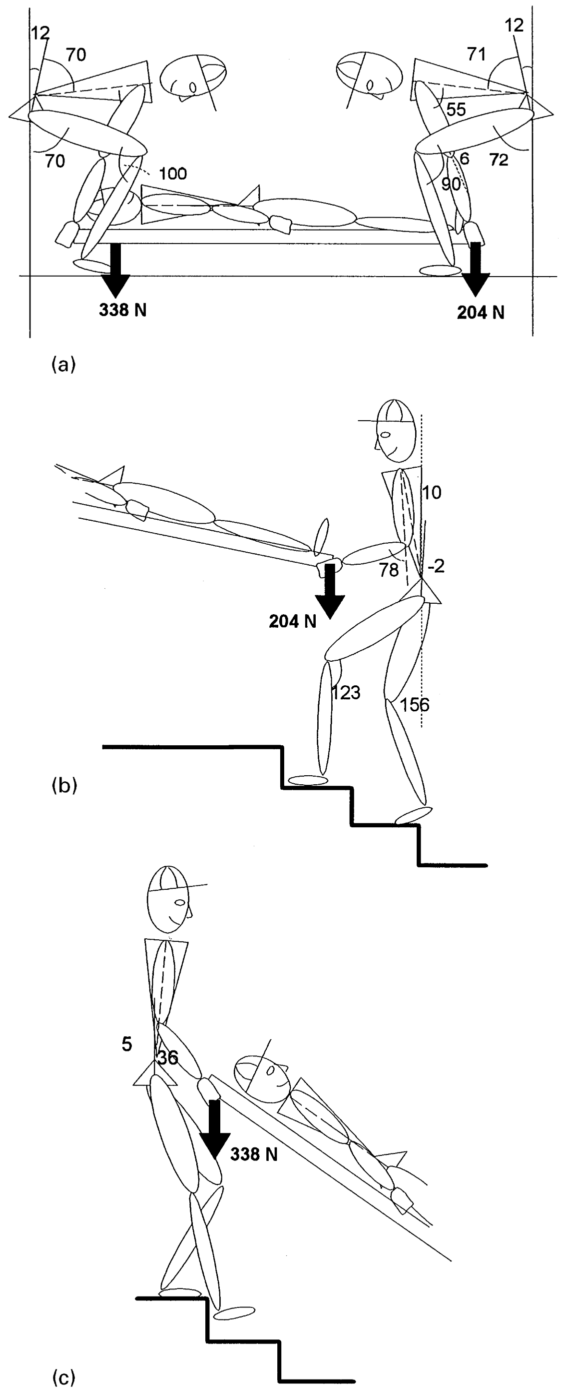

Fig. 4. The lifting (a) and transporting a victim down stairs (b, c) with a backboard.

maximally flexed, the elbows were essentially fully extended, and the knees flexed approximately 90° (sd = 21). The force distribution between the two FF/Ps indicates that the center of mass of the victim was closer to the paramedic who would carry the end of the board with the victim's head and torso and would assume the follower role on the steps.

Figs. 4b and c show the initial sagittal plane postures as each paramedic started down the stairs. In the leader role the trunk posture was essentially upright. The elbows tended to be flexed to maintain the victim in a more horizontal orientation and provide clearance for the legs as the leader was beginning to step backwards down the stairs. The first couple of steps were accompanied by approximately 10° of side bending (sd = 3) and 11° (sd = 1) of twisting motion within the torso. This motion primarily occurred as the leader turned to view the stairs. In the follower these motions were less, approximately 5–6° (sd = 2) in each direction. The follower's elbows were more extended than the leader's and the trunk more upright. For both roles the trunk and upper extremity postures were essentially unchanged throughout the decent of the remaining stairs. Relative to the follower role, the leader continued to show slightly more twisting and side bending of the torso as visual checks of the stairs were usually repeated.

The landing required a 90° turn. The still images from the video, Figs. 5a and b, show that the trunk was typically upright to hyper-extended, twisted, and laterally bent as the leader backed around the corner. Most of the FF/Ps in this role had their elbows flexed an average of 73° (0° being a straight arm) (sd = 29). Two individuals elected to carry the backboard in a raised position with the elbows flexed approximately 120°, thereby bringing the board up to near chin level. This variation in method may have reduced the horizontal distance from the hands to the spine, and hence, reduced the forward bending moment acting on the spine. Unfortunately LMM data was only available for one of these individuals. It showed greater twisting and lateral bending, 17 and 19°, respectively, than found with the lower arm posture (12° twisting (sd = 4) and 7° lateral bending (sd = 2)). This occurs because as the FF/Ps proceeded through the landing with the lower arm posture, the shoulders could be rotated to shift the board laterally rather than use trunk motion. With the arms raised the effectiveness of the shoulder rotation is greatly diminished.

3.4. Transport down stairs using a stretcher

For purposes of analysis this task was broken into two subtasks: the initial lift as the stretcher was rolled off the top of the stairs, and the actual activity of descending the stairs. Discussions with the participating FF/Ps confirmed the survey results which indicated that if the rescue required any maneuvering in addition to transport down a straight flight of stairs a stretcher would not be used. Therefore, the landing component of this task was not simulated.

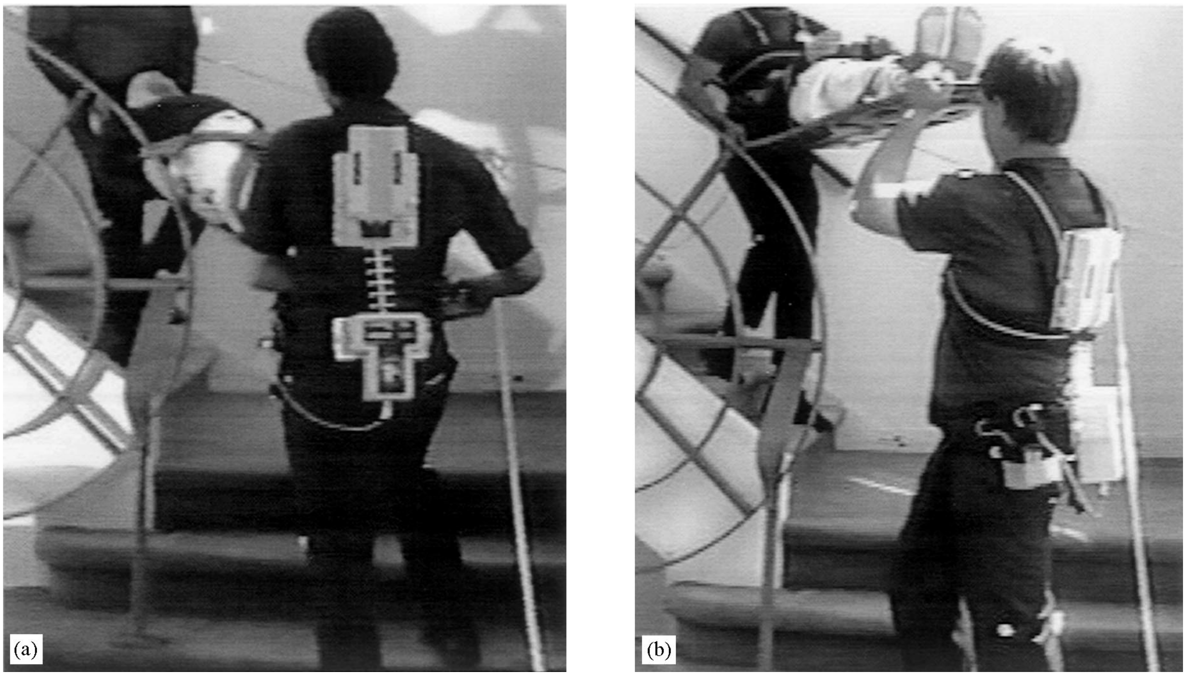

Fig. 5. Representative postures observed in the leader role as the backboard was carried through a 90° turn on a landing. The figure on the left shows the arms in the lower position (a) versus performing the same task with the arms raised (b).

The individual in the leader role of the first subtask (Fig. 6a) initiated the lift from a position two to three stairs below the initial level of the stretcher. This lowered position resulted in only an average of 24° (sd = 16) of trunk flexion during the initial lift. There was 9° of twisting (sd = 1) and lateral bending (sd = 4) motion measured by the LMM during the lift. This occurred primarily as the paramedic reached for the stretcher or when a visual check of the stairs was performed. The leader lifted 48% of the total weight which averaged 404 N across the stretchers used.

Relative to the leader, the paramedic in the follower role showed more forward bending of the spine as the stretcher was lifted (49°, sd = 29). Generally, there was very little twisting or lateral bending of the torso accompanying the follower's lift. The torso flexion, combined with moderate degree of shoulder flexion (42°, sd = 35) and small amount of elbow flexion (20°, sd = 19), allowed the hands to be positioned just in front of the knees at the point the stretcher was lifted. The follower lifted 52% of the stretcher's weight, or 431 N.

Once on the stairs the postures of both FF/Ps were much more erect (Fig. 6b). By extending the shoulders 17° (sd = 11) and flexing the elbows 84° (sd = 6) the leader raised the stretcher away from his or her legs and held it close to the torso. Alternatively, the stretcher was carried by the leader in an arms raised posture (Figs. 6c and d). This lift was initiated with the hands near

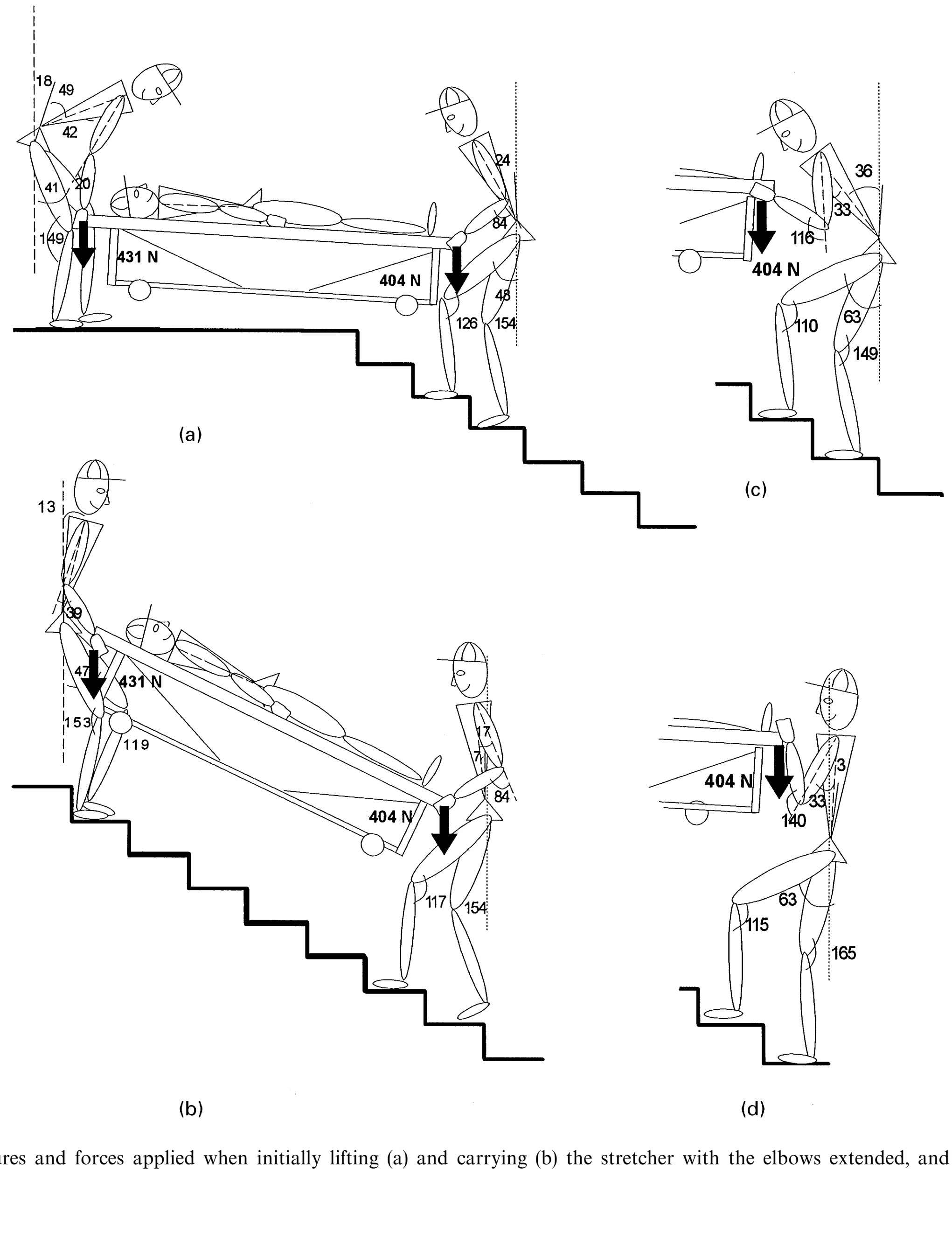

Fig. 6. The postures and forces applied when initially lifting (a) and carrying (b) the stretcher with the elbows extended, and with the elbows flexed (c, d).

shoulder level, through a combination of shoulder and elbow flexion, and with greater forward bending of the torso (mean = 36°, sd = 27). Once lifted the stretcher remained in a more horizontal orientation as it was carried down the stairs. The leader's hands were approximately the same distance horizontally from the spine as with the conventional method. Thus, the moment introduced by the 467 N was equivalent once the stretcher was lifted, however, the lifting process because of the additional forward bending would increase the moment placed on the spine.

3.5. Transport down stairs using a stairchair

Three components of this task were studied: The initial entry onto the stairs, the actual carry down the stairs, and the carry through a 90° turn on a landing. The total weight of stairchair and victim used in this test averaged 555 N. Of this the leader and follower carried 38 and 62% of the load, respectively.

At the top of the stairs the chair is typically rolled to a position near the edge of the top step and tilted prior to lifting. The leader bends forward on average 34° (sd = 15) during the initial lift (Fig. 7a). The handle locations were more varied on the stairchair than any other piece of equipment. Typically, the handles were in close proximity to the frame, although, on one model the handles for the leader extended approximately 0.30 m to provide separation between the paramedic and the victim's lower extremities. Often the paramedic's feet were vertically separated by one stair as the chair was lifted. This allowed some of the lifting force to be generated by the lower extremities and helped to maintain fore-aft stability on the part of the leader. The follower's role changed at this point from one of primarily pushing to one of lifting. The torso was flexed slightly forward (15°, sd = 16) and the elbows were flexed about 22°, (sd = 17). This nearly straight arm posture continued by the follower as the victim was carried down the flight of stairs (Fig. 7b).

As the carry progressed the trunk postures tended to be erect in both roles. The leader's elbows were flexed approximately 100° (sd = 18) whereas the followers elbows were flexed only 28° (sd = 28). Thus, even though the leader carried less of the combined patient and chair weight, the flexed arm posture increased the moment acting on the spine. Similarly, the compression predicted with the Three-dimensional Static Strength Prediction Model (SSPM) developed by the University of Michigan, was 13% larger (Lavender et al., 2000). These postures were maintain through the landing to the point at which the stairchair was placed on the ground. As the chair was lowered the leader's trunk flexed 31° (sd = 17), whereas the higher handles on the back of the chair only required 10° (sd = 10) of forward bending by follower.

3.6. Slat-stretcher

Figs. 8a and b show the lifting of the slat-stretcher from the floor and it being carried down the steps by the leader using the one handed method. The initial lift is very similar to that found when lifting a backboard, although with slightly less forward bending at the point that the load is experienced by the FF/Ps. As with the initial lift using the backboard, the victim is straddled so that the legs can be used to provide some of the lifting force, and the hands can be kept close to the torso in order to minimize the resulting moment placed on the spine.

The advantage of the slat-stretcher is that, depending upon the weight of the victim and the strength of the paramedic, it can be carried down the stairs with the leader facing forward (Fig. 8b). Generally, the posture is upright with a small degree of shoulder extension in the arm supporting the stretcher. However, it should be noted that while this method was only observed in one paramedic. The leader of the second team that used the slat-stretcher descended the stairs backwards in a manner that was very similar to that observed with the backboard. While carrying the slat-stretcher with one hand may reduce the safety risk, the strength capacity of the leader's supporting upper extremity and contra-lateral back muscles may be exceeded with this method, potentially leading to a muscle strain type injury.

4. Discussion

This paper has described the postures adopted and the forces applied by FF/Ps as they simulated frequently performed strenuous work tasks. As found in nursing applications, patient handling and transport tasks are physically demanding and often tax the musculoskeletal system to its limit (Gagnon et al., 1986,1987; Jensen, 1987). What makes the paramedic job challenging from an ergonomic intervention standpoint is the variation that exists from one situation to the next. But when the tasks are broken down there are several components that are common to many emergency rescue calls. For example, victims are often found in bed, victims are frequently transported down stairs that may include landings and a corresponding change in direction, and most emergency rescue calls terminate with the transfer of the victim from the stretcher to a gurney at the hospital. Thus, by breaking the frequently performed strenuous work tasks into components ergonomic risk factors can be more accurately identified and effective injury control measures can be developed

During the simulation the FF/Ps were permitted to vary the method in which the task was performed if it was consistent with the task described in the survey component of this research (Conrad et al., 1997). The only exception to this occurred when two teams offered to

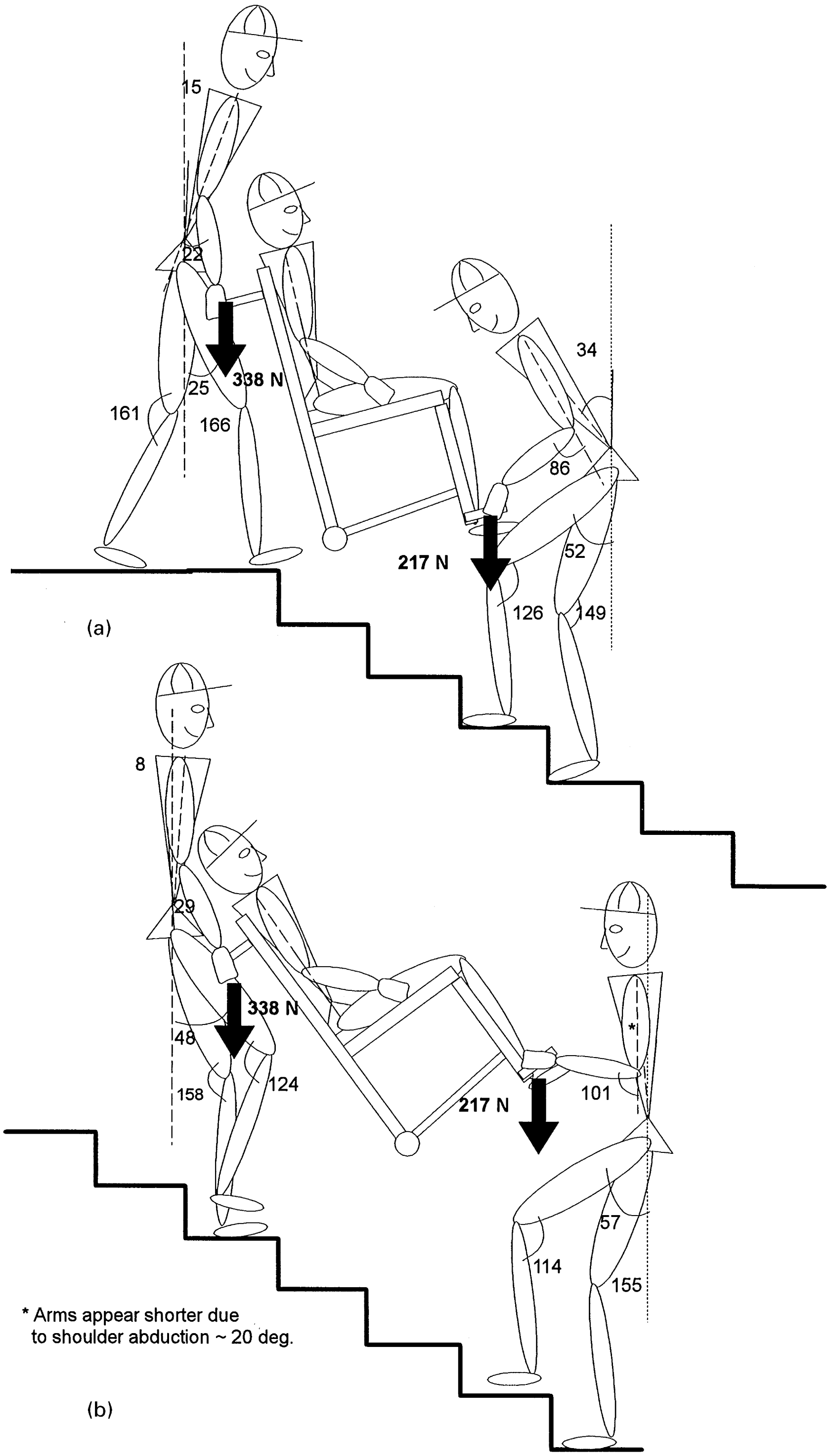

Fig. 7. The postures assumed as the stairchair was initially lifted at the top of the stairs (a) and as it was carried down the flight of stairs (b).

demonstrate the slat-stretchers that they regularly used. Both teams indicated that they regularly used the slat-stretcher to carry prone victims down stairs, primarily because the slat-stretcher was much lighter than the conventional stretcher and they believed the victims health or comfort would not be compromised. They also commented that the handle design, in allowing for a one-handed carry, potentially frees the one hand for holding a banister during stair decent; potentially preventing a catastrophic fall. Moreover, it affords the leader the flexibility of walking forwards down the steps. Most method variations during the transport tasks with the

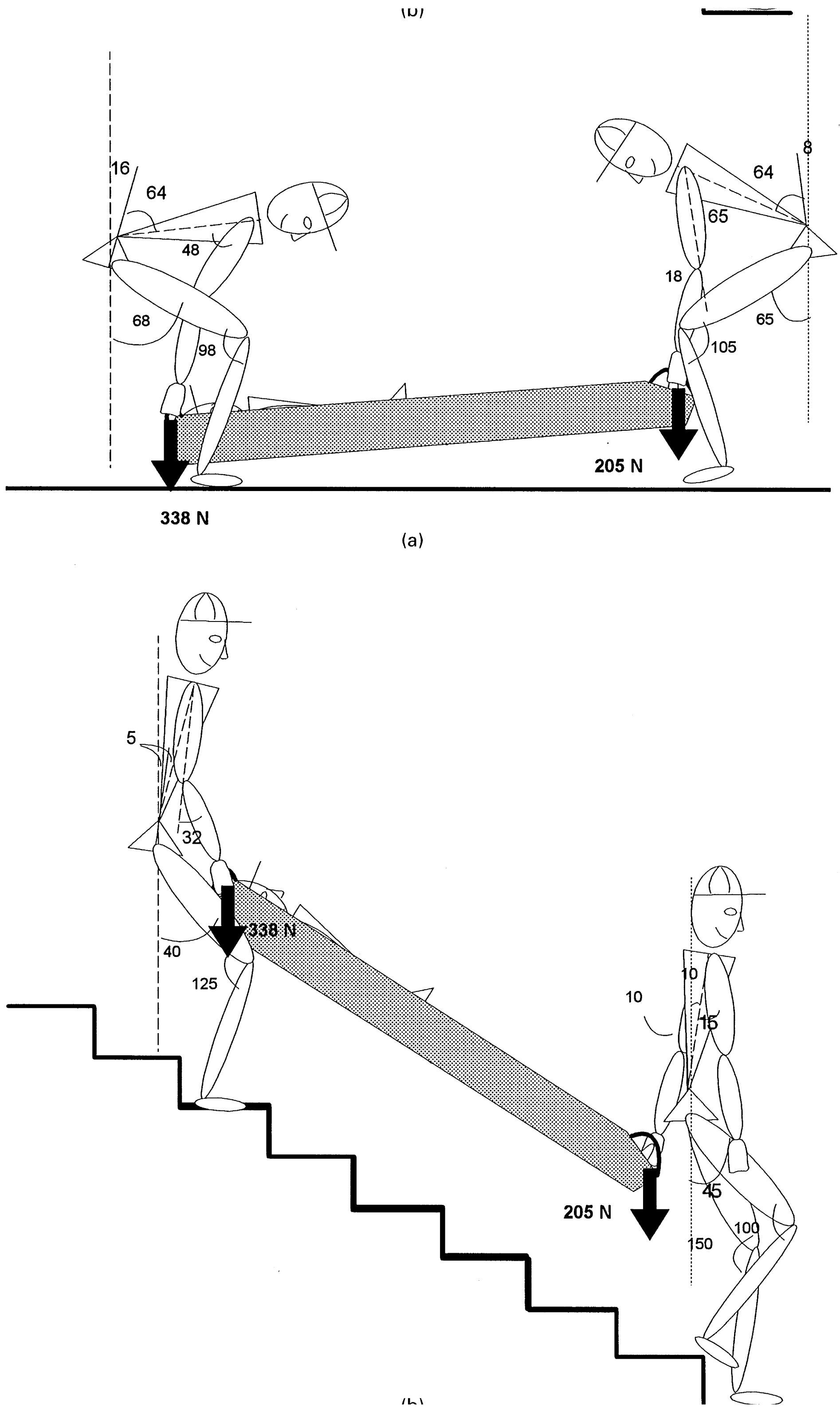

Fig. 8. The initial lift (a) of the slat-stretcher and the one-handed grasp by the leader during stair decent (b).

backboard and stretcher involved the leader raising the hand-transport device interface to about shoulder level. This permitted the victim to be carried in a more horizontal orientation on the stairs, and with the backboard facilitated the 90° turn at the bottom if the leader was tall enough to guide the backboard over the railing on the inside of the turn. When the paramedic was not tall enough the higher backboard position led to increased side bending and twisting in the torso. Moreover, while this posture may reduce the static load on the elbow flexing muscles during the carry, it may reduce the stability of the leaders stance because of the elevation of the victim's center of mass relative to the paramedic.

The other notable method variation that occurred during the simulation was where the bedside paramedic during the bed to stretcher transfer elected to stand on the bed rather than kneel. Biomechanically, this puts the paramedic in a much stronger position. The muscles that extend the knees are now capable of exerting force and the muscles that extend the hips and spine are at a stronger position within their range of motion. This method also allows the lifter mobility and lessens the need for hands positions far away from the torso at the completion of the lift. Further analysis is needed, however, before FF/Ps should be trained with this method. The optimal hand position on the sheet relative to the victim must be determined so that strength capacity of the paramedic is maximized while the risk of musculoskeletal injury is minimized.

The results presented here have focussed on the means with regard to the postures assumed. It should be recognized that there was variation across individuals. Standard deviations were presented with the data in the text to indicate the extent of this variation. Sources of variation within the data include: anthropometric differences of the volunteers (heights, reach capacity, strength), specific design parameters of the equipment used (location of handles, weight of equipment), and possibly fatigue. It should be recognized that there would be considerably more variability had these tasks been observed in real-world settings.

Aside from the variability there are numerous sampling, data collection, and legal issues that preclude data collection during real emergency rescue situations. For example, there are restrictions that prevent filming on private property, measurements that adversely affect the response time of FF/Ps could not be obtained (force measurements), and the low and unpredictable call frequency would make data collection a long-term endeavor. By simulating the tasks, the components identified through the survey process could be thoroughly studied, albeit, with some limitations. The time stress that may exist in real situations was not a component of this simulation. Clearly, a limitation in our study was that the weight of the dummy (471 N) was considerably lower than the average adult weight in an industrial population (774 N: Marras and Kim, 1993). We believe, however, that this weight was adequate to obtain realistic postural measures. Many of the suburban FF/Ps that participated in our study indicated that, if the victim was much heavier than our dummy, additional personnel were usually recruited to assist in the transport tasks studied. Moreover, had we performed the simulations with a heavier dummy it is likely that fatigue would be a significant concern, since FF/Ps usually lift less frequently on the job. It could be also be argued that the use of a dummy as opposed to a human victim may have biased our observations in that the normal social interaction and monitoring functions with the FF/P's job may have been overlooked. However, while we acknowledge these functions are part of the job, we believe that the postural data presented for the tasks described in this paper would remain relatively unchanged providing the victim was "cooperative".

This analysis has indicated several areas in which design changes could be incorporated into future equipment. The patient transfer task from bed to stretcher and from stretcher to gurney would be facilitated by having a low friction interface available that bridges the gap between the two surfaces. By building flaps coated with a low friction surface into the equipment, the sliding of victims from one surface to another would be facilitated, and the need to actually lift the victim would be reduced.

The limited testing with the slat-stretcher was useful in that it really highlighted the obvious benefits of the leader walking down the stairs facing forward. Designers of emergency response equipment should consider the use of waist harness systems where backboards could be "clipped" in. This would have three principle benefits: First, the leader is facing forward looking at the steps. Second, the hands are free to hold the railing. Third, the weight of the victim is placed directly on the pelvis rather than the standard transmission through the arms and spine. Along these same lines a backboard with a pivot that allows up to 20° of frontal plane motion at the hip level would facilitate transporting a victim through a landing on a set of stairs. While such a board would need a mechanism to prevent this motion should this region need to be rigid, in many situations this flexibility in the board would reduce the stress placed on the body as the board is jockeyed around corners. Likewise, developing a board that can be adjusted in length may relieve some of the same stresses at least when shorter victims are carried.

In conclusion, this paper, by analyzing the postures and forces applied during the frequently occurring strenuous work tasks of FF/Ps provides insight as to where there are intervention opportunities. The data show that: (1) when transferring victims from a bed to a stretcher the FF/P on the bed was able to maintain an upright and more stable posture by standing as opposed to kneeling, (2) an interface board should be used to reduce the frictional forces when transferring victims from a bed to a stretcher or from a stretcher to a gurney, thereby reducing the need to lift the victim with flexed torsos and /or shoulders, and (3) equipment and training that encourages the FF/P in the leader role to walk facing forward during victim transport, especially when descending stairs, potentially results in safer transit. This is a profession where the employees handle very high loads that cannot be reduced except through added personnel. However, we have found through this analysis that there is plenty of room for engineering changes to the equipment used, especially once the more repetitive tasks are considered that should have an impact on musculoskeletal injury prevention.

Acknowledgements

This work was funded by NIOSH R03: OHO3123-02. We wish to thank the Fire Chiefs within the North Suburban Fire Protection District (MABAS 3) who served as technical advisors during this project.

References

Andersson, G.B.J., 1997. The epidemiology of spinal disorders. In: Frymoyer, J.W. (Ed.), The Adult Spine: Principles and Practice, 2nd Edition. Lippincott-Raven Publishers, Philadelphia, pp. 93–141.

Cady, L.D., Bischoff, D.P., O'Connell, E.R., Thomas, P.C., Allan, J.H., 1979. Strength and fitness and subsequent back injuries in fire fighters. J. Occup. Med. 21, 269–272.

Chaffin, D.B., 1979. Manual materials handling: the cause of overexertion injury and illness in industry. J. Environ. Pathol. Toxicol. 2, 31–66.

Conrad, K., Reichelt, P., Lavender, S.A., Meyer, F., 1997. Ergonomic study of fire service musculoskeletal injuries. Final Report for NIOSH Grant number: R03: OHO3123-02.

Doolittle, T.L., Kaiyala, K., 1986. Strength and musculo-skeletal injuries of firefighters. Proceeding of the Annual Conference of the Human Factors Association of Canada, pp. 49–52.

Doormaal, M.T.A.J., Drissen. A.P.A., Landeweerd, J.A., Drost, M.R., 1995. Physical workload of ambulance assistants. Ergonomics, 38, 361–376.

Ellam, L.D., Fieldman, G.B., Fordham, M., Goldsmith, R., Barham, P., 1994. The perception of physical fitness as a guide to its evaluation in firemen. Ergonomics 37, 943–952.

Gagnon, M., Chehade, A., Kemp, F., Lortie, M., 1987. Lumbo-sacral loads and selected muscle activity while turning patients in bed. Ergonomics 30, 1013–1032.

Gagnon, M., Sicard, C., Sirois, J.P., 1986. Evaluation of forces on the lumbo-sacral joint and assessment of work and energy transfers in nursing aides lifting patients. Ergonomics 29, 407–421.

Hilyer, J.C., Brown, K.C., Sirles, A.T., Peoples, L., 1990. A flexibility intervention to reduce the incidence and severity of joint injuries among municipal firefighters. J. Occup. Med. 32, 621–637.

Hogya, P.T., Ellis, L., 1990. Evaluation of the injury profile of personnel in a busy urban EMS system. Am. J. Emergency Med. 8, 308–311.

Jensen, R.C., 1987. Disabling back injuries among nursing personnel: research needs and justification. Res. Nursing Health 10, 29–38.

Lavender et al., 2000: Biomechanical analysis of frequently performed and strenuous work tasks encounterd by firefighters and paramedics. Appl. Ergon., in press.

LeCuyer, J., 1994. Where tools and people meet. Fire Chief, 34–41.

Marras, W.S., Fatallah, F., 1992. Accuracy of a three dimensional lumbar motion monitorfor recording dynamic trunk motion characteristic. Int. J. Ind. Ergon. 9, 75–87.

Marras, W.S., Kim, J.Y., 1993. Anthropometry in industrial populations. Ergonomics 36, 371–378.

Matticks, C.A., Westwater, J.J., Himel, H.N., Morgan, R.F., Edlich, R.F., 1992. Health risks to fire fighters. J. Burn Care Rehab. 13, 223–235.

Reichelt, P.A., Conrad, K.M., 1995. Musculoskeletal injury: ergonomics and physical fitness. In: Duffy, R., Melius, J., Oris, P. (Eds.), Occupational Medicine. State of the Art Reviews, Vol. 10 (3), Firefighters. Philadelphia, PA: Manloy Belfus.

Webb Associates, 1978. Anthropometric Source Book Volume II. NASA Reference Publication 1024, National Aeronotics and Space Administration, Yellow Springs, Ohio.