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Biomechanical analyses of paramedics simulating frequently performed strenuous work tasks

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Abstract

Firefighters performing emergency rescue functions are at an elevated risk of musculoskeletal injuries. The objective of the current study was to analyze the biomechanical stresses placed on the body based on simulations of the following strenuous *and* frequently performed emergency rescue tasks: (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 through a landing using a stairchair, (4) carrying a victim down a set of stairs and through a landing using a backboard, and (5) carrying a victim down a straight set of stairs using a stretcher. Postural data were analyzed using the University of Michigan's Three-Dimensional Static Strength Prediction Program™ and the relative risk of low back disorder (LBD) was quantified using the trunk motion model published by Marras et al. (1993, spine 18, 617–628). Peak compression values and the probabilities from the Marras et al. (1993) model indicated that the most hazardous tasks performed as part of this simulation included pulling a victim from a bed to a stretcher, the initial descent of a set of stairs when using the stretcher, and lifting a victim on a backboard from the floor. Overall, the two models were well correlated in their assessment of the task components modelled ($r = 0.78$). These data indicate where engineering changes to equipment regularly used by emergency rescue personnel would have the greatest impact in reducing the risk of musculoskeletal injury.

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

1. Introduction

Hogya and Ellis (1990) reported that emergency medical technicians and paramedics have high back injury rates. This is not surprising given that firefighters and emergency rescue personnel frequently engage in heavy lifting as they lift and transport patients. This is consistent with Andersson (1997) review of the epidemiological literature in which he summarizes numerous studies supporting the link between low back disorders and the performance of heavy lifting and material handling.

Ergonomic design efforts to reduce the exposure of firefighters to the hazardous lifting conditions associated with the performance of emergency rescue functions have been minimal. This is due to two main factors: First, there has been a poor understanding of the tasks performed, including the degree to which these tasks stress the workers and their frequency of performance. Second, very little task analysis work is available that describes the postures assumed and the forces applied when firefighters, cross-trained as paramedics (FF/Ps), perform emergency rescue tasks. This may in part be due to the enormous amount of variability across what could broadly be classified as similar emergency rescue tasks.

Our previous work has addressed these issues and has identified stereotypical components in emergency rescue tasks performed by suburban FF/Ps and described these components via a four-step process (Conrad et al., 1997; Lavender et al., 1997). In the first step interviews with 28 FF/Ps were conducted in which they were asked to identify frequently performed strenuous work activities (task components). In the second step, a survey was used to validate and rank the 20 most frequent task

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components identified in the interviews across a wider sample of suburban FF/Ps ($n = 374$). Each task component was rated separately according to its perceived level of strenuousness and its expected frequency. Composite scores were created so that the 10 most frequently performed and strenuous task components could be further analyzed.

Once the set of frequently performed strenuous task components were identified, the third step in the evaluation process was the development of task analyses. In ergonomics, task analyses are used to identify which specific task components expose a worker to ergonomic risk factors and the magnitude of those exposures. In the fourth step simulations of the identified task components were developed, under the guidance of an advisory panel from a consortium of suburban fire departments, to provide data that would allow the postures assumed during each task component to be described and allow biomechanical analyses of each task component. These analyses are required to determine where ergonomic interventions are necessary, and the potential impact of such interventions on the FF/P's risk of musculoskeletal injury. The objective of this paper was to biomechanically evaluate the data obtained during the task simulation and analysis phase using two commonly applied models for quantifying musculoskeletal loading and low back injury risk.

2. Methods

2.1. Approach

Data obtained from simulated emergency rescue tasks were used in this analysis. A complete description of the simulation process and the postural analysis has been described elsewhere (Lavender et al., 1999). The simulated tasks, selected on the basis of the survey results were:

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.

Tasks 3–5 contain components (subtasks) that were individually rated in the survey. Task 3 included the following subtasks:

initial lift -	lifting the backboard from the floor
initiate stairs-	beginning of stair descent
mid-stair-	carrying the victim down the stairs after the first few steps
through a landing	working the backboard through the confined space associated with the landing.

Task 4 with the stretcher included the second and third subtasks in this list while Task 5 included the last three subtasks in the list. When the stretcher and stairchair were used (Tasks 4 and 5) the initial lift occurred simultaneously with the stair initiation.

A two-person team performed each task; thus, 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 interview and survey process:

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

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

Roles in the stair descent tasks were defined as either "leader" or "follower" to indicate which FF/P led the stair descent (usually walking backwards).

2.2. Task simulations

Subjects: The analyses presented in this paper are based on data obtained from 10 two-person teams of experienced FF/Ps from 7 suburban fire departments that participated in the task simulations. Twenty FF/Ps, 17 male and 3 female, who were cross-trained as firefighters and paramedics volunteered to participate in an "ergonomic" study. Eighteen of the 20 worked full time for their respective departments and two FF/Ps came from a volunteer fire department. The mean height and weight of these individuals were 1.79 m (range: 1.60–1.93 m) and 87 kg (range: 57–118 kg), respectively.

Apparatus and simulation environment: In the simulations 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 the raised position (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 weight is similar to that of a small female victim. While this weight is not representative of the entire population, our advisory panel indicated that, in the suburban communities, victims that are significantly heavier are typically handled by more than two people.

Each team of FF/Ps brought their own equipment to use during the simulation. This equipment included a stretcher, a backboard, a stairchair, and the straps

Table 1
The mean, minimum, and maximum weights in Newtons of the transport devices used during the task simulations

Transport Device	Mean (N)	Minimum (N)	Maximum (N)
Backboard	69	62	71
Stretcher	368	303	401
Stairchair	94	80	107
Slat-stretcher	71	71	71

necessary to secure a victim to these transport devices. The average weights and their ranges are given in Table 1. Also shown in Table 1 is a device called a "slat-stretcher". Two teams from one of the fire departments indicated that they would never transport a victim down a flight of stairs using a conventional stretcher but instead regularly used a slat-stretcher for that purpose. This piece of equipment is constructed out of canvas with two-meter wood strips sewn into the fabric to provide the carrier with longitudinal stiffness and lateral flexibility. The slat-stretcher has fabric handles sewn into the canvas.

The testing environment included an open staircase with 19 steps including the landing, which required a 90° turn. The staircase width was restricted, using a rope barrier, to one meter (a width similar to that found in most suburban residences in this region). Each step had a 180 mm rise and a 305 mm run.

Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of each team of subjects. Trunk positions and motions were measured with the lumbar motion monitor (LMM) manufactured by Chattanooga Group, Inc. (Chattanooga, TN). This device measures the motion in the lumbar and lower thoracic sections of the spine.

Simulation procedures: Each member of the team was instrumented with a LMM. Markers were placed over the ankles, the lateral side of each knee, the greater trochanters, the acromium processes, the mid-line of the elbow, and over the mid-point of the wrist breadth dimension.

The data collection started with the bed-to-stretcher transfer, followed by the stretcher-to-gurney transfer, and concluded with the three stair descent tasks. The sequence of the stair descent tasks with the stretcher, stairchair, and backboard was randomized for each team. Each task was repeated three times. For the two teams using the slat-stretcher, these trials were substituted for the standard stretcher trials. 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 (a) standing on the bed rather than kneeling during the bed-to-stretcher transfer task, and (b) the use of different arm postures by the leader during the stair descent 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. Static hand forces were determined for each role within each simulated subtask.

2.3. Data analysis

The postural data were extracted from the videotapes using the cameras with the most orthogonal view for the given subtask. Body segment orientations were expressed in terms of the coordinate system specified within the University of Michigan's Three-Dimensional Static Strength Prediction Model (hereinafter referred to as 3DSSPP). The three-dimensional trunk postures, namely the degree of forward bending, side bending, and twisting, were obtained from the LMM.

Each task component was modelled for each individual in the simulation using the 3DSSPP. Each FF/P's height and weight were entered into the model. The 3DSSPP was then scaled according to these anthropometric dimensions. The hand forces obtained with the dynamometer were assumed to be an evenly distributed between the two hands. Postures in the 3DSSPP were adjusted according to each subject's measured posture. The model uses the postural and force data to compute the static moment at each joint. The moments computed by the model were then compared with population strength data for each of the articulations to determine the percentage of the population with similar anthropometric characteristics that would have the strength capacity to perform the modelled task. Tasks in which strength is a limiting factor should be thought of as putting workers at risk for overexertion-type injuries (Chaffin, 1979).

Spine Compression values were computed by the 3DSSPP software for the inter-vertebral disc between the fourth and fifth lumbar vertebrae (L4/L5) using the 3-D trunk model developed by Bean et al. (1988). This model uses a double linear optimization approach. First, the model predicts the minimum muscle intensities (muscle force divided by cross-sectional area) that are feasible. Second, the model selects the solution in the first step that minimizes the spine compression forces. Compression values were compared with the compression tolerance limits used by NIOSH (1981).

The logistic regression model developed by Marras et al. (1993) was used to quantify low back disorder (LBD) risk based upon the trunk motion and dynamometer data. This logistic regression model uses the following five factors to determine the probability that the observed task is representative of a high LBD risk task: (a) the lifting rate per hour, (b) the average twisting velocity, (c) the maximum load moment during the lift, (d) the amount for forward (sagittal) bending during the lift, and (e) the peak lateral bending velocity. The trunk motion data were obtained from the LMMs, the moment data were obtained by multiplying the dynamometer reading by the maximum horizontal reach distance, and the lifting rate was set to a value of 5, representing the average lifting rate per hour.

Descriptive statistics were computed for each of the five calculated factors just described to show the overall trends in the data. Strength capacities extracted from the 3DSSPP output were not normally distributed, so the median value is used here to describe the central tendencies in these data. Mean values have been used for all other quantities. The logistic regression model probabilities, the strength percentages, and the compression estimates were compared across conditions (tasks, subtasks, methods, and roles) by using analyses of variance (ANOVAs) and the Mann–Whitney non-parametric tests.

3. Results

3.1. Bed-to-stretcher task

Strength limitations were most apparent for the FF/Ps standing on the side of the stretcher during the transfer. The median values across the ten FF/Ps modelled indicated that only 71% the population would have adequate back strength to perform the modelled task (Fig. 1). However, only 17% the population would have enough strength in the shoulders to abduct the arms into the modelled posture (30° of shoulder abduction). Lifting and pulling the 47 kg dummy onto the stretcher resulted in spine compression values at L4/L5 between 3700 and 7600 N (mean = 5476 N). Therefore, all compression values that were observed during the performance of stretcher-side role in this task exceeded the NIOSH action limit (AL) of 3434 N. Some values even exceeded the maximum permissible limit (MPL) of 6377 N. Fig. 2 shows that the spine compression values were significantly greater ($p < 0.001$) for the stretcher-side role as opposed to the bed-side role.

Strength in the upper extremities and the back were not limiting factors for the FF/Ps kneeling or standing on the bed. Spine compression values were 45% less (Fig. 2), while anterior shear forces were nearly 90% greater, in the standing (stooped) posture as compared with the kneeling posture.

The logistic regression model indicated that the bed-to-stretcher transfer task is a high-risk task with respect to low back disorders. The mean probability values, averaged for the FF/Ps on the stretcher and the bed side of the transfers, were 96 and 89%, respectively (Fig. 3).

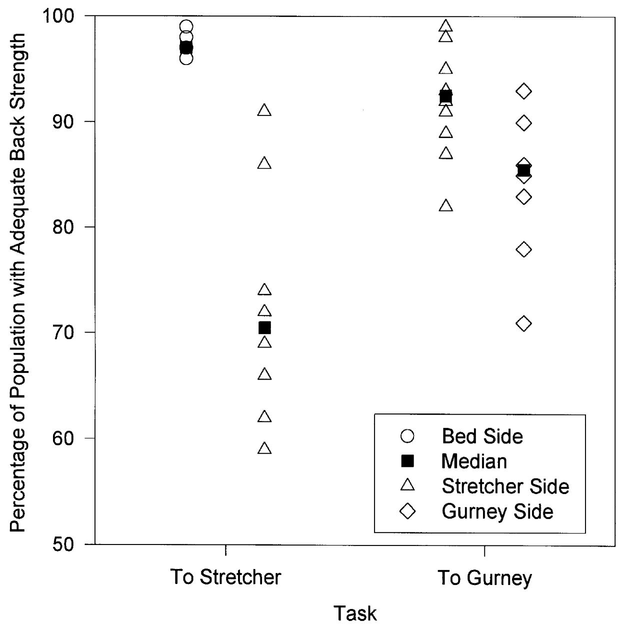

Fig. 1. Percentage of the population with adequate back strength based on each individual FF/P modelled with the 3DSSPP during the *bed-to-stretcher* and *stretcher-to- gurney* transfer tasks.

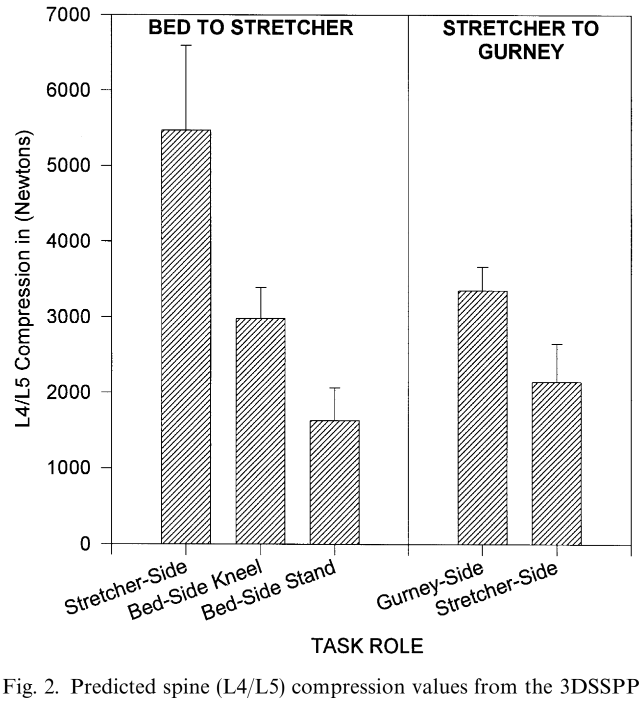

Fig. 2. Predicted spine (L4/L5) compression values from the 3DSSPP for the *bed-to-stretcher* and *stretcher-to-gurney* transfer tasks.

The primary factors responsible for these high probability values were (a) the moments due to the extreme reach, and (b) the degree of forward bending. The greater reach on the stretcher side probably accounts for the significantly higher risk ($p < 0.01$) associated with this role. Moreover, both roles showed some moderately fast

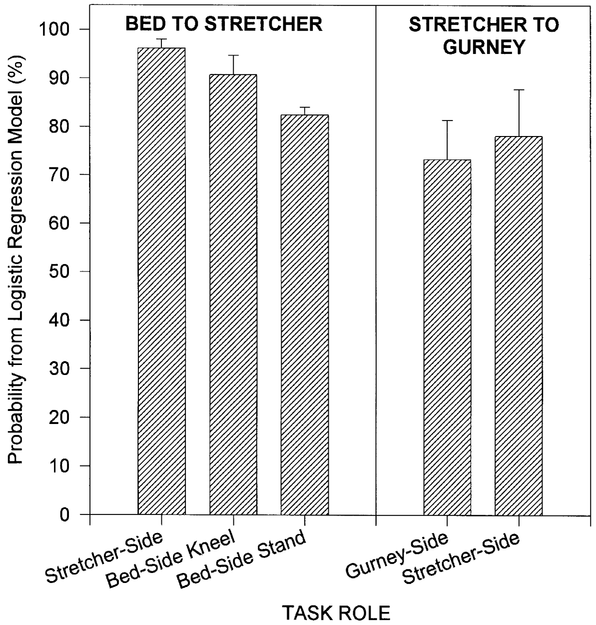

Fig. 3. The probability values from the logistic regression model for the *bed-to- stretcher* and *stretcher-to-gurney* transfer tasks.

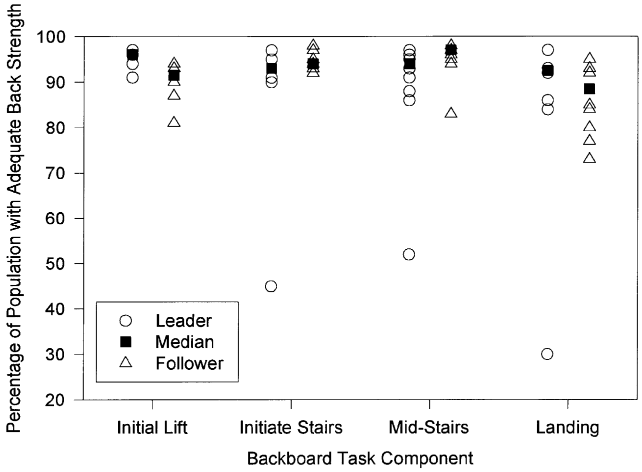

Fig. 4. Percentage of the population with adequate back strength based on each individual FF/P modelled with the 3DSSPP during the *backboard* transport task components.

twisting motions (over 8°/s) which also served to elevate these probabilities. The probability values, on average, were less in the FF/Ps who elected to stand, as opposed to kneel, on the bed (82% versus 90%). However, due to the small sample size, this difference was not statistically tested. The difference was primarily due to faster twisting and side-bending motions in the kneeling posture.

3.2. Stretcher to hospital gurney

Only 86% of the population would have adequate back strength to pull the victim off the stretcher and onto the gurney (Fig. 1). This pulling role was significantly more demanding on the back and shoulder abduction strength of the FF/P on the gurney side than the lifting performed by the FF/P on the stretcher side ($p < 0.05$). Only 35% of the population would have sufficient shoulder abduction strength to perform the pulling role in this task. Knee strength, however, was a limiting factor in the FF/P on the stretcher side during the transfer. Only 80% of the population would have adequate knee flexion (hamstring) strength to perform this function.

The estimated spine compression was 56% higher ($p < .001$) for the FF/P on the gurney side (3350 N) as compared to the stretcher side (2147 N) of the transfer (Fig. 2). On the other hand, anterior shear was over six times greater for the FF/P on the stretcher side (323 N) than for the FF/P on the gurney side (52 N) during the transfer ($p < .001$).

Probability values generated by the logistic regression model were 78% for the stretcher side and 73% for the gurney side of this transfer task (Fig. 3). The primary factor in the logistic regression model driving these high probability values was the moment associated with the extended reach distances.

3.3. Transport down stairs using a backboard

The backboard transport task was broken into four components: (a) the initial lift from the floor, (b) initiate stairs, (c) mid-stair (both FF/Ps on the stairs), and (d) transport through a landing (90° turn). The starting height of the handles during the initial lift was between 20 and 50 mm. The resulting low-level lift was significantly more strenuous for the FF/P lifting the head of the backboard ($p < 0.05$). Only 92% of the population would have the back strength necessary to complete the lift at the head of the backboard with the 467 N victim (Fig. 4). Fig. 5 shows that the compression forces between the forth and fifth lumbar vertebrae were also significantly greater ($p < 0.01$) for the FF/P at the head of the backboard (5224 N) as opposed to the foot of the backboard (3955 N). Similarly, the anterior shear was significantly greater ($p < 0.05$) when lifting the head of the backboard. The logistic regression model output yielded a significantly higher mean probability value of 58% for the head of the backboard as opposed to 44% for foot of the backboard (Fig. 6). The primary factor distinguishing between these two roles was the weight lifted and the resulting moment that was generated about the spine (69 Nm at the head of the backboard versus 41 Nm at the foot of the backboard).

As the stair descent is initiated with the backboard, knee strength could be a limiting factor for up to 10% of the population, especially in the leader role. Analysis of the median values indicated that the upper extremity strengths were not of significant concern. Spine compression values during this task component were much lower

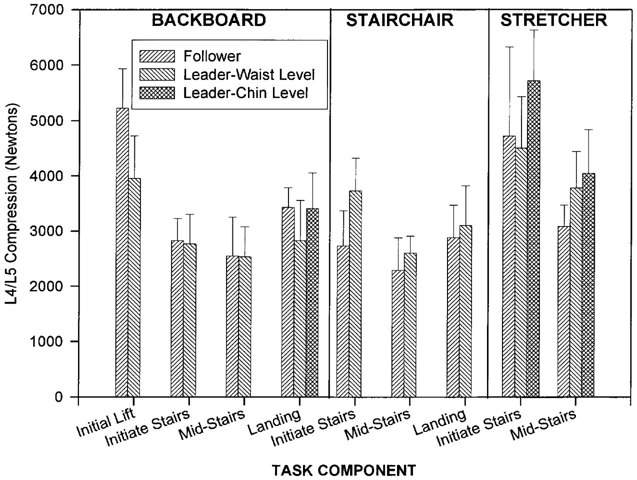

Fig. 5. The mean L4/L5 compressions predicted with the 3DSSPP for the backboard, stairchair, stretcher transport tasks and subtasks.

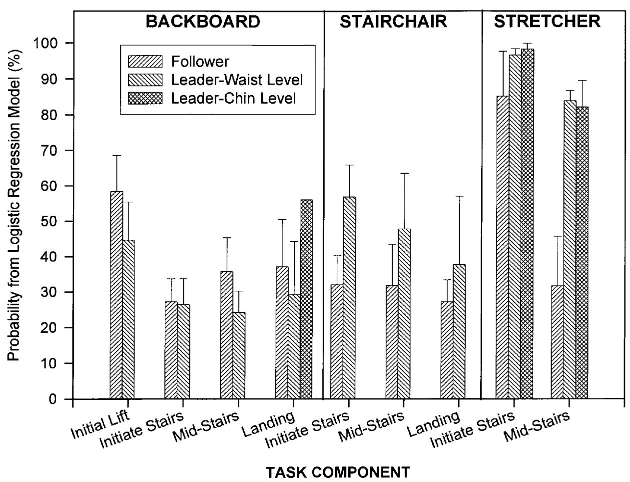

Fig. 6. Probability values from the Logistic Regression Model for the backboard, stairchair, and stretcher transport tasks.

than during the initial lift (Fig. 5). The FF/P at the head of the backboard experienced an average of 2826 N of spine compression whereas the FF/P at the foot of the backboard only experienced 2763 N of spine compression. This task component was of relatively low risk according to the logistic regression model (Fig. 6). The probability that this task component was representative of a high-risk task was only 26% for the role at the foot of the backboard and 27% for the role at the head of the backboard. While the moment contribution to the logistic regression model was greater at the head (supporting the upper body weight), the leaders (FF/Ps at the foot, descending the stairs backwards) displayed more rapid twisting motions as they turned to view the stairs behind them.

During the mid-stair task component the logistic regression model probability value increased slightly for the FF/P in the follower role to 33%, primarily due to an increase in the trunk's twisting velocity. The probability value for the leader remained essentially unchanged (Fig. 6). For either role, upper extremity strength was not a limiting factor. However, according to the 3DSSPP output, knee strength could potentially be a limiting factor for up to 14% of the population. On average, back strength was generally more of a limiting factor for the leader than the follower, although not significantly so. Spine compression values were relative low and very similar between these two roles (2535 for the leader, 2549 for the follower).

When carrying the backboard through a landing, the leaders showed two variations in arm postures that affected the spine loading. Most FF/Ps in the leader role ($n = 8$) continued through the landing carrying the backboard between waist and elbow level. Two leaders elected to raise the backboard to approximately chin level during this task component. There were no significant differences between the two roles with regard to joint strength capacities, nor was there any difference due to the method variation just described. Spine compression values were not significantly different due to the role, but were on average larger than those experienced while descending the stairs (mean = 3185 N across all FF/Ps tested) (see Fig. 5). From Fig. 6 it can be seen that the probability values from the logistic regression model associated with the landing component of this task, while elevated above the mid-stair values, are still relatively low risk compared to the values for other tasks performed by FF/Ps. Trunk motion data were available from only one individual who raised the board to chin level while leading through the landing. But this data point suggests a considerably elevated risk as this task component is performed using this particular method (Fig. 6).

3.4. Transport down stairs using a stretcher

Back strength becomes a limiting factor when the stretcher is carried down the stairs. Only half (53%) of the population would have adequate strength to carry the 467 N victim on the stretcher in the leader role (Fig. 7a). A smaller percentage of the population (41%) would have enough back strength to initiate the stair descent carrying the stretcher in the raised (chin-level) position used by three of the leader FF/Ps performing this task component. Furthermore, in the more common waist-level position less than half (45%) of the population would have enough elbow flexion strength to support the load introduced by the combined weight of the stretcher and the victim. Conversely, 99% of the population would have the elbow strength necessary to carry the stretcher in the chin-level position. This fact explains why, in part, this posture was selected. The chin-level posture reduces the moment acting at the elbow by

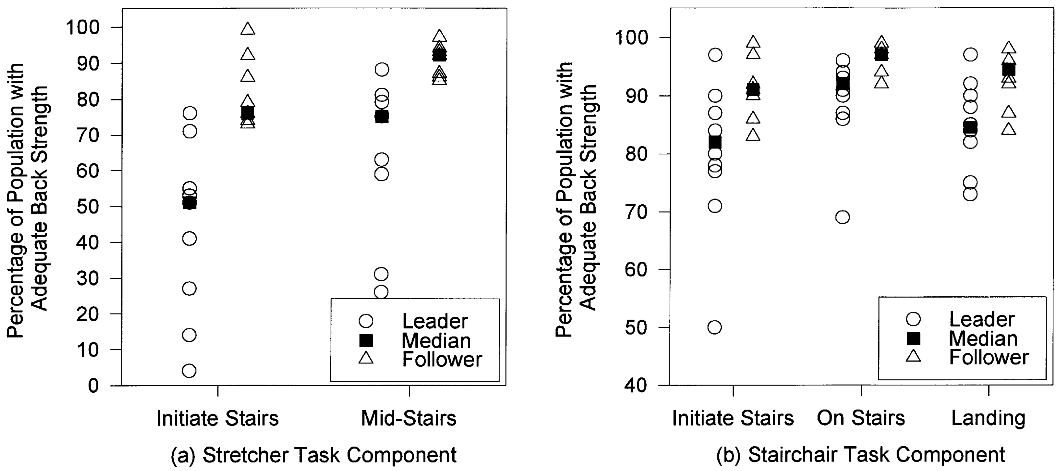

Fig. 7. Percentage of the population with adequate back strength based on each individual FF/P modelled with the 3DSSPP during the (a) *stretcher* and (b) *stairchair* transport task components.

reducing the horizontal distance between the grasping point on the stretcher and the elbow's axis of rotation. However, there tended to be increased shoulder adduction moment in the raised posture, thereby increasing the shoulder abduction strength requirements to the point that only 37% of the population would have adequate shoulder strength to use the chin-level posture in this task.

The back strength demands on the follower during the initiate stairs subtask, while significantly lower ($p < 0.01$) than those of the leader, were still quite high. Fig. 7a shows that only 76% of the population could be expected to perform the initiation of stair descent in the follower role. There were no strength limitations found for the upper extremities.

Associated with the high strength demands are large spine compression forces. These were 4500 N for the leader carrying the stretcher at waist level and 5700 N for the leader carrying the stretcher at chin level (Fig. 5). Both values exceed the AL proposed by NIOSH. The compression for the follower was 4700 N, which was not significantly different from that observed in the leader role. After the stair descent was initiated the spine compression values were reduced down to 3700 and 4000 N for the waist level and chin level postures, respectively. This occurred as the reach distances were minimized and the trunk postures became more upright

The probability values generated by the logistic regression model were greatest for the leader in the initiate stairs subtask (Fig. 6). The analysis of variance indicated a significant interaction effect between the task component and the role within that task component ($p < 0.001$). In essence, this LBD risk index was extremely high (97%) for the leader and somewhat less (85%) for the follower FF/P (Fig. 6). Both probability values decrease once the stretcher was initially lifted and the FF/Ps are on the stairs (mid-stair subtask) down to 82% for the leader and down to 32% for the follower. Overall, carrying the stretcher at chin level versus waist level had only a small effect on the probability values generated by the model (Fig. 6).

Ninety-two percent of the population would have enough back strength to carry the stretcher in the mid-stair subtask (Fig. 7a). Elbow strength could be problematic for up to 13% of the population performing this subtask. The leader's role, on the other hand, while less demanding than the initial lift at the top of the stairs, still would exceed the back strength capacity of 31% of the population when carrying the stretcher at approximately waist level, and for 19% of the population when carrying the stretcher at chin level. Similar trends and trade-offs between elbow and shoulder abduction strength exist across these method variations as found in the initiate stairs task component.

3.5. *Transport down stairs with a stairchair*

The initiate stairs subtask with the stairchair was significantly ($p < 0.05$) more demanding on the back for the leader as opposed to the follower. Only 82% of the population would have adequate back strength to perform the leader's task, while 91% would have the back strength to perform the follower's task (Fig. 7b). In general, this task component was within the strength capacity of the upper extremities. Spine compression forces followed a similar pattern. The compression on the leaders' spines was, on average, 37% larger than that experienced by the followers (see Fig. 5).

Analysis of variance of the outputs from the logistic regression model indicated that there were significant differences between the roles within this task ($p < 0.001$), and between components of the task ($p < 0.05$), but that these relationships did not change across task components ($p > 0.05$). The probabilities associated with the leader's role went from a maximum of 57% during the initiate stairs component, to 48% during the mid-stair component, and down to 37% as the leader passed through the landing. The probabilities for the FF/P in the follower role were 32%, 32%, and 27% for the same sequence of task components (Fig. 6).

3.6. Slat-stretcher

Based on a very small sample ($n = 2$) the 3DSSPP indicated that only 83% of the population would have enough back strength to lift the head of the slat-stretcher. Once the slat-stretcher is lifted, however, handling the victim (modelled at 467 N) is within the back and upper extremity strength capacity for most of the population until a landing is encountered. While 92% of the population would have adequate back strength, only 88, 81, and 82% of the population would have the necessary shoulder abduction strength, elbow strength, and knee extension strength, respectively, to perform the follower's role in the landing. Spine compression values were relatively low except for the initial lift. However, this analysis was based on data from only two FF/Ps in each role. When the spine compression for the initial lift subtask with the slat-stretcher are compared with the compression values obtained from these same individuals when they initially lifted the backboard, comparable L4/L5 compression values were obtained. The logistic regression model indicated that the slat-stretcher resulted in similar probability values during the initial lift subtask to those found when handling the backboard during the initial lift. However, the slat-stretcher values for the remaining task components compare favorably with those reported for the other transport devices.

4. Discussion

This study has documented the muscular strength capacities, the mechanical loadings of the spine, and the relative risks of low back disorder associated with several task components identified by FF/Ps as being both the strenuous and frequently performed. It was shown that strength limitations would be a limiting factor for a significant proportion of the population, especially when a victim is transferred on to or off of a stretcher, and when transport equipment is initially lifted. This finding should be cause for concern, especially given the relatively dummy's weight. Clearly, with heavier victims a smaller percentage of the population would have the strength capacity to perform the FF/P tasks studied.

Likewise, these same tasks were shown to have components similar to those found in jobs with a high historical risk of low back disorder (LBD). Table 2 shows all the task components studied sorted according to the probability values obtained from the logistic regression model. Large moments, introduced by either heavy loads as during the stretcher transport tasks, or extended reaches as during the victim transfer tasks, are common to all the task components near the top of the list. The riskiest task components tended to include substantial forward bending of the torso (e.g., the initial lift and the initiate stairs subtasks). Given that the static moment and the forward trunk bending are the most critical factors affecting the probabilities generated by the logistic regression model, it should not be surprising that the *rankings* of the task components were similar when evaluated using the compression value generated by the 3DSSPP (Spearman's rho = 0.73) (see Table 3). The correlation between the predicted L4/L5 compression *values* and the logistic regression model's probability *values* was 0.78 (Pearson's r).

A review of Tables 2 and 3 suggest that the transporting victims on a set of stairs while using the stretcher should be avoided whenever possible. When a stretcher is used, extra personnel should be recruited to assist in the carry, thereby reducing the moment introduced because of the heavy equipment. Moreover, the leader should never carry the stretcher in the chin-level position given that the predicted compression values were, on average, 27% higher with the stretcher at chin level as compared with waist level.

Overall, the data from stairchair showed favourable results when evaluated with the logistic regression model. For example, data from the initiate stairs subtask yielded only a 56% probability. Therefore, these data suggest that the stairchair should be the recommended means for transporting a victim down a set of stairs and to a waiting ambulance. Note that with a stairchair, the victim can be wheeled to the ambulance (providing a smooth enough surface is available). A limitation of the stairchair, however, is that once the victim has been transported to the ambulance, the victim must be placed on the stretcher in preparation for the drive to the hospital. It is interesting to note that this particular task component was not identified in the interview and survey process as a frequently performed strenuous work task, and therefore, was not simulated.

Once lifted, the backboard becomes an acceptable mode of transport, especially if no sharp turns are required along the way. In other words, if the initial lift from the floor can be avoided, for example when the victim is laying on a bed, then the use of the backboard is less risky. This is especially true if no landing is encountered in the descent of the stairs. Carrying the backboard through a landing could in turn be facilitated through some innovations in backboard design. Currently, backboards have a fixed length that will accommodate most of the taller people within the population. If a backboard

Table 2
The ranking of task, component, role, and method combinations according to the probability value generated by the logistic regression model

Ranking	Task	Component	Role	Method	Probability
1	Stretcher transport	Initiate stairs	Leader	Raised	98.3
2	Stretcher transport	Initiate stairs	Leader	Normal	96.6
3	Bed-to-stretcher transfer	Stretcher-side	Pull	Normal	96.2
4	Slat-stretcher transport	Initial lift	Follower	Normal	95.4
5	Backboard transport	Initial lift	Follower	Normal	91.4
6	Bed-to-stretcher transfer	Bed-side	Push	Kneeling	90.7
7	Stretcher transport	Initiate stairs	Follower	Normal	85.1
8	Stretcher transport	Mid-stairs	Leader	Normal	83.8
9	Bed-to-stretcher transfer	Bed-side	Push	Standing	82.5
10	Stretcher transport	Mid-stairs	Leader	Normal	82.1
11	Stretcher-to-gurney transfer	Stretcher-side	Push	Normal	78.2
12	Backboard transport	Initial lift	Leader	Normal	75.1
13	stretcher-to-gurney transfer	Gurney-side	Pull	Normal	73.4
14	Slat-stretcher transport	Through landing	Follower	Normal	73.1
15	Slat-stretcher transport	Initial lift	Leader	Normal	70.5
16	Slat-stretcher transport	Mid-stairs	Follower	Normal	66.0
17	Slat-stretcher transport	Initiate stairs	Follower	Normal	61.4
18	Stairchair transport	Initiate stairs	Leader	Normal	56.9
19	Backboard transport	Through landing	Leader	Raised	56.1
20	Stairchair transport	Mid-stairs	Leader	Normal	48.0
21	Backboard transport	Mid-stairs	Leader	Normal	39.5
22	Backboard transport	Initiate stairs	Leader	Normal	39.2
23	Stairchair transport	Through landing	Leader	Normal	37.9
24	Backboard transport	Through landing	Follower	Normal	37.2
25	Backboard transport	Mid-stairs	Follower	Normal	35.7
26	Stairchair transport	Initiate stairs	Follower	Normal	32.2
27	Stairchair transport	Mid-stairs	Follower	Normal	31.9
28	Stretcher transport	Mid-stairs	Follower	Normal	31.8
29	Backboard transport	Through landing	Leader	Normal	29.3
30	Slat-stretcher transport	Mid-stairs	Leader	One-hand	27.7
31	Slat-stretcher transport	Through landing	Leader	One-hand	27.5
32	Stairchair transport	Through landing	Follower	Normal	27.3
33	Slat-stretcher transport	Initiate stairs	Leader	One-hand	25.2
34	Slat-stretcher transport	Initiate stairs	Leader	Two-hand	24.0
35	Slat-stretcher transport	Mid-stairs	Leader	Two-hand	18.7
36	Backboard transport	Initiate stairs	Follower	Normal	16.8
37	Slat-stretcher transport	Through landing	Leader	Two-hand	13.2

was adjustable in length, then when shorter victims are carried, the board could be shortened to facilitate handling in confined spaces (landings, etc.) In addition, a waist harness system could be developed to allow the board to be carried in a hands free mode when confined spaces are not a concern. With the weight transferred directly to the pelvis, the spine would remain unloaded during the transport task. Similar harness systems have been designed for military stretcher transport (Tharion et al., 1993).

The use of the slat-stretcher was not indicated as a frequently performed and strenuous task during the interview and survey process. This may be due to its limited use among the suburban fire departments participating in this study. The teams from the one fire department that carried slat-stretchers on their ambulances were willing to demonstrate its use during the simulations. The probability values and compression data for the slat-stretcher must be evaluated cautiously in light of the small sample size. However, the slat-stretcher data showed some interesting trends. On the one hand, the initial lift for the follower yielded the highest average predicted compression value and the fourth-largest probability value across all the task components sampled, thereby indicating that the initial lift subtask is particularly hazardous. On the other hand, once the slat-stretcher was lifted, the probability values and the peak compression values were among the lowest values observed for the leader role in any of the subsequent task components assessed. The selection of the one-handed slat-stretcher carry by the leader allows one to walk forwards during the stair descent. This orientation reduces the likelihood of a fall as the stairs can now be visualized. But it should be recognized that this one

Table 3
The ranking of task, component, role, and method combinations according to the 3DSSPM predicted compression values. The top 11 subtasks had mean compression values that exceeded the NIOSH 1981 Action Limit when handling the 48 kg dummy

Ranking	Task	Component	Role	Method	Compression (N)
1	Slat-stretcher transport	Initial lift	Follower	Normal	6074
2	Stretcher transport	Initiate stairs	Leader	Raised	5717
3	Bed-to-stretcher transfer	Stretcher-side	Pull	Normal	5476
4	Backboard transport	Initial lift	Follower	Normal	5223
5	Stretcher transport	Initiate stairs	Follower	Normal	4722
6	Stretcher transport	Initiate stairs	Leader	Normal	4501
7	Slat-stretcher transport	Initial lift	Leader	Normal	4442
8	Stretcher transport	Mid-stairs	Leader	Raised	4049
9	Backboard transport	Initial lift	Leader	Normal	3955
10	Stretcher transport	Mid-stairs	Leader	Normal	3785
11	Stairchair transport	Initiate stairs	Leader	Normal	3727
12	Backboard transport	Through landing	Follower	Normal	3428
13	Backboard transport	Through landing	Leader	Raised	3409
14	Stretcher-to-gurney tranfer	Gurney-side	Pull	Normal	3350
15	Stairchair transport	Through landing	Leader	Normal	3099
16	Stretcher transport	Mid-stairs	Follower	Normal	3083
17	Bed-to-stretcher transfer	Bed-side	Push	Kneeling	2980
18	Stairchair transport	Through landing	Follower	Normal	2884
19	Backboard transport	Initiate stairs	Follower	Normal	2826
20	Backboard transport	Through landing	Leader	Normal	2826
21	Slat-stretcher transport	Through landing	Follower	Normal	2817
22	Backboard transport	Initiate stairs	Leader	Normal	2763
23	Stairchair transport	Initiate stairs	Follower	Normal	2730
24	Slat-stretcher transport	Initiate stairs	Follower	Normal	2642
25	Stairchair transport	Mid-stairs	Leader	Normal	2600
26	Slat-stretcher transport	Initiate stairs	Leader	Two-hand	2565
27	Backboard transport	Mid-stairs	Follower	Normal	2549
28	Backboard transport	Mid-stairs	Leader	Normal	2535
29	Slat-stretcher transport	Mid-stairs	Follower	Normal	2437
30	Stairchair transport	Mid-stairs	Follower	Normal	2290
31	Slat-stretcher transport	Mid-stairs	Leader	Two-hand	2248
32	Stretcher-to-gurney tranport	Stretcher-side	Push	Normal	2147
33	Slat-stretcher transport	Mid-stairs	Leader	One-hand	1893
34	Slat-stretcher transport	Through landing	Leader	Two-hand	1737
35	Slat-stretcher transport	Through landing	Leader	One-hand	1658
36	Slat-stretcher transport	Initiate stairs	Leader	One-hand	1645
37	Bed-to-stretcher transport	Bed-side	Push	Standing	1632

handed method results in an asymmetric loading of the spine, and therefore increases the stress on the contralateral musculature and the potential for an overexertion injury particularly with heavier victims. However, when this technique is used, it is important for the leader to grasp the railing to help offset the side-bending moment on the spine.

The bed-to-stretcher and the stretcher-to-gurney transfer tasks were representative of high risks tasks according to logistic regression model. In each case the risk was greater for the FF/P in the pulling role. In part, this was due to the large frictional forces encountered when sliding a victim across and between the two surfaces. Some sort of low-friction interface that would help bridge the gap between the surfaces would greatly reduce the moment acting on the spine, and hence the spine compression. With regard to the bed-to-stretcher transfer, the logistic regression model probability values and the 3DSSPP compression values were reduced when the FF/P stood on the bed. Based on these data, the use of this technique may be warranted; however, the biomechanical effects of these two methods should be more closely investigated before the standing technique is recommended.

4.1. Limitations of this study

There are three major limitations to this study which need to be acknowledged. First, the dummy's weight was relatively light for an adult in the United States. We believe, however, that the victim weight was heavy enough for us to sample realistic working postures and that these postures would remain consistent with those used in the handling of heavier victims. Although, had the victim been heavier, the spine compression values would have been larger and the percentage of the population with adequate strength would have been smaller for each task component modelled. Thus, while testing and/or modelling with a heavier victim would have increased the LBD risks and biomechanical stresses determined in the analysis section, we do not believe that such testing or modelling would have changed the recommendations put forth in this section of the paper.

A second limitation of this study is that the biomechanical loading of the spine was computed with a static model, thereby resulting in low estimates of the true spine compression and shear forces experienced during some of the task components modelled. This means that the dynamic and inertial forces acting on the body segments were neglected in this analysis. However, given the combined weight of the victim and the equipment lifted, the dynamic force contribution should have been relatively modest given previous findings (Tsuang et al., 1992).

The third limitation of this study pertains to the quality of the simulations. Ideally, these observations would be obtained under real emergency conditions. It is clear that this cannot be done without interfering with the quality of EMS service and without first overcoming numerous legal obstacles. The simulations were developed under the guidance of an advisory panel of fire chiefs from the consortium of suburban fire departments participating in the study. The chiefs' expertise was used to make sure the simulated tasks were as representative as possible of the generic situations encountered by their personnel. Thus, we have good confidence that what we have learned from this study is applicable to real-world emergency rescue situations.

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