Biomechanical Analyses of Paramedics Using Stairchairs

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Abstract. The objective of this study was to analyze the biomechanical stresses placed on paramedics while transporting a victim down a flight of stairs using different designs of stairchairs. A total of six different models of stairchairs were used in this simulated study. Three components of each descent (the initial entry onto the stairs, the mid-point of the descent, the negotiation of a 90? turn on a landing) and the carrying positions (leader backward, leader forward, follower) of the paramedics were evaluated. Results indicated that the leader forward position presented the lowest relative risk of low back disorder. Furthermore, stairchairs designed to have the stairwell support the weight of the victim significantly reduced the biomechanical stresses on the body as compared to their counterparts.

INTRODUCTION

While it is recognized that firefighter/paramedics (FF/Ps) perform a range of potentially hazardous manual material handling tasks (Hogya and Ellis, 1990), very few systematic studies have been conducted to evaluate high-risk activities. The application of ergonomic design to fire service tasks, including emergency rescue tasks, has made very little progress. Studies conducted by Lavender et al. (2000a; 2000b), however, identified the most frequently performed strenuous emergency rescue tasks encountered by the FF/Ps. One of the identified tasks was the transportation of a patient down the stairs and around a landing using a stairchair. This study expands on that study by investigating the biomechanical stresses placed on paramedics while transporting a victim down a flight of stairs using different designs of stairchairs.

METHODS AND PROCEDURES

Subjects

Eight male paramedics with age ranges between 20 and 47 years (mean 31 and std. dev. 8) volunteered to participate in this study. The mean height and weight of these individuals were 1.81 m (range: 1.71-1.98 m) and 101 kg (range: 58-123 kg), respectively.

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Apparatus and Simulation Task

The six different models of stairchairs used in this experiment are depicted in Figure 1. Prior to testing, the distribution of the load each paramedic was required to support was determined by mounting Chatillon force measurement gauges on the handles of each chair. The simulated task was the transporting of a victim down a staircase (20 steps) and a landing, which required a 90? turn. The staircase width was 840 mm and each step had a 180 mm rise and a 280 mm run. Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of each subject. Trunk positions and motions were measured with the Lumbar Motion Monitor (LMM). Reflective 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 the mid-point of the wrist breadth dimension of each subject.

Simulation Procedures

Prior to testing, each subject was provided with basic instruction and training on how to operate all the stairchairs. Since all the paramedics had experience with stairchairs, the training was brief. A total of six different models of stairchairs and three different carrying positions (i.e., follower, leader facing backward, and leader facing forward) were presented to each subject in random order. Three trials for each combination were collected.

Data Analysis

Data were collected on three task components of each trial: the initial entry onto the stairs, the mid-point down the stairwell, and the carry through a 90? turn on a landing (Lavender et al. (2000a; 2000b)). The postural data were extracted from the videotapes using the cameras with the most orthogonal view for the given task. Body segment orientations were expressed in terms of the coordinate system specified within the University of Michigan's 3D Static Strength Prediction Program™ (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 modeled for each subject in the simulation using the 3DSSPP. Each paramedic's height and weight were entered into the 3DSSPP which then scaled the models according to these anthropometric dimensions. The forces on the handles were assumed to be evenly distributed between the two hands. Postures in the 3DSSPP were adjusted according to each subject's measured posture from the videotape. The shear and compressive forces acting on the spine, particularly the L5/S1 joint, were computed by the 3DSSPP.

The logistic regression model developed by Marras et al. (1993) was used to quantify the relative risk of low back disorder (LBD) based upon the trunk motion and dynamometer data. This logistic regression model used the following five factors to determine the probability that the observed task was representative of a high LBD risk task: (1) the lifting rate per hour, (2) the average twisting velocity, (3) the maximum load moment during the lift, (4) the amount for forward (sagittal) bending during the lift, (5) the peak lateral bending velocity.

RESULTS AND DISCUSSION

As can been seen from Table 1, stairchair, position, task, and the interaction between chair and position all had a significant effect upon spinal stress and variables comprising the relative risk of low back disorder (Marras et al., 1993).

MODEL 1

MODEL 2

MODEL 3

MODEL 4

MODEL 5

MODEL 6

Figure 1: Six models of stairchairs used in this study

Table 1: Summarized ANOVA results for response variables.

Response Variable	**Stairchair F-value (p>F)**	**Position F-value (p>F)**	**Task F-value (p>F)**	**Chair*Position F-value (p>F)**
L5/S1 Compression Force	0.001*	0.001*	0.001*	0.001*
L5/S1 Shear Force	0.001*	0.001*	0.001*	0.001*
Average Twisting Velocity	0.001*	0.001*	0.001*	0.001*
Maximum Moment	0.001*	0.001*	0.001*	0.001*
Maximum Sagittal Flexion	0.001*	0.001*	0.001*	0.001*
Maximum Lateral Velocity	0.001*	0.001*	0.001*	0.001*
Relative Risk of Low Back Disorder	0.001*	0.001*	0.001*	0.001*

* Value of (p>F) which is less than 0.05 indicates that the effect of the factor is significant at ? =0.05.

Table 2 presents the summary of means and standard deviations of L5/S1 compression forces as determined by the 3DSSPP for the stairchair, position, and task. Duncan's Multiple Range test was performed on the means to determine the differences between mean values. The resulting homogenous subsets are indicated in the header (italic letters) of Table 2. As can be seen in Table 2, under the heading of stairchair, Model 6 had significantly lower compression values as compared to all other chairs. Models 1 and 5 were not significantly different from each other and Models 2 and 4 were not significantly different from each other. Model 3 generated significantly higher compression values as compared to all other chairs. In terms of carrying position, the leader facing forward position was determined to have significantly lower compression values as compared to the other two positions. The spinal compression force on the followers and the leaders facing backward were, on average, 48% and 53% larger than that experienced by the leaders facing forward, respectively. Tasks 1 and 3 generated significantly higher compression values as compared to Task 2.

Table 2: Summary of mean (std. dev.) L5/S1 Compressions across treatment combinations (Newton).

Position ? **Stairchair**	**Task 1: Initial** (*B*)			**Task 2: Middle** (*A*)			**Task 3: 90? Turn (Landing)** (*B*)		
	Follower (*B*)	Leader Facing Backward (*B*)	Leader Facing Forward (*A*)	Follower (*B*)	Leader Facing Backward (*B*)	Leader Facing Forward (*A*)	Follower (*B*)	Leader Facing Backward (*B*)	Leader Facing Forward (*A*)
Model 1 (*B*)	2815 (831)	1870 (640)	1215 (458)	2087 (777)	1836 (691)	1057 (428)	1915 (698)	1828 (1040)	1300 (777)
Model 2 (*C*)	2996 (725)	2465 (794)	*	2386 (747)	2089 (739)	*	1608 (538)	2215 (792)	*
Model 3 (*D*)	3920 (1372)	2307 (794)	1716 (841)	3092 (1209)	2063 (761)	1113 (513)	1881 (1165)	3539 (1102)	3440 (899)
Model 4 (*C*)	2433 (716)	2354 (1008)	*	1743 (738)	2195 (801)	*	2211 (988)	2978 (2058)	*
Model 5 (*B*)	2330 (938)	2481 (948)	1429 (588)	1625 (707)	2166 (922)	1158 (544)	1791 (510)	2411 (1337)	1310 (573)
Model 6 (*A*)	1291 (839)	1391 (710)	1300 (860)	1166 (764)	1024 (443)	718 (343)	838 (385)	**	**

* Stairchair not designed for operation in this position. ** Stairchair designed to be operated by the follower alone.

Table 3 presents the summary of means and standard deviations of relative risk of low back disorders across the treatment combinations. Duncan's Multiple Range test was performed on the means to determine the differences between mean values. The resulting homogenous subsets are indicated in the header (italic letters) of Table 3. As can be seen in Table 3, under the heading of stairchair, Model 6 had significantly lower probabilities of LBD as compared to all other combinations. Model 3 was significantly different than all other models. Models 1 and 5 were not significantly different from each other and Models 2 and 4 were not significantly different from each other. All three carrying positions were significantly different from one another. The relative risk of LBD on the followers and the leaders facing backward were, on average, 31% and 50% higher than that experienced by the leaders facing forward, respectively. Task 3 posed significantly higher risk than the other two tasks.

Table 3: Summary of mean (std. dev.) of relative risk of low back disorder (%) across treatment combinations.

Position ? **Stairchair**	**Task 1: Initial** (*A*)			**Task 2: Middle** (*A*)			**Task 3: 90? Turn (Landing)** (*B*)		
	Follower (*B*)	Leader Facing Backward (*C*)	Leader Facing Forward (*A*)	Follower (*B*)	Leader Facing Backward (*C*)	Leader Facing Forward (*A*)	Follower (*B*)	Leader Facing Backward (*C*)	Leader Facing Forward (*A*)
Model 1 (*C*)	25.8 (5.7)	30.5 (9.6)	19.2 (9.5)	26.3 (5.0)	32.5 (8.9)	16.2 (7.9)	30.3 (4.2)	35.0 (7.9)	28.3 (5.6)
Model 2 (*D*)	27.7 (6.4)	34.5 (9.8)	*	31.8 (8.5)	30.7 (7.3)	*	35.2 (6.4)	32.8 (12.0)	*
Model 3 (*B*)	16.3 (10.1)	17.3 (7.5)	13.3 (8.8)	14.3 (11.1)	18.6 (5.2)	9.6 (6.1)	22.2 (7.8)	32.9 (7.7)	39.7 (8.9)
Model 4 (*D*)	31.4 (7.0)	33.8 (8.6)	*	30.1 (7.3)	31.3 (8.0)	*	36.1 (7.8)	36.8 (8.9)	*
Model 5 (*C*)	30.2 (10.9)	33.1 (11.0)	20.6 (12.4)	28.5 (9.3)	34.1 (9.7)	16.1 (9.5)	31.9 (8.4)	33.7 (10.3)	26.4 (10.4)
Model 6 (*A*)	15.1 (11.5)	15.9 (7.7)	14.6 (10.6)	13.0 (10.1)	18.3 (7.9)	13.2 (8.3)	19.4 (7.8)	**	**

* Stairchair not designed for operation in this position. ** Stairchair designed to be operated by the follower alone.

CONCLUSIONS

Results from this study demonstrate that, although patient transport is a high-risk task, the design of stairchairs can significantly influence the biomechanical loads experienced by paramedics. Designs, like Model 6, can significantly reduce compression force (L5/S1) and relative risk of low back disorder by using the stairwell to support the weight of the victim and chair rather than the paramedic. Furthermore, stairchairs that are designed to allow the leader to descend the stairs forward facing reduces the biomechanical loads placed on that individual. The negotiation of a 90? turn was determined to be hazardous, thus identifying the need to develop stairchairs which can maneuver easily in tight situations. Overall, this study highlights the importance of equipment design and selection for paramedics and firefighters.

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