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BIOMECHANICAL ANALYSIS OF EMS PERSONNEL USING STAIR CHAIRS WITH TRACK SYSTEMS

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Abstract: Emergency medical technicians, paramedics and firefighters have the potential of incurring a back injury when transporting a patient down stairs. A stair chair is one device used to assist in the transport of a patient down one or more flights of stairs. The stair chair's design can impact its ability to alleviate potential injury due to the biomechanical stresses imposed on the operator during transport. Traditional stair chair designs force two operators to lift and carry the chair down the stairs while more recent chair designs are equipped with tracks that glide down the stairs and thus eliminate the need to lift and carry the patient. In most situations, two operators are still required to operate a track-equipped chair. One operator, the follower, is positioned behind the chair and walks forward down the stairs while the second operator, the leader, is positioned in front of the chair and walks down the stairs backward during operation. In this study, two different designs of track-equipped stair chairs were considered to determine the biomechanical stresses imposed on the operators during the transport of a patient down a flight of stairs. It was determined that one of the chairs imposed lower L5/S1 shear and compression forces on the user than the other chair. Furthermore, regardless of chair design, the leader experienced higher L5/S1 shear and compression forces than the follower. The difference in the spinal loadings experienced with the two chairs may be due to engineering design differences. Other results regarding the comparison of the chairs studied are discussed in the body of the paper.

1. INTRODUCTION

Overexertion, due to lifting, carrying, twisting, and bending, is the primary cause for musculoskeletal disorders that account for approximately 50% of all injuries to firefighters and emergency rescue personnel (Conrad, 2004). High back injury rates have been documented for emergency medical technicians and paramedics whose primary function involves lifting and transporting patients (Hogya and Ellis, 1990). One potentially hazardous task performed by paramedics involves transporting a patient down one or more flights of stairs using a stair chair. Traditional stair chairs are designed such that two operators, a follower (located behind the chair) and a leader (located in front of the chair and facing the patient), lift and carry the stair chair down the stairs with the patient securely positioned in the chair. In recent years, track-equipped stair chair designs have been developed which do not require the chair to be lifted by the operators, but rather the chair tracks rest on the stairs and the two operators glide the chair to the bottom of the staircase. Since much of the load associated with the patient and the stair chair is now translated to the stairs through the tracks, the load borne by the operators would appear to be lessened and would hopefully reduce the risk of back injury. Five traditional designs and one track-equipped stair chair design were the subject of a set of investigations performed by Fredericks *et al* (2002a and 2002b) and Butt *et al* (2002). It was shown that the stair chair equipped with tracks significantly reduced the compression force (L5/S1) and the probability of high risk group membership for low back disorders associated with both the follower and leader operator tasks in comparison to the traditional designs (Fredericks *et al*, 2002a). In the time following the studies by Fredericks *et al* (2002a and 2002b) and Butt *et al* (2002), other track-based stair chair designs have been developed which primarily differ in elements such as weight, handle length and placement, and track angle and mechanism. Therefore, the objective of this research study was to compare two track-equipped stair chair designs with respect to biomechanical stresses imposed on the operators.

2. METHODS AND PROCEDURES

2.1. Participants

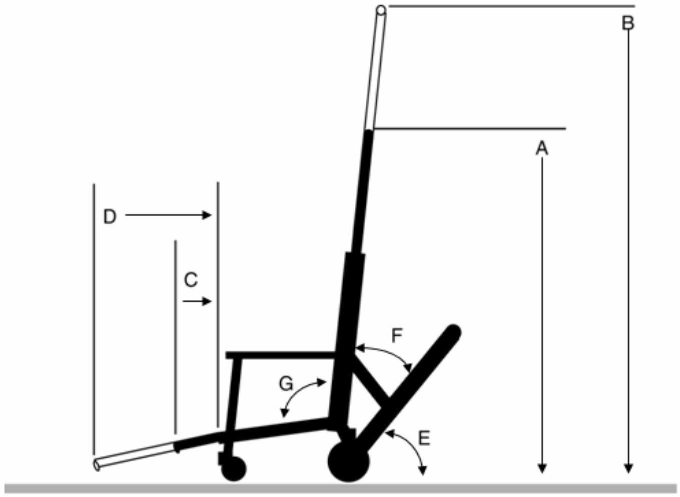
Ten male Emergency Medical Services (EMS) professionals with age ranging between 20 and 39 years (mean 31.0 and SD 5.6) volunteered to participate in this study. Consent was obtained from each of the 10 participants and the participants were compensated for their time during the study. The mean height and weight of the participants were 1.81 m (range: 1.74 - 1.87 m) and 94.0 kg (range: 75.0 - 113.6 kg), respectively. Table 1 provides the mean and standard deviation of selected anthropometric dimensions of the participants.

Table 1. Anthropometric measurements of the 10 male EMS participants.

(*n* = 10)	**Age** (years)	**Weight** (kgs)	**Height** (cm)	**Hip Height** (cm)	**Elbow Height** (cm)	**Acromial Height** (cm)	**Trunk Length** (cm)	**Trunk Circumference** (cm)	**Illiac Breadth** (cm)	**Upper Arm Length** (cm)	**Lower Arm Length** (cm)
Mean	31.0	94.0	181.0	18.3	113.0	148.6	71.0	87.5	33.7	33.9	29.6
SD	5.6	10.8	4.9	3.0	2.4	3.5	26.4	27.5	5.0	2.4	1.5

2.2 Apparatus and Simulated Task

The two stair chair models selected for this experiment, and their respective characteristics, are displayed in Figure 1. Prior to testing, the distribution of the load that was required to be supported was determined by mounting Chatillon force measurement gauges (Ametek) on the handles of each chair. The simulated task was to transport a victim down a staircase with a landing after the 13th step. Each step had a 170 mm rise and a 240 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) (Chattanooga Group Inc). Upon arrival, each subject was instrumented with the LMM and 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.



Model 1:
*Weight**: 38.15 lbs.
Handle Height Range
Leader: 0.14 m **(C)** – 0.48 m **(D)** with 5 positions.
Follower: 0.95 m **(A)** – 1.61 m **(B)** with 5 positions.
Track Angle **(E)**: 62°.
Track to Follower Handle Angle **(F)**: 21°.
Follower Handle to Leader Handle Angle **(G)**: 110°.

Model 2:
*Weight** : 32.8 lbs.
Handle Height Range
Leader: 0.16 m **(C)** – 0.31m **(D)** with 2 positions.
Follower: 0.95 m **(A)** – 1.42 m **(B)** with 3 positions.
Track Angle **(E)**: 52°.
Track to Follower Handle Angle **(F)**: 30°.
Follower Handle to Leader Handle Angle **(G)**: 103°.

Note: * Weight measured with follower lift handles, ABS plastic seat, and no patient restraints.

Figure 1. Two Models of Stair Chairs Used in the Study.

2.3 Simulation Procedures and Data Analysis

Prior to testing, each participant was provided with basic manufacturer instructions and a demonstration of how to perform the task of transporting a victim down the stairs with each stair chair. The participant was allowed to practice with each stair chair until they felt comfortable with the procedures. Two different carrying positions, follower (located behind patient and walking forward down the stairs) and leader (facing patient and walking backward down the stairs), for each chair design were presented to the participant in random order. Three trials for each combination of stair chair and carrying position were collected for each participant. The adjustment of the handle positions for both carrying positions was chosen by the participant during the practice period and remained the same for all trials of the same combination of stair chair and carrying position. The experienced professional in the other carrying position was the same for each set of trials for a participant.

Data were collected on two task components of each trial: (1) the initial entry to the stairs ("Stair Entry") and (2) the mid-point down the staircase ("Middle of Stairs"). Postural data was extracted from the video tapes 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 3-D Static Strength Prediction Program^{TM} (3DSSPP) (University of Michigan, 2006). The three-dimensional trunk postures, namely degree of forward bending, side twisting and bending were obtained from the LMM.

Each task component was modeled for each participant in the simulation using the 3DSSPP software. Each EMS professional's height and weight were entered into the 3DSSPP, which then scaled models according to the participant's anthropometric dimensions. The forces on the handles were assumed to be evenly distributed between both hands. Postures in 3DSSPP were adjusted according to each participant'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 acquiring a low back disorder (LBD) based upon the trunk motion and force gauge data. This logistic regression model used the following five factors to determine the probability of high risk group membership for a low back disorder (LBD Risk): (1) the lifting rate per hour, (2) the average twisting velocity, (3) the maximum load moment during the lift, (4) the amount of forward (sagittal) bending during the lift, and (5) the peak lateral bending velocity.

3. RESULTS AND DISCUSSION

Table 2 presents the p-value results of ANOVA testing for three response variables, L5/S1 Compression, L5/S1 Shear, and LBD Risk. This testing is based on a model which includes one block effect: subject ("Participants"); three main effects: stair chair design ("Chair"), carrying position ("Position"), task component ("Task"); and the two-way and three-way interactions between the main effects. As can be seen from this table, the main effects (with the exception of Task for L5/S1 Compression) and many of the interactions had a significant influence on the associated response variable. ($\alpha = 0.05$).

Table 2. Summary of ANOVA P-values by response variable (blocked by subject).

Response Variables	**Block**	**Effects**						
	Subject	*Chair*	*Position*	*Task*	*Chair x Position*	*Chair x Task*	*Position x Task*	*Chair x Position x Task*
L5/S1 Compression	0.000*	0.000*	0.000*	0.603	0.489	0.047*	0.000*	0.020*
L5/S1 Shear	0.000*	0.000*	0.000*	0.003*	0.000*	0.000*	0.022*	0.467
LBD Risk	0.000*	0.001*	0.000*	0.030*	0.002*	0.033*	0.000*	0.774

* significant at $\alpha = 0.05$

To further investigate the main effects and interaction effects for L5/S1 Compression, L5/S1 Shear, and LBD Risk, Post Hoc homogenous subsets were constructed based on Tukey Post-Hoc Comparisons ($\alpha = 0.05$). The results of the Post Hoc tests and the mean and standard deviations for each of the treatment combinations corresponding to each of these three response variables can be found in Tables 3, 4, and 5, respectively. In these tables, the homogeneous subsets are identified with parentheses and labeled alphabetically. The mean values of the homogeneous subsets for the respective response variables increase alphabetically. Therefore, all treatment means within subset A cannot be considered statistically different, but their means are statistically smaller than the treatment means in all other homogeneous subsets (B, C, etc.).

From the interaction information in Table 3, it can be inferred that the carrying position (Follower or Leader) plays a significant role on the mean L5/S1 compression loadings for both chair designs, with the Follower yielding statistically lower mean L5/S1 compression than the Leader. Based on the interactions it can be inferred, that the task does not play a significant role on the mean L5/S1 compression loadings; with the exception of the Leader position with Chair Model 1 in which the Middle of the Stairs task yields a lower mean L5/S1 compression than the Stair Entry task. Comparing Chair Model 1 to Chair Model 2 for each carrying position, Chair Model 2 yields statistically lower mean values than Chair Model 1 for both the Follower and Leader positions. And finally, with respect to main effects for the 10 participants, Chair Model 2 yielded statistically lower mean L5/S1 compression values than Chair Model 1 over both task components and carrying positions (approximately 40% lower) and the Follower yielded statistically lower mean L5/S1 compression values than the Leader over both task components and chair models (approximately 59% lower).

Table 3. Summary of Mean (SD) L5/S1 Compression (Newtons) across treatment combinations
with the highest order significant interactions for the 10 participants.

Task	**Position**	**Chair**		**Interactions with Homogenous Subsets**
		***Chair Model 1* (B)**	***Chair Model 2* (A)**	***Chair x Position x Task***
Task 1 Stair Entry	***Follower* (A)**	459.9 (229.9)	170.9 (72.3)	A-(C2•F•E, C2•F•M) B-(C1•F•E, C1•F•M) C-(C2•L•M, C2•L•E) D-(C1•L•M) E-(C1•L•E)
	***Leader* (B)**	1163.7 (190.3)	739.1 (250.6)	
Task 2 Middle of Stairs	***Follower* (A)**	546.5 (232.1)	242.0 (93.5)	
	***Leader* (B)**	964.6 (323.0)	733.9 (261.0)	

Note: C1 = Chair Model 1; C2 = Chair Model 2; F = Follower; L = Leader; E = Stair Entry; M = Middle of Staircase

Table 4 identifies main effects and interaction differences with respect to L5/S1 shear forces. From the interaction homogeneous subsets in this table, Chair Model 2 yields statistically lower mean L5/S1 shear values than Chair Model 1 with respect to both carrying position and task component. When comparing carrying position by task component, it can be inferred that the Follower yields statistically lower mean shear force values than the Leader and that the Stair Entry yields statistically higher mean shear values than the Middle of the Stairs task component within a carrying position. The main effects findings are similar to those of compression with Chair Model 2 yielding statistically lower mean L5/S1 shear values than Chair Model 1 over both task components and carrying positions (approximately 34% lower). The Follower yielded statistically lower mean L5/S1 shear values than the Leader over both task components and chair designs (approximately 29% lower).

Table 4. Summary of Mean (SD) L5/S1 Shear (Newtons) across treatment combinations
with the highest order significant interactions for the 10 participants.

Task	**Position**	**Chair**		**Interactions with Homogenous Subsets**		
		***Chair Model 1* (B)**	***Chair Model 2* (A)**	***Chair x Position***	***Chair x Task***	***Position x Task***
***Task 1 Stair Entry* (B)**	***Follower* (A)**	109.6 (13.1)	48.45 (6.4)	A-(C2•F) B-(C2•L) C-(C1•F) D-(C1•L)	A-(C2•E, C2•M) B-(C1•M) C-(C1•E)	A-(F•M) B-(F•E) C-(L•M) D-(L•E)
	***Leader* (B)**	129.4 (16.5)	101.4 (11.8)			
***Task 2 Middle of Stairs* (A)**	***Follower* (A)**	101.5 (15.9)	54.53 (6.2)			
	***Leader* (B)**	116.9 (19.3)	99.0 (13.8)			

Note: C1 = Chair Model 1; C2 = Chair Model 2; F = Follower; L = Leader; E = Stair Entry; M = Middle of Staircase

Table 5 summarizes the mean (SD) of LBD Risk, which was calculated using the logistic regression model developed by Marras *et al* (1993). The most informative inference which can be gleaned from this table is that the Leader carrying position has a statistically higher mean LBD Risk than the Follower. This finding is supported by the compression and shear values on the L5/S1 disk. While there are additional statistical differences in this table, most of the differences are not of any relative practical significance.

Table 5. Summary of mean (SD) LBD Risk across treatment combinations with the highest order significant interactions for the 10 participants.

Task	**Position**	**Chair**		**Interactions with Homogenous Subsets**		
		***Chair Model 1* (B)**	***Chair Model 2* (A)**	***Chair x Position***	***Chair x Task***	***Position x Task***
***Task 1 Stair Entry* (B)**	***Follower* (A)**	9.1 (3.8)	6.1 (2.3)	A-(C2•F) B-(C1•F) C-(C2•L, C1•L)	A-(C2•M) B-(C2•E, C1•M, C1•E)	A-(F•E) B-(F•M) C-(L•M) D-(L•E)
	***Leader* (B)**	23.6 (9.0)	24.8 (10.0)			
***Task 2 Middle of Stairs* (A)**	***Follower* (A)**	14.1 (5.8)	7.6 (2.8)			
	***Leader* (B)**	18.4 (7.8)	16.9 (9.5)			

Note: C1 = Chair Model 1; C2 = Chair Model 2; F = Follower; L = Leader; E = Stair Entry; M = Middle of Staircase

4. CONCLUSION

The EMS task of transporting a patient down one or more flights of stairs is a strenuous task commonly completed using a stair chair (Lavender *et al*, 2000a and 200b). With respect to biomechanical variables, it has been shown that stair chairs that are equipped with a track system, which rests on and glides down the stairs during use, drastically outperform stair chairs that must be lifted and carried (Fredericks *et al*, 2002a). The results of this study also show that the design of the track-equipped stair chair can impact spinal loading, particularly with respect to L5/S1 compression and L5/S1 shear, which has been used as a means to identify the potential of developing a low-back injury (Callaghan *et al*, 2001). Furthermore, based on the two chair designs tested, the operator who is located in front of the chair and walking down the stairs backward is at a higher LBD Risk and will experience higher L5/S1 compression and shear force values than the operator who is located behind the chair and walking forward, regardless of the stair chair design. While the track system stair chair designs are a vast improvement over traditional stair chairs, this study highlights that additional design improvements may be possible to further reduce the spinal loading experienced by operators, particularly for the operator in the leader carrying position.

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