The XXVth Annual Occupational Ergonomics and Safety Conference
Atlanta, GA, USA
June 6-7, 2013

Evaluation of Medical Cot Design Considering the Biomechanical Impact on Emergency Response Personnel

Tycho K. Fredericks, Steven E. Butt, Kimberly S. Harms, and James D. Burns

Department of Industrial & Manufacturing Engineering
College of Engineering & Applied Sciences
Western Michigan University
Kalamazoo, MI 49008-5536 USA

Corresponding author's Email: tycho.fredericks@wmich.edu

Author Note: Tycho K. Fredericks, Ph.D., CPE, Professor, IEE Program Coordinator and Director, Human Performance Institute; Steven E. Butt, Ph.D., Professor and Interim Chairman; Kimberly S. Harms, B.S. I.E.; James D. Burns, M.S. I.E., Doctoral Associate.

Abstract: Emergency medical service (EMS) response personnel face significant risk of developing musculoskeletal disorders (MSDs) through work-related activities. Lifting and loading cots into the back of an ambulance is one important and common responsibility of EMS personnel. This physically demanding task presents a potentially harmful situation due to awkward working postures and high loading forces. In this study, the biomechanical impacts on paramedics and emergency medical technicians (EMTs) were evaluated when lifting and loading three cot designs into an ambulance using three different cot fastener systems. Measurements for working posture and reaction forces at the hands were direct inputs for biomechanical analysis using the University of Michigan's Three-Dimensional Static Strength Prediction Program (3DSSPP) to determine loading forces on the low back. Additionally, this research compared cot designs based on subjective ratings of perceived exertion (RPE). The results of this research show that design features, specifically powered mechanisms, may reduce the severity of biomechanical risks placed on paramedics and EMTs.

Keywords: emergency medical service, lift, musculoskeletal, biomechanical

1. Introduction

Patient transport can be a potentially dangerous task routinely carried out by medical professionals. Patient transport by emergency medical service (EMS) professionals includes the use of devices such as backboards, stair chairs, and ambulance cots. Lavender et al. (2000a & 2000b) studied biomechanical implications for emergency medical personnel when performing tasks such as transporting patients down stairs using different devices. Previous work in this area has also included the investigation of the impact of ambulance cot design on the strain of the muscles and circulatory system (Kluth & Strasser, 2006) and the investigation of the impact of different ambulance loading systems on the biomechanical loads experienced by ambulance workers (Cooper, 2007).

Patient transport procedures and equipment offer a growing opportunity for research that leads to better working environments for emergency response personnel and others in the medical field. Studnek et al. (2012) tracked a decrease in the number of work-related injuries resulting from the use of powered transport equipment. The goal of this research was to evaluate the biomechanical impacts on emergency response personnel from using different ambulance cot and fastener designs during the lifting and loading process. Manual and powered systems were analyzed through objective and subjective measures. Additionally, North American and European models of cots and fastening systems were evaluated to illustrate possible biomechanical differences among commercially available equipment. By informing equipment designers, future researchers, and healthcare stakeholders of the inherent risks associated with the EMS profession and use of its associated equipment, better equipment, research, and practices may be developed to further reduce instances of MSDs.

2. Evaluation and Experiment Methodology

2.1 Evaluation Criteria

The basis for evaluation in this study is a comparison of objective and subjective responses that result from operating cots during simulated lifting and loading of a patient into an ambulance. Two participants are necessary for the task; one person located at the end of the cot nearest a patient's feet and the other nearest the patient's head (Note: the head end of a cot is loaded into an ambulance first). This study includes North American and European style cots. Three basic steps are involved in loading a patient using a North American style cot: 1. Raising the cot from a lowered position (Lift). 2. Holding the foot end of the cot with the head end supported by the ambulance while the cot legs are retracted (Hold). 3. Loading the cot into an ambulance by maneuvering the cot into the correct position to be secured by the fastener system (Load). For a European style cot, Step 1 and Step 3 are performed, but Step 2 is unnecessary as the cot is supported by the platform and frame as it is loaded.

The objective comparisons for this study center on biomechanical measures of compression and shear forces acting on the L4/L5 disc of the lower back and assessment of risk of Low Back Disorder (LBD) (Marras, 1993). Static biomechanical analyses were performed for two aspects of the operation that may be considered the most physically demanding on the low back: The initial movement of the lifting operation, and holding the cot prior to loading. Analyses using LBD risk models, which are well suited to evaluate dynamic material handling activities, were employed for the lifting and loading portions of the task. Task completion time and the subjective measurement of perceived exertion were also analyzed.

2.2 Participants

Participants for this study included males and females recruited from local Emergency Medical Services organizations. Because the operation of the cots required the presence of two individuals, two-person EMT/Paramedic teams were recruited. Individuals who frequently work together or had previously worked together were encouraged to participate during the same session. Participants were asked to wear normal work clothing and footwear. Table 1 presents a summary of participant information and select anthropometric measurements.

Table 1. Study Participant Information and Select Anthropometric Measurements (Mean (SD))

	n	Age (years)	Stature (mm)	Weight (kg)	Shoulder Height (mm)	Elbow Height (mm)
Female	5	29.0 (8.69)	1,646.4 (36.77)	74.7 (7.51)	1,312.0 (58.05)	1,020.0 (38.08)
Male	5	30.0 (8.69)	1,749.0 (94.90)	87.3 (14.95)	1,385.8 (94.13)	1,081.0 (78.15)
Overall	10	29.5 (8.21)	1,697.7 (86.76)	81.0 (12.97)	1,348.9 (24.63)	1,050.5 (219.08)

2.3 Equipment

Equipment used in this study consisted of the individual cots being tested, their associated fastener systems, and data collection equipment. Table 2 presents a summary of each of the six testing segments and the associated data collection points for each combination of cot (COT), position relative to the patient (POSITION), and fastener type (FASTENER).

2.3.1 Cots

The study centered on the evaluation of three unique commercially available cots with varying design features. Two

Table 2. Testing Segment Summary

COT	Weight* (kg)	Cot Type	Platform	FASTENER	POSITION = Foot				POSITION = Head			
					No.	Lift	Hold	Load	No.	Lift	Hold	Load
NA1	63.5	Power Lift	Deck	Powered	1	(A)	-	(D)		-	-	-
				Antler	2	(A)	(B)	(B)	3	(A)	(B)	(B)
NA2	41.5	Manual Lift	Deck	Antler	4	(A)	(C)	(D)	5	(A)	-	-
E1	59.0	Manual Lift	Tray	Roll-in	6	(A)	-	(D)		-	-	-

* Approximate weight as measured during study provided for illustrative purposes, rounded to nearest 0.5 kg.
( ) Identifies data collection and analysis points., with parenthetical notation of Subject Position as shown in Figure 1.

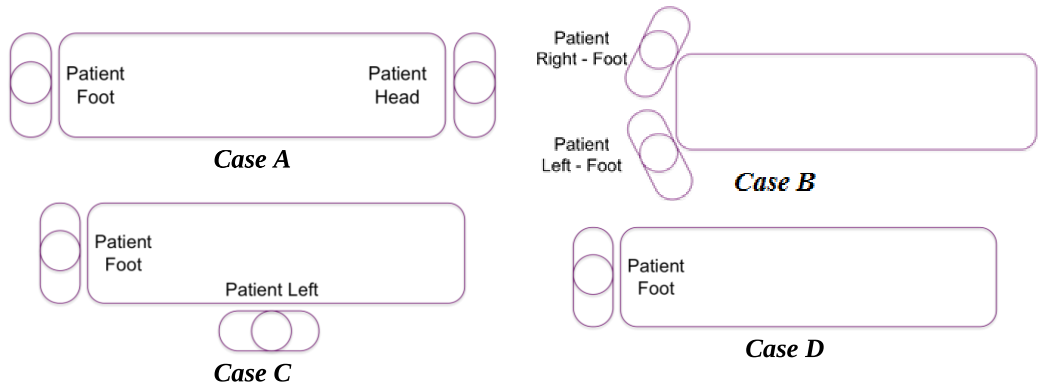

Figure 1. Subject Positions

of the cots used were classified as North American (NA1, NA2), and one was considered European (E1). Both manual lift cots (NA2 & E1) were tested using only one cot fastener system, while a powered cot (NA1) was tested on two fastener systems. Of these four combinations, two are completed with the participant rotating through each of the two positions (Foot and Head) on the cot. This results in six testing combinations. Figure 1 depicts the participant positions listed in Table 2.

The powered cot (NA1) allows for the cot to be raised or lowered by controls located in the right handle of the Foot position, eliminating the need for EMS workers to manually raise the cot from a lowered position or to collapse the frame when loading into an ambulance. NA1 has two fixed handle heights at the Foot, and the Head has one handle bar. Two fasteners are evaluated for the NA1 Hold and Load procedure. The powered fastener required only one operator (Case D) to load the cot while the antler fastener required two operators (Case B). Holding and loading with the antler fastener shifted the participant from the Head position to the patient-right side of the Foot position and the participant in the Foot position moved to the patient-left side of the Foot position (Case B).

For the manual lift of NA2, the operator located at the Foot activates a release lever with the left hand to permit the cot frame to extend. Following the lift, the participant at the Head rotates to the patient-left side of the cot for the Hold procedure (Case C). During the Hold, the Foot operator and platform bear the weight of the cot while the Head operator retracts the legs by lifting the carriage. Only the Foot operator controls the cot during loading (Case D).

Lifting for the European model requires both the Foot and Head operators to use a release lever since the two sets of legs operate independently. This study only evaluated the operator at the Foot, of which the release lever is positioned for the right hand. The European cot was loaded into a tray fastener termed a *roll-in* system, requiring a fully lifted cot to be guided forward onto the fastener (Case D). The E1 design has a safety mechanism built into the Foot-controlled leg release. A button located on the left handle is used in conjunction with a release lever to release the legs at the Head. The handle on the right, used to extend the legs during the lift, then releases the Foot legs to retract during loading.

All cots were weighted for data collection with a 167 lb. (75 kg) dummy to represent the human weight distribution on the cot (Cooper, 2007). Each of the ten participants was an experienced user of the NA2 testing segment.

2.3.2 Loading Platforms and Fastener Systems

To simulate the loading of a cot into an ambulance, two unique loading apparatuses were constructed to accommodate either a North American or European style cot. North American style cots were loaded onto a platform with an approximate height of 815mm, and a flat deck fitted with mounts for both the powered and antler fasteners. The European style cot was loaded onto a tray with an approximate height of 700mm. In industry, these trays are fitted with a cot-specific rail that creates a track to guide the cot during loading.

2.3.3 Data Collection Equipment

Instrumentation sufficient to facilitate a biomechanical analysis and LBD risk assessment for the different cot styles were used. An anthropometric kit was used to collect participant information. During data collection, participants were outfitted with a Lumbar Motion Monitor (LMM, The Biodynamics Laboratory, The Ohio State University) to record trunk position and motion. A digital video system was used to capture images orthogonal to the primary planes of the body suitable for extracting body segment angles using reflective markers placed on the lateral side of the ankle, knee, greater trochanter, acromion process, and mid-line of the elbow and wrist. An ErgoPak (Hogan Health Industries, West Jordan, UT) load cell was used to estimate reaction forces on the hands. Body angles, spine posture, hand forces, and subject anthropometry were inputs of the University of Michigan's Three-Dimensional Static Strength Prediction Program (3DSSPP).

2.4 Experimental Procedures

Upon arrival, both participants completed HSIRB consent and were screened for back disorders with a questionnaire and body discomfort map (Marley, 1994). Participants were then introduced to the cots and fastener systems used in the study, along with the procedure for data collection. Any questions asked by the participants were answered.

Subjects were tasked with lifting the cot from the lowest position up to transport height, maneuvering the cot into position for loading, and then loading the cot onto the platform and/or into the fastener system. Subjects were also instructed to allow the power lifting mechanism to do the work while still maintaining control during the lift by keeping both hands on the cot. After each trial, the research team unloaded the cot from the platform and staged the cot for the next trial.

At the start of each segment, participants were given instruction on cot operation and were given adequate unloaded trials to become familiar with the lifting and loading procedure of that cot onto the respective fastener. Again, questions were answered as the participants became comfortable with the equipment. Once consistency was achieved in the process, the cot was weighted with the dummy and data collection began.

Task completion time was defined as the moment when the Subject's hands first touched the cot for the Lift until their hands left the cot following the Load. Back posture and body angles were recorded during each trial. After each trial, the Subject was asked to respond with a rating of perceived exertion (RPE) using a 6-20 scale (Borg, 1990). A minimum of four and maximum of seven trials were performed for each combination. Three trials were used for analysis. After each testing combination was complete, load cells were attached to the cot's handles to capture reaction forces on the hands.

3. Results & Discussion

3.1 Statistical Comparisons

The study consisted of a randomized block design, with the combinations of COT, POSITION, and FASTENER presented randomly to the study participants (SUBJECT). Variables of interest included responses for task completion time (TIME), RPE, L4/L5 compression (COMP) and shear forces (SHEAR), and risk of low back disorder (LBD). The experiment called for the EMT/paramedic team to perform the basic steps required to complete the simulated task of lifting and loading a cot into an ambulance. For each data collection session, one participant was designated as the SUBJECT with the other designated as the *helper*. Data was collected for the SUBJECT only. Upon completion of all combinations, the roles were reversed and a new session started. Analysis of variance (ANOVA) techniques were used to test for the main effects representing either combinations of COT and POSITION, or main effects representing combinations of COT and FASTENER. Effects due to gender were investigated, but did not impact groupings of any main effect of interest. Tukey's pairwise comparisons ($\alpha = 0.05$) were used to identify differences in mean responses.

For this study, responses for TIME and RPE (Table 3) are representative of the overall effect of using the cot, and are independent of the effect of POSITION. For each combination of COT and FASTENER the main effect for TIME ($F(3, 167) = 114.58$, $p < 0.001$, $R^2 = 0.73$) and RPE ($F(3,167) = 103.46$, $p < 0.001$, $R^2 = 0.72$) were both significant. For comparisons between biomechanical variables (Table 4), main effects for the Lift portion of the study consist of combinations of COT and POSITION. Responses for both COMP ($F(4,163) = 136.68$, $p < 0.001$, $R^2 = 0.80$) and SHEAR ($F(4,163) = 81.45$, $p < 0.001$, $R^2 = 0.74$) were significant. For the Hold portion (North American cots only), combinations of COT and FASTENER were modeled and revealed COMP ($F(2,90) = 33.82$, $p < 0.001$, $R^2 = 0.70$) and SHEAR ($F(2,90) = 47.38$, $p < 0.001$, $R^2 = 0.71$) to be significant. For responses of LBD (Table 5), combinations of COT and POSITION were modeled and found to be significant ($F(4,46) = 60.00$, $p < 0.001$, $R^2 = 0.85$) for the Lift portion. For Load, responses of LBD were significant when modeling COT and FASTENER ($F(3,37) = 14.60$, $p < 0.001$, $R^2 = 0.70$).

3.2 Task Completion Time and Ratings of Perceived Exertion

Table 3 presents mean responses, standard deviations, and statistical grouping information regarding all cot segments for both task completion time and ratings of perceived exertion. The grouping of time reveals that manual cots are statistically faster than powered units, and the use of a power fastener significantly increases the task completion time.

Table 3. Time & RPE (Mean Response/SD/Tukey Grouping)

COT	FASTENER	TIME *M (SD)*	RPE *M (SD)*
NA1	Powered	28.79 (3.08) A	6.30 (0.47) D
	Antler	21.06 (3.77) B	8.45 (1.76) C
NA2	Antler	15.54 (4.57) D	9.65 (2.08) B
E1	Roll-in	18.58 (4.62) C	13.10 (2.92) A

* Tukey Grouping Convention: A = Group A independent of position.

Differences were also found for RPE responses, with the powered cot and fastener system resulting in comparatively less perceived exertion than any other cot and fastener combination. The NA1 manual load had the next lowest perceived exertion, followed by the NA2 design. The E1 cot had significantly greater responses of perceived exertion.

3.3 Biomechanics & Low Back Disorder Risk

The biomechanics results are shown in Table 4. For Lift, responses for compression and shear forces at the L4/L5 disc for the NA2 cot were significantly higher than the powered cot in both the Head and Foot positions. Lifting of the European cot had statistically higher compression forces compared to both NA1 and NA2. For the Hold, statistically lower L4/L5 compression force resulted with the use of a powered fastener. Cot NA2 produced statistically higher responses of compression and shear forces than both NA1 COT/FASTENER combinations.

The LBD risk assessment percentages are shown in Table 5. For Lift, the powered cot (NA1) has significantly lower responses for LBD than the manual cot (NA2), regardless of position, and the European cot (E1). Significant differences were also identified among combinations of COT and FASTENER for the Load segment, with a powered fastener producing statistically lower responses versus an antler fastener, and a powered cot having statistically lower responses versus a manual cot. Although no statistical difference was identified in the pairwise comparison between E1 and NA1 using a powered fastener, the inherent differences in the loading process and equipment suggest that a practical difference is masked by the comparatively large standard deviation of E1 and the small sample size of the study. For this reason, a Paired t-test on responses of LBD, paired on SUBJECT, was performed for NA1 with a powered fastener and E1, and was found to be significant at $p = 0.057$.

4. Conclusion

The purpose of this study was to investigate potential biomechanical effects of different medical cot design features on EMS workers. Six combinations from three cot designs and three fastener systems were evaluated, and the results suggest

Table 4. Spine Loadings (Mean Response/SD/Tukey Grouping)

		Lift				Hold	
		POSITION=Foot		POSITION=Head		Combined	
COT	FASTENER	L4/L5 Comp *M (SD)*	L4/L5 Shear *M (SD)*	L4/L5 Comp *M (SD)*	L4/L5 Shear *M (SD)*	L4/L5 Comp *M (SD)*	L4/L5 Shear *M (SD)*
NA1	Powered	506.20 (131.20) C_F	39.70 (14.01) B_F	557.20 (178.80) B_H	38.00 (15.64) B_{NA}	157.70 (58.90) C	40.40 (10.67) B
	Antler					227.60 (90.80) B	44.25 (11.21) B
NA2	Antler	1,001.70 (315.80) B_F	74.17 (13.48) A_F	1,300.10 (333.60) A_H	91.33 (32.32) A_{NA}	290.40 (107.90) A	59.57 (11.96) A
E1	Roll-in	1,315.20 (369.00) A_F	75.13 (29.76) A_F	- -	- -	- -	- -

* Tukey Grouping Convention: A_F = Group A for Foot position, A_H = Group A for Head position, A = Group A independent of position.

Table 5. LBD Risk Assessment (Mean Response/SD/Tukey Grouping)

COT	FASTENER	LBD for Lifting POSITION=Foot *M (SD)*			LBD for Lifting POSITION=Head *M (SD)*			LBD for Loading Combined *M (SD)*		
NA1	Powered	24.80	(6.96)	B_F	29.10	(7.03)	B_F	11.20	(5.65)	C
	Antler							19.65	(8.51)	B
NA2	Antler	48.00	(5.08)	A_F	51.60	(5.44)	A_F	28.90	(8.71)	A
E1	Roll-in	47.30	(8.26)	A_F	-	-		15.80	(10.08)	B C

* Tukey Grouping Convention: A_{NA} = Group A for North American Cots, A_E = Group A for European Cots.

the addition of powered mechanisms may provide a significant reduction in biomechanical stresses. In this study, decreases of compression forces on the L4/L5 disc of up to 50% were observed when raising a cot with a power lift feature over a manual cot and up to 60% over a European cot. The power lift feature also reduces compression forces when a cot is being held in preparation for loading into an ambulance, and an even greater reduction is possible when using a powered load system which eliminates the need for supporting the weight of a cot prior to loading. Although the L4/L5 shear forces observed in this study are far below that which is generally assumed to cause acute injury (Marras, 2008), percent reductions similar to those of compression forces were observed. Likewise, lower LBD responses for the load approach improvements of 60% from the manual cot, suggesting the risk of low back disorders may also be reduced by adding a powered lift and load. Physiological benefits may also be realized through the addition of powered features. Responses for perceived exertion were up to 35% lower when operating a cot with a power lift and a power loading feature versus a manual cot and up to 50% lower versus the European cot.

Although there are natural limitations stemming from difficulties in reproducing real-world conditions, the study results are no less important. Testing with only one patient weight and two attending emergency personnel are examples of the limitations of this research. In practice, lighter patients may be loaded by only one EMS worker while heavier patients may be lifted and loaded by three or more EMS personnel. Cot and fastener designs should continue to be evaluated through biomechanics and other metrics, and future research should include the usability aspects of the equipment. It was noticed that release lever accessibility and function was an impeding factor for operators with smaller grip spans. Lifting and loading is an essential process of providing emergency medical service and the results discussed here suggest a difference in the magnitude of risk to the service provider of using different cot and fastener designs.

5. References

Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health, 16(1)*, 55-58.

Cooper, G. & Ghassemieh, E. (2007). Risk Assessment of Patient Handling with Ambulance Stretcher Systems (ramp/(winch), easi-loader, tail-lift) Using Biomechanical Failure Criteria. *Medical Engineering & Physics, 29*, 775-787.

Lavender, S.A., Conrad, K.M., Reichelt, P.A., Johnson, P.W., & Meyer, F.T. (2000a). Biomechanical Analyses of Paramedics Simulating Frequently Performed Strenuous Work Tasks. *Applied Ergonomics, 31*, 167-177.

Lavender, S.A., Conrad, K.M., Reichelt, P.A., Meyer, F.T., & Johnson, P.W. (2000b). Posture Analysis of Paramedics Simulating Frequently Performed Strenuous Work Tasks. *Applied Ergonomics, 31*, 45-57.

Kluth, K. & Strasser, H. (2006). Ergonomics in the rescue service-Ergonomic evaluation of ambulance cots. *International Journal of Industrial Ergonomics, 36*, 247-256.

Marley, R.J. & Kumar, N. (1994). An improved musculoskeletal discomfort assessment tool. *International Journal of Industrial Ergonomics, 17*, 21-27.

Marras, W.S. (2008). The Working Back, a Systems View. John Wiley & Sons, Inc., New Jersey.

Marras, W.S., Lavender, S.A., Leurgans, S.E., Rajulu, S.L., Allread, W.G., Fathallah, F.A., Ferguson, S.A. (1993). The Role of Dynamic Three-Dimensional Trunk Motion in Occupationally-Related Low Back Disorders. *SPINE, 18(5)*, 617-628.

Studnek, J.R., Crawford, J.M., & Fernandez, A.R. (2012). Evaluation of Occupational Injuries in an Urban Emergency Medical Services System Before and After Implementation of Electrically Powered Stretchers. *Applied Ergonomics, 43*, 198-202.