Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

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Ergonomics
Vol. 55, No. 11, November 2012, 1350–1361

A biomechanical and subjective assessment and comparison of three ambulance cot design configurations

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(*Received 25 July 2011; final version received 22 June 2012*)

Effects of ambulance cot design features (handle design and leg folding mechanism) were evaluated. Experienced ambulance workers performed tasks simulating loading and unloading a cot to and from an ambulance, and a cot raising task. Muscle activity, ratings of perceived exertion, and performance style were significantly affected by cot condition ($p < 0.05$). Erector Spinae activity was significantly less when using Cot-2's stretcher-style handles. Shoulder muscle activity was significantly less when using Cot-2's loop handle. During loading and unloading, operators allowed the cot to support its own weight most often with Cot-2's stretcher-style handles. Preference for Cot-2 (either handles) over Cot-1 (with loop handle) was consistent across tasks. Handle effects were influenced by operator stature; taller participants received more benefit from Cot-2's stretcher-style handles; shoulder muscles' demands were greater for shorter participants due to handle location. Providing handle options and automatic leg folding/unfolding operation can reduce cot operator's effort and physical strain.

Practitioner Summary: Paramedics frequently incur musculoskeletal injuries associated with patient-handling tasks. A controlled experiment was conducted to assess effects of ambulance cot design features on physical stress of operators, as seen through muscle activity and operator's perceptions. Differences between cots were found, signalling that intentional design can reduce operator's physical stress.

Keywords: musculoskeletal injury; EMS; paramedic; occupational injury; engineering control; patient handling

1. Introduction

Emergency Medical Service (EMS) workers are exposed to a variety of occupational risk factors that can lead to injury or even death. Sprains and strains are the most common types of injuries leading to visits to emergency departments and lost time from work for these workers (Maguire *et al*. 2005, Reichard and Jackson 2010). In the United States in 2010, non-fatal injury rates for Emergency Medical Technicians (EMTs) working in the private sector or local government were 452 and 377, respectively, per 10,000 workers (BLS 2010; Tables R98 and L98). Fifty to sixty per cent of these injuries were attributed to overexertion, with 64 to 76% of these classified as overexertion due to lifting (BLS 2010; Tables R12 and L12). In both areas, about 40% of the injuries involved the back, while 20% were about equally divided between shoulders and the upper extremity (BLS 2010; Tables R10 and L10). As is the case with hospital personnel, these types of injuries often occur while performing patient-handling tasks.

Researchers have begun to investigate ways to reduce the occurrence of these injuries. One approach is to attempt to improve the physical capacity of EMS workers (Aasa *et al*. 2008). An alternative approach is to attempt to reduce the physical stress imposed by various patient-handling tasks on EMS workers (Lavender *et al*. 2007a, 2007b, 2007c). Studies by Lavender and colleagues have shown that different tools for lateral transfers, e.g. slideboards and lifting straps, and tools for transporting patients down stairs, e.g. devices that can be rolled or slidden down stairs, directly affect EMS workers' muscle activity and their subjective ratings of perceived exertion. In general, devices that promoted sliding of patients as opposed to lifting during lateral transfers and devices that rolled down stairs on tracks or tri-wheel configurations reduced electromyographic activity of the back muscles. Other studies of patient-handling equipment, e.g. lifts used to transfer patients from a bed to a wheelchair, show that the design of such equipment has an effect on joint loading of patient handlers (Garg *et al*. 1991a, 1991b). The goal of introducing these interventions is to reduce the injury risk factor exposure and thereby reduce rates of injuries experienced by workers who perform patient-handling tasks.

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ISSN 0014-0139 print/ISSN 1366-5847 online

http://dx.doi.org/10.1080/00140139.2012.706715
http://www.tandfonline.com

The objective of the current study was to examine the effect of ambulance cot design, specifically the leg folding mechanism and handle design and location, on the physical stresses imposed on EMS workers when they perform three common, physically demanding tasks: loading a cot into an ambulance, unloading a cot from an ambulance, and raising a cot from the legs-folded state to legs-extended state. These tasks have been investigated in prior studies of ambulance cots, in part due to work published by Furber *et al.* (1997) who found that pushing a cot into an ambulance ranked third and raising a cot ranked fourth of all patient-handling tasks associated with injuries to ambulance workers in a two-year study of workers' compensation claims data. Kluth and Stasser (2006) explained the benefit of shorter cot lifting and support time that results if the front and rear parts of the undercarriage retract independently during loading and unloading tasks. The two cots evaluated in this study (model M-1, Stryker, Kalamazoo, MI, USA and model Mondial, Ferno-Washington, Wilmington, OH, USA) both have independent front and rear retraction, which enables them to be loaded into and removed from an ambulance by one operator. The principle differences between the cots, that are expected to affect the physical stress on operators, are listed in Table 1.

Two primary hypotheses were examined in the study:

Hypothesis 1: The two-handle-options cot (Cot-2) will require less muscle activity and elicit lower ratings of perceived exertion in comparison to the one-handle-option cot (Cot-1), because of the mechanical design features that are described in Table 1.

Hypothesis 2: There will be differences in both objective and subjective measures as a result of handling the two-handle-options cot with the two different styles of handles; results may differ between participants of different stature because handle design is confounded with handle height.

Table 1. Design elements that differ between the cots in this study and effects on cot operation.

	One-handle-option cot (Cot-1 – Stryker M-1)	Two-handle-options cot (Cot-2 – Ferno Washington Mondial)
Design features		
Leg folding/unfolding control mechanism	Release button and levers on handle are pressed and held when folding or unfolding legs; slight lifting of the rear end of the cot is required in order to release the rear legs.	Ratchet mechanism precludes the need for manually operated release latches
Support wheels	Support wheels are provided on one front and aft axle. The front wheels make contact with the ambulance bed during loading and unloading.	Support wheels are provided on three axles, one front, one aft, and one about 1/3 of the cot's length from the front.
Handle design	One-handle-option: Straight horizontal handles, oriented perpendicular to the long axis of the cot and located about 10 cm below the patient support surface; button and lever controls are located between the two handles, and are operated by the thumb and index fingers, respectively	Two-handle-options: (1) a horizontal continuous loop handle (straight in the centre and curved at both ends), oriented perpendicular to the long axis of the cot and located about 13 cm below the patient support surface; (2) stretcher-style horizontal pull-out handles, oriented parallel to the long axis of the cot and located at the level of the patient support surface
Design effects		
	Handle must be grasped with hands/forearms pronated, which reduces effectiveness of biceps muscles; combination and timing of button and lever activation increases task complexity; lever activation requires use of the index finger, so the hand force for grasping the handle is supplied by the other digits	Hands/forearms are supinated or in neutral position, facilitating recruitment of biceps; wheels on additional axle support 1/3 of the load, reducing stress on operator during part of loading and unloading operations; cot operation is simplified; all fingers can be used to grasp the handle; option for load moment to be reduced through use of stretcher-style handles

2. Methods

2.1. Experimental design

A within-subject experimental design was used to investigate two different cot operation mechanisms used for deploying and retracting the wheels. The leg folding mechanism of Cot-1 required manual activation of release buttons and a lever that were built into the handle, and as such, the design supported only one method for gripping the handle, which was with forearms and hands pronated. Cot-2, due to a self-ratcheting leg-folding design, did not require manual activation. This allowed operators to grasp either a loop handle or a telescoping pair of pull-out, stretcher-style handles when moving the cot. In total, there were three levels of the independent variable, cot condition: Cot-1 (C1), Cot-2 with loop handle (C2L), and Cot-2 with pull-out handles (C2P).

A repeated measures design was used, in which all participants were asked to perform three tasks (loading, unloading, and raising) three times. The sequences of loading and unloading tasks and cot raising tasks were counter-balanced across participants to control for carry-over effects.

Dependent measures included muscle activity, task performance style, and subjective perceptions. Median and peak (50th and 90th-percentile) normalised electromyographic (EMG) statistics were calculated from EMG activity collected at six muscle sites, five of which were located on the right side of the body: forearm flexor group, biceps, middle-deltoid, descending trapezius, and erector spinae (bilateral at the level of L4). These muscle sites were selected in order to assess the relative physical demands of the cot configurations at common sites of injury (back, shoulders, upper extremity). Median and 90th percentile values were use to capture average level of activity and to capture peak demands on the muscle during these dynamic tasks.

Performance was assessed in terms of task duration and style. Style was assessed to capture the extent to which the operator allowed the cot's legs and wheels to support the weight of the cot or, conversely, the extent to which the operator supported the cot while loading and unloading. Subjective ratings of perceived exertion (RPE) were assessed for each trial using the Borg CR-10 scale (Borg 1998), and information on preferences was solicited via questionnaire at the end of the testing session.

2.2. Participants

Fifteen people, 11 males and 4 females, who had at least Basic Certification in EMS work and who were currently working full-time or part-time, on a paid or volunteer basis, as an EMS worker, were recruited into the study. They were screened to ensure that they were experienced in performing cot-handling tasks and were free of any history of musculoskeletal disorders or prior injury that could affect the way they performed the tasks of interest. The screening process confirmed that they had at least three months experience if they were employed full time or at least six months experience if employed part time. Demographic and anthropometric information is provided in Table 2.

2.3. Testing protocol

The protocol was approved by the university's Institutional Review Board. Informed consent was obtained and documented for each participant upon arrival at the testing facility. The participant was then introduced to each cot via an instructional video recording, prepared by the respective cot's manufacturer, followed by practice time with

Table 2. Participant demographic and anthropometric summary information.

	Total sample	Males	Females
N	15	11	4
Age, mean (sd)	32.0 (5.8)	29.6 (4.1)	38.5 (4.8)
Weight, kg	83.7 (20.8)	92.4 (16.9)	59.8 (5.0)
Stature, cm	178.0 (10.4)	182.5 (8.3)	165.8 (1.5)
Shoulder height, cm	147.7 (9.2)	151.4 (7.7)	137.5 (3.1)
Elbow height, cm	110.6 (6.7)	112.9 (6.2)	104.3 (2.9)
Certification	2 basic 3 intermediate 10 paramedic	2 basic 3 intermediate 6 paramedic	4 paramedic
Years as EMS worker	8.7 (7.1)	6.6 (6.1) range: 0.5 to 20 yrs	14.3 (7.5) range 4 to 22 yrs

each task. Practice was continued until each participant was able to load and unload the cot smoothly. Typically, the practice period lasted 10 to 15 min. The order of introduction to the cots was alternated between participants. After a participant demonstrated that he/she was comfortable and effective at performing the tasks with the first cot, introduction and practice was provided for the other cot. The cots were always referred to by colour rather than manufacturer or model name, because the focus of the study was the design characteristics and not the brand.

Following the training, anthropometric data were collected per recommended methods (Pheasant 1988) using an anthropometer (model 101, GPM, Switzerland). Next, electrode sites were located via palpation and measurement. The electrodes for the forearm flexor group were positioned one-third of the distance on a line from the elbow joint (medial epicondyle) to distal palmar wrist crease; biceps and deltoid electrodes were positioned per Soderberg (1991); trapezius electrodes were positioned per Jensen *et al*. (1993); erector spinae electrodes were positioned per Mirka and Marras (1993). Sites were prepared by shaving and then cleaning with isopropyl alcohol, electrodes were placed over the muscles of interest, and participants performed a series of brief maximum isometric voluntary exertions (MVE) designed to elicit maximum muscle activity from individual muscle groups. Electromyographic data collected during the cot task trials were normalised to the maximum value obtained for each muscle across the two maximum exertions. The following isometric exertions were performed to elicit maximum muscle activity from the muscles of interest: maximum grip force for forearm flexor group, elbow flexion with the elbow flexed 100 deg. for biceps, shoulder abduction with shoulder abducted 45 deg for deltoid, shoulder shrug for trapezius, and back extension with trunk flexed 25 deg. for erector spinae. These exertions were temporally separated by 2-min rest periods. For each muscle, the exertion that elicited the largest processed EMG value was used to normalise the trial data for the given muscle.

To ensure that the participant did not become fatigued, the cot-related tasks were performed with 1 min of rest between trials. A 5-min sitting break was given between the sequences of loading and unloading tasks and cot raising tasks. Total time required of each participant was about 2.5 h.

The tasks the participants performed in the study were similar to or less stressful than those they encounter in their EMT work. Each cot weighed 55 kg (540 N). The load on each cot was 45 kg (441 N) for male participants and 22.7 kg (220 N) for female participants. This reduced load was considered necessary to reduce the risk of injury to the participants, given that they were performing several repetitions of each task with each cot condition within a relatively short period of time. The weight difference is supported by results from a study that assessed strength relative to lean body mass in male (1.26) and female (0.99) firefighters (Boyce *et al*. 2008). The female group's average strength relative to lean body mass was 78% of the male group's value. The ratio of the loads for females and males in the current study was similar (0.78) when considering the weight of the cot and the added respective loads. An ambulance was not used in the current study; instead participants loaded and unloaded the cots onto a simulated ambulance; the height and surface characteristics matched those of ambulances with which these cots are used.

2.4. Data collection and processing

Electromyographic data were collected at 1200 Hz, using a multi-channel EMG system (Bagnoli-8 with single differential surface electrodes, Delsys, Boston, MA, USA) and a Motion Monitor data acquisition system (Innsport, Chicago, IL, USA). The data were notch filtered at multiples of 60 Hz, up to 360 Hz. The data were further processed through a custom MATLAB programme that filtered (20 Hz high pass, 500 Hz low pass, and 4th order Butterworth filter) and processed the data through a 75 ms moving average window, and applied a Hanning filter. The data for each muscle were then normalised to its maximum value (from the MVE trials). Fiftieth and 90th percentile statistics were determined for each muscle, for the time period of interest within each task. The period of interest for the loading task began when the front legs touched the simulated ambulance and concluded the moment the entire cot was on the ambulance bed. For the unloading task, the period of interest began when the participant started to pull the cot and ended when the rear wheels (those closest to the participant) touched the ground. For the raising task, the time period of interest began when the coordination countdown ('1..2..3') given by the researcher reached '3'; this signalled the point when the participant (at foot of the cot) and researcher (at head of the cot) would together begin to perform the two-person task of raising the cot by simultaneously lifting their respective ends of the cot. The period ended when the cot's legs were fully extended and the wheels contacted the floor. For each task, these were the periods during which the operator was required to exert the most effort. Each time period was defined by a series of event markers recorded in each EMG data file.

For the loading and unloading tasks, video recordings were examined in order to evaluate and categorise performance style, which was based on the extent to which the participant let the cot support its own weight during a task. A rating of '1' was given when a participant made full use of the wheels to support the cot, rather than lifting the cot early (in loading) or supporting it during unloading. Trials in which participants supported the cot were rated '0' and those in which the participant allowed the cot to support the weight for some portion of the trial (but not as long as they could have) were rated '0.5'. Associations between cot condition and performance style were examined, as well as performance style and RPE; RPE were collected from participants after each task repetition.

2.5. Statistical analysis

The three tasks were analysed separately. ANOVA procedures were used to examine the effects of cot condition on muscle activity and the RPE scores across the three repetitions (using Proc Mixed in SAS, Cary, NC, USA). Cot condition was treated as a fixed factor; participant was treated as a random factor. Pairwise comparisons of cot conditions were conducted with the Tukey–Kramer post-hoc test. Initial family-wise assessment was conducted via the MANOVA option in the SAS GLM procedure.

3. Results

3.1. Loading task

MANOVA tests were significant ($p < 0.001$ for Wilk's Lamda, Pillai's Trace, and Hotelling–Lawley Trace). Figure 1a and b shows the EMG results for the 50th and 90th percentile analyses, respectively. Post-hoc tests results for both variables are provided in the figures. When loading, there were significant effects of cot condition in the 50th and 90th percentile EMG values for the forearm flexors, deltoid, trapezius, and erector spinae muscles; for 50th percentile biceps as well. All univariate p-values were less than 0.005. With the exception of the biceps muscle, for which there was no effect of cot condition, 90th percentile muscle activity values were lower for at least one of the handle conditions of Cot-2 in comparison with Cot-1. Forearm flexor muscle activity was lower with both Cot-2 handles. Erector spinae activity was lowest with the pull-out handles of Cot-2. Shoulder muscle activity (deltoid and trapezius) was lowest with the traditional loop handles of Cot-2. One exception to the pattern of similar outcomes for the 50th and 90th percentile statistics was the 50th percentile bicep activity, which was lower for Cot-1 than either Cot-2 condition.

Perceived exertion ratings during loading were lowest for Cot-2 with the traditional loop handles (RPE = 3.5, s.e. = 0.43), followed by Cot-2 with the pullout handles (RPE = 3.9, s.e. = 0.43), and Cot-1 (RPE = 4.8, s.e. = 0.43). While overall the ANOVA showed a significant effect of cot condition ($F = 4.96$, $p = 0.014$), the post-hoc tests only identified a significant difference between ratings for Cot-2 loop handle and Cot-1 (Tukey–Kramer Adj $p = 0.0149$).

As for performance measures, the duration of the loading was about 1.2 s shorter for Cot-2, with either handle configuration, than that measured for Cot-1 ($p < 0.0001$). Performance style, which indicates effectively when participants used the wheels to support the weight of the cot, was different across the three cot conditions when loading (Table 3). For Cot-1, 42% of the trials were performed with participants supporting the weight of the cot when the cot could have supported the weight (= rating of '0'); percentages for use of that performance style with Cot-2 were 29% for the loop handles (C2L) and only 2% for the pull-out handles (C2P). In comparison, for the pull-out handle condition (C2P), 83% of the trials with the pull-out handles of Cot-2 were performed with the cot fully supporting itself (= rating of '1'). For the traditional loop handles on Cot-2 (C2L), the largest percentage of trials were rated as '1' (48%), while the majority of trials were rated as fully or partially using the wheels (71%).

3.2. Unloading task

MANOVA tests were significant ($p < 0.001$ for Wilk's Lamda, Pillai's Trace, and Hotelling–Lawley Trace). All of the muscles showed significant effects of cot condition during unloading (Figure 2); all univariate p-values were less than 0.005 with the exception of p-value for 90th percentile biceps which was 0.0056. Similar to the loading operation, the forearm flexor, deltoid, trapezius and erector spinae muscle activity was less with at least one of the handle conditions of Cot-2 when compared with Cot-1. Similar to the loading task, activity of the forearm flexor muscle group was lower with Cot-2, for both handles. Relative to the activity levels seen with Cot-1, erector spinae activity was significantly reduced when using the pull-out handles on Cot-2. The loop handles on Cot-2 significantly reduced the shoulder muscle (deltoid and trapezius) activity. As with the loading task, the biceps muscle activity was the exception to this pattern. The bicep activity statistics were lowest for Cot-1, though for the 90th percentile statistics Cot-1 and the pull-out handles of Cot-2 were not significantly different.

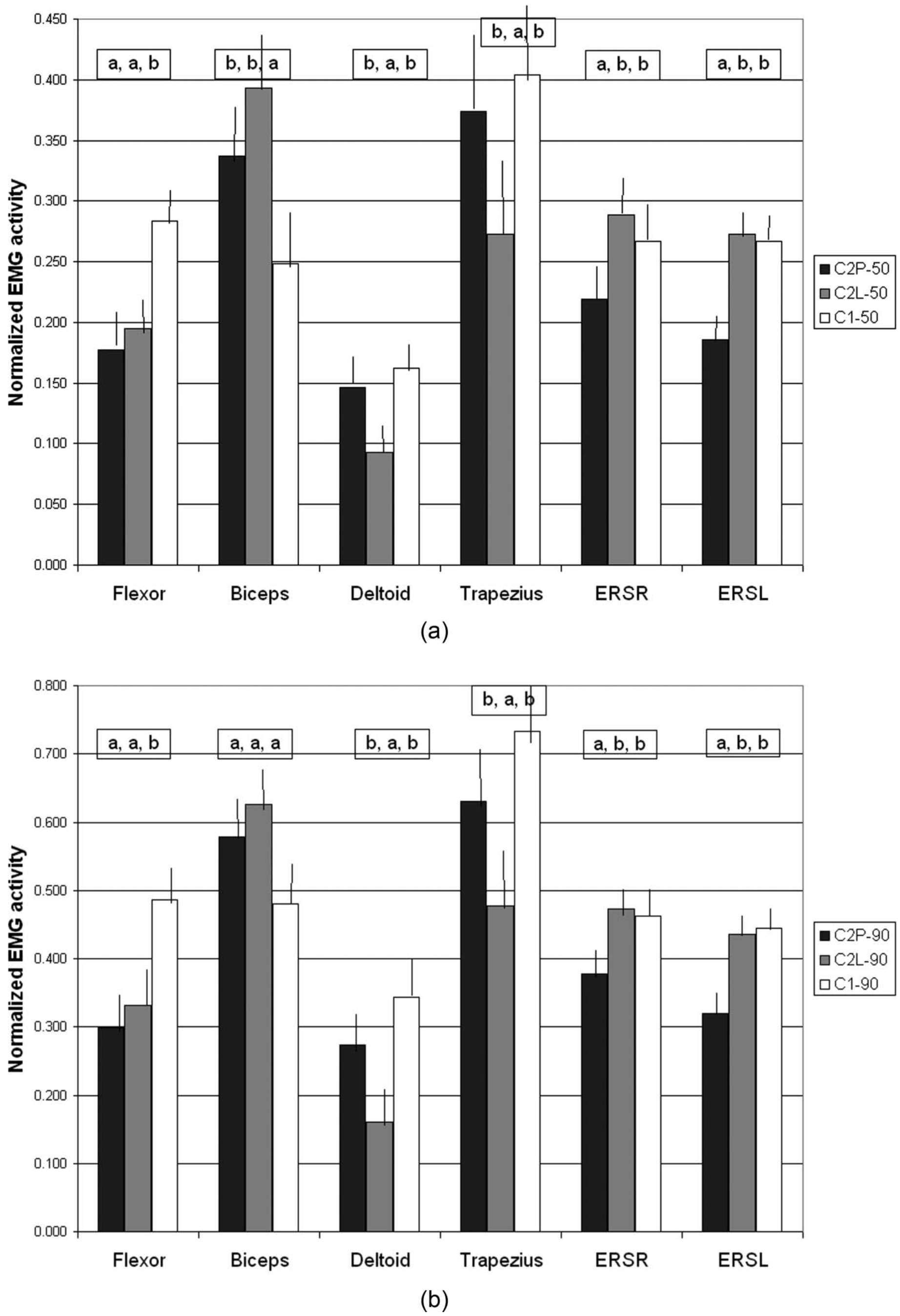

Figure 1. 50th percentile (a) and 90th percentile (b) normalised EMG results for the loading task. For each muscle, no significant differences were found between conditions with the same letter.

When unloading the cots, there were no significant differences in the perceived exertion ratings or task duration. The performance style assessment (Table 3) indicated that the participants most effectively used the cot wheels when unloading Cot-2 with the pull-out handles (used the wheels 88% of the time), followed by unloading Cot-2 with the loop handles (used the wheels 65% of the time) and unloading Cot-1 (used the wheels only 49% of the time).

3.3. Raising task

MANOVA tests were significant ($p < 0.001$ for Wilk's Lamda, Pillai's Trace, and Hotelling-Lawley Trace). When raising the cots from the travel position to the loading level, the 90th percentile EMG analysis indicated that the

Table 3. Performance style categorization frequency counts by cot condition for loading and unloading tasks.

	Performance style score*		
	0	0.5	1
Loading			
C2P	1	6	35
C2L	12	10	20
C1	18	4	21
Total	*31*	*20*	*76*
Unloading			
C2P	0	5	39
C2L	9	7	30
C1	16	7	22
Total	*25*	*19*	*91*

Note: Loading: Chi-Square (DF = 4): 22.73, $p = 0.0001$; Unloading: Chi-Square (DF = 4): 20.84, $p = 0.0003$. *"1" = full use of wheels to support the cot; '0.5' = some use of wheels to support the cot; '0' = operator supported the cot instead of allowing the wheels to support the cot.

erector spinae muscles showed the lowest activation levels when using the pull-out handles on Cot-2 (Figure 3). However, use of the pull-out handles with Cot-2 elicited significantly higher activation of the deltoid muscle, which showed the least activation with the Cot-2 loop handles. Cot condition had no effect on the 90th percentile trapezius activity statistic, but 50th percentile activity was lower with the Cot-2 loop handle condition. Similar to the loading and unloading tasks, the 90th percentile activation of the forearm flexor group was less with Cot-2, while the activation of the biceps was lower when using Cot-1. All significant tests had p-values less than 0.005.

While there were no differences in perceived exertion ratings when raising the cots, there were differences in the task duration measures. The time to perform the task was about 0.5 s longer for Cot-1 ($p < 0.0001$).

4. Discussion

To summarise the findings from the muscle activity data, in general Cot-1 tended to elicit higher levels of muscle activity for the load and unload tasks, compared with Cot 2. Forearm flexor muscle activity was higher with Cot-1 due to the lever operation requirement. As for Cot-2, on average, muscle activity tended to be lower for the back muscles and higher for the shoulder muscles when participants used the pull-out handles in comparison with the loop handle. With Cot-1, the biceps activation was reduced in all tasks, because the hands and forearms were pronated, thereby placing the biceps at a mechanical disadvantage.

The practical benefit of the Cot-2 pull-out handles for the raise task, as also noted by Kluth and Strasser (2006), is that the moment arm of the load is reduced because the hands are positioned closer to the side of the operator, rather than being positioned in front, as is the case for the loop handle on Cot-2 and the handle on Cot-1. This biomechanical benefit of reducing the moment arm is consistent with prior findings (Schultz *et al.* 1982; Seroussi and Pope 1987; Schipplien *et al.* 1995) and NIOSH recommendations (Waters *et al.* 1993). In the current study, median and peak erector spinae activity levels for the loading and unloading tasks were about 20% less when using the pull-out handles than the next best cot handle option. Kluth and Strasser (2006) did not find any effect on erector spinae muscle activity during loading and unloading in a comparison of three roll-in cot systems, all of which required grasping a loop-style handle in front of the operator in order to operate manually-operated leg release levers or buttons. Based on their analysis of ramp, tail-lift, and easi-loader (roll-in) cot systems, Cooper and Ghassemieh (2007) recommended against the roll-in style, because they found higher handle loads and estimated higher spinal loading with the roll-in model used to represent that system. Results from the current study revealed differences in muscle activity, which is related to spinal loading, showing that design features can be incorporated that would reduce the physical stress experienced by operators when using this type of system. Roll-in systems have some workflow advantages, though (e.g. faster loading and unloading time than a ramp and winch system, and smaller footprint than a ramp or tail-lift systems), which will continue to make them appealing to ambulance operators. Therefore, efforts to improve the cot design to reduce the physical effort required during operation of roll-in systems should be encouraged.

Based on observations and conversations with the participants, the pull-out handles seemed to offer more of an advantage to taller participants in each of the tasks. The pull-out handles are located about 13 cm higher than the loop handles, which places them in a somewhat awkward location for shorter participants, forcing them to elevate,

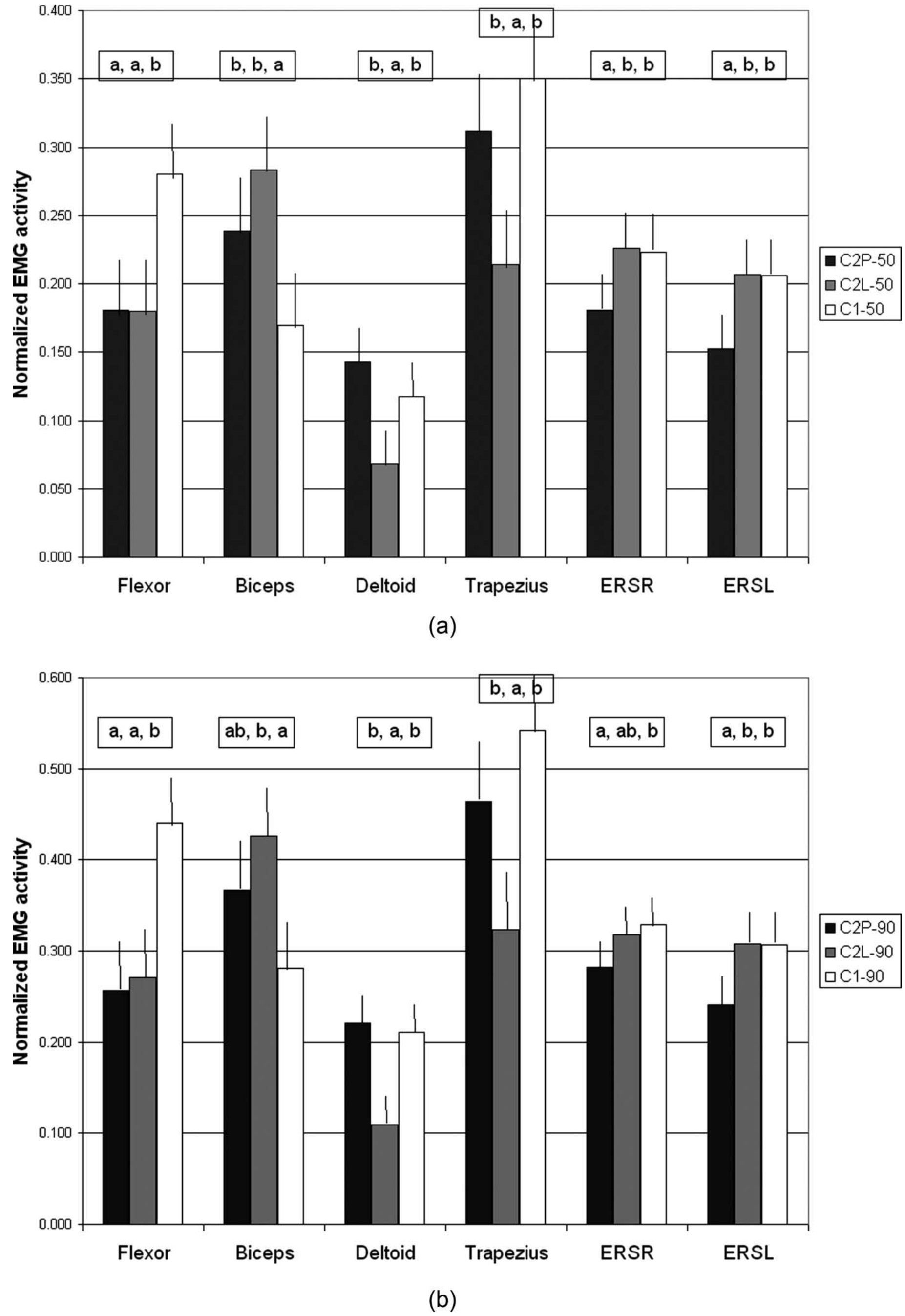

Figure 2. 50th percentile (a) and 90th percentile (b) normalised EMG results for the unloading task. For each muscle, no significant differences were found between conditions with the same letter.

extend, and/or abduct their shoulders more when using the pull-out handles in each task. Conversely, with the loop handle on Cot-2, elbow posture was more relaxed and hands better positioned for the biceps to contribute to the task. An illustration of this is provided in Figure 4. Given the limited sample size, an exploratory statistical analysis was conducted to assess whether a height grouping factor would significantly account for the variability observed in the shoulder muscle activity. This analysis suggested that C2P and C2L shoulder muscle use tended not to differ for the taller participants, while shoulder muscle activity tended to be higher for C2P and lower for C2L in the shorter participants.

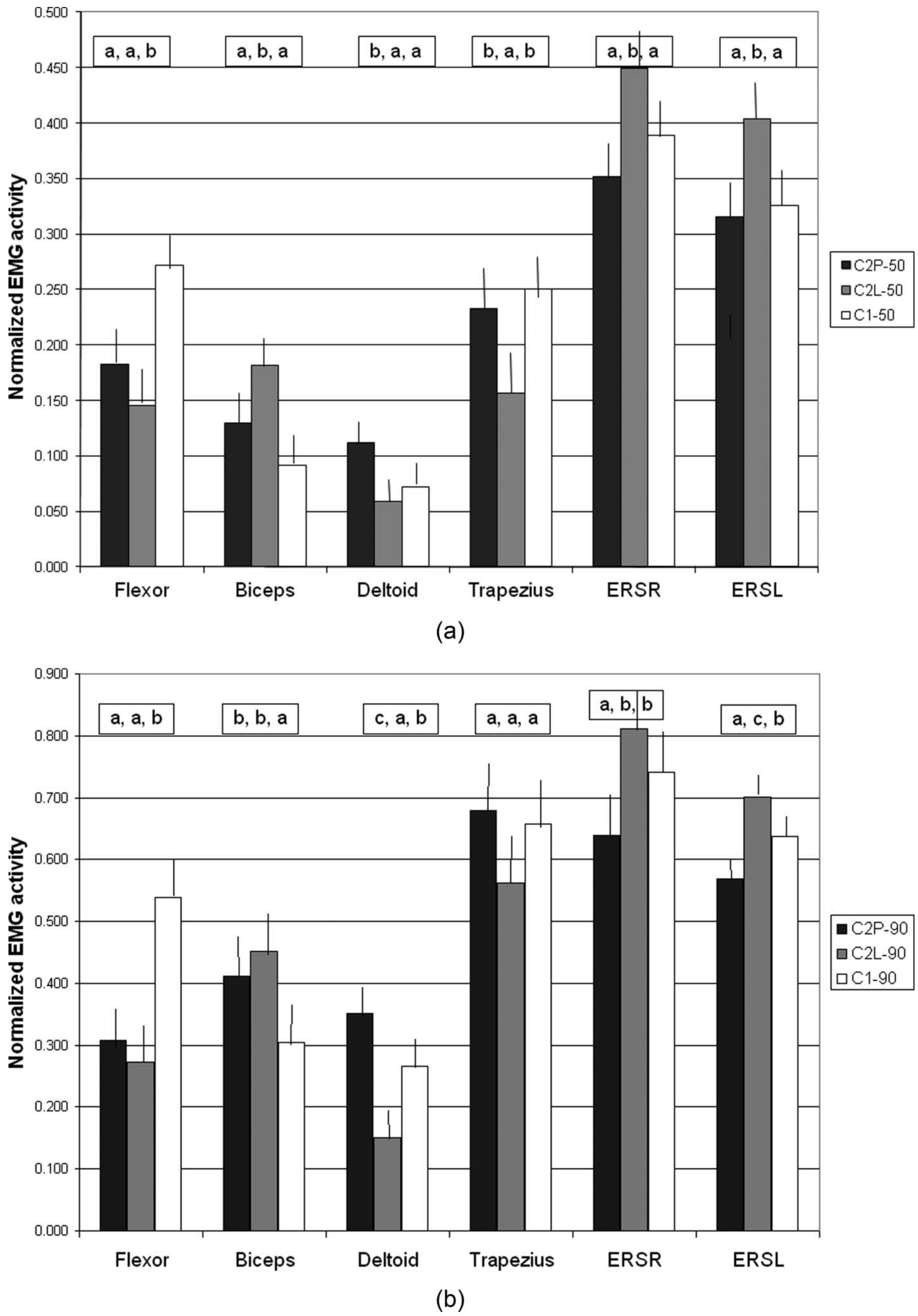

Figure 3. 50th percentile (a) and 90th percentile (b) normalised EMG results for the raising task. For each muscle, no significant differences were found between conditions with the same letter.

Once participants completed all of the trials, they were asked which cot condition they preferred most and least for each task. These preference ratings consistently showed an overall preference for Cot-2 over Cot-1, but there were no significant differences between the two different handle styles for Cot-2 (Friedman's test *p*-values: $p < 0.0001$ for load and unload, $p = 0.0128$ for raise). Participants were also asked 'If you were asked to recommend either of the two non-powered cots that you used today, would you recommend either of them, or would you recommend another cot?' Seventy-three per cent specifically responded that it would be Cot-2, while 26% would recommend a different cot from either of the two in the study. Explanations were based either on features they liked about Cot-2 or another cot, or problems they identified with Cot-1. Several commented about

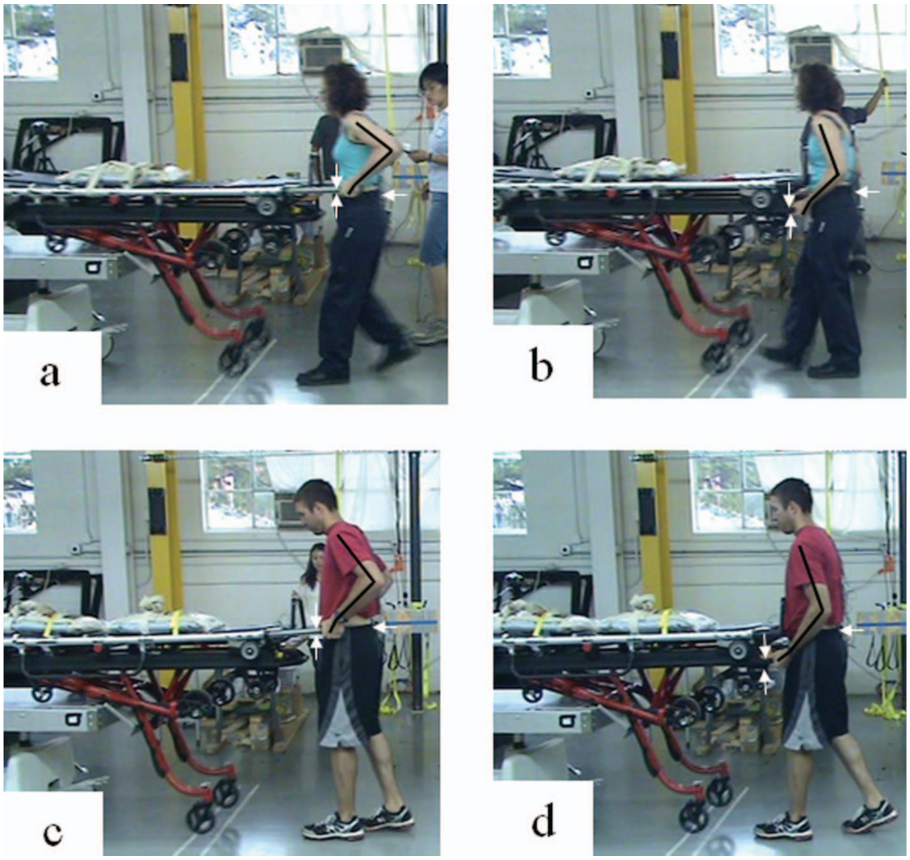

Figure 4. Representative examples of shoulder and arm postures of shorter (167 cm; a & b) and taller (190 cm; c & d) participant using pull-out handles (a & c) and loop handles (b & d) while unloading Cot-2. Note more pronounced shoulder extension and elbow flexion in a v. c, a v. b, and c v. d. Paired arrows mark handle location relative to L3 marked by horizontal arrow.

their dislike of the overhand (pronated) grip required with Cot-1 and the required button and lever operation. Conversely, they reported liking the ease of use of Cot-2.

There were several limitations to the study, and the results should be evaluated in light of the limitations. First, the study was conducted with a small number of participants, though they were all highly experienced EMS workers and the sample was sufficiently large to identify statistical differences between the test conditions. Additionally, the sample included both males and females and represented a wide range of stature. For the 11 male participants, stature ranged from 18th to 99th percentile for US males (Pheasant 1988), and for the four females the range was from 59th to 76th percentile for US females. The small number of female subjects is a limitation of the study. Results from the current study suggest that further investigation of the interaction of cot design elements and subject anthropometry is warranted.

Second, the amount of time to practice with each cot was limited. For each cot, participants were shown an instructional video and were then given repeated opportunities to practice with the cots, though none of the participants had prior experience with either of the cots used in the study. Emergency Medical Service workers told us it may take a few weeks to become highly proficient with a new piece of equipment. That said, if participants had pronounced difficulty during a particular trial, that trial was re-run. This occurred rarely and only for a few participants. The performances in the study should be considered representative of experienced EMS workers using equipment that is new to them.

Third, this study was conducted in a controlled laboratory setting. The ground surface and other environmental factors, as well as psychosocial factors, were not what is experienced in an EMS run. During a real run, muscle activity will likely be elevated beyond the levels seen in this study, due to stress (Marras *et al.* 2000) and also likely due to faster movements of the EMTs (Kluth and Strasser 2006). All but two participants wore their regular work footware, which contributed to the face validity to the study.

Fourth, the loads on the cots were different from what would be experienced on an actual run. Due to safety concerns, because of the number of repetitions of each task that were performed during the study, the weight on the cot was limited to 223 N for female participants and 445 N for males. This is lower than the weight of most patients and does not account for medical kits, oxygen tanks, and other pieces of equipment that typically add to the weight of a cot. A follow-up study involving load weights that are representative of typical adult patients should be conducted to determine if the differences in cots persist with heavier loads.

In spite of these limitations, the fact that an anthropometrically diverse sample of experienced male and female EMS workers participated in the study is a major strength of the design. The experiment employed a within-subject design that facilitates comparisons between the three cot conditions; statistically significant differences were found between cot conditions. Further, multiple methods of assessments were utilised, including both objective and subjective; this methodological triangulation is recommended by Wilson (1995). There was a great deal of consistency amongst the different types of measures, which makes conclusions about the cot conditions more robust.

5. Conclusions

This study showed that cot design had significant effects on a sample of 15 experienced EMS workers, including effects on muscle activity and subjective perceptions. The electromyographic results, in combination with the subjective measures, suggest that Cot-2, the cot that provided two types of handle options, a third axle of support wheels, and a ratchet mechanism that precluded the need for manually operating latches to allow the cot's legs to fold and unfold, offered some advantages over Cot-1, with respect to lower back, shoulder, and forearm muscle activity. There was some variability in these results that seems in part associated with participant stature and performance style that may be worthy of further investigation.

Acknowledgement

The authors wish to thank Ferno-Washington, Inc. for their support of this study, including providing access to ambulance cots and the simulated ambulance bed used in this study.

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