EVALUATION OF THE DESIGN AND PERFORMACE OF LOADING AND UNLOADING SYSTEMS USING AMBULANCE STRETCHERS

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Abstract: The aim of the research is to carry out a detailed analysis of the loads applied by the ambulance workers when loading/unloading the stretchers. The research follows its aim of evaluation of the performance of the loading and unloading systems through both experimental and mathematical techniques. The forces required of the ambulance workers for each system are measured. The process of loading and unloading is video recorded for all the systems. Kinematic analysis of each stretcher loading system is performed. Input data and various parameters required for the kinematic analysis are extracted from the video records. The task of loading and unloading is divided into several sub-tasks and analyzed to simulate the movements. Comparison of the kinematic analysis and measurements shows very close agreement for most of the cases. Safe working limits are chosen and compared with the measured values. The critical tasks of each ambulance worker for each system are identified.

Introduction

Accident and Emergency ambulances can be called to any location, at any time, to provide an emergency service to all types of clinical situations and events. Although some patients can be treated on site, most will need to be taken to a hospital for further investigation and/or treatment. Some patients are able to mobilize independently but many require transportation on a stretcher which has to be loaded into the ambulance at the call site and unloaded at the hospital. This process is performed by the ambulance workers and is known to cause a high incidence of back pain, resulting in early retirement due to musculoskeletal injuries. However, ambulance work is a very under-researched area of healthcare. The main causes of these injuries have never been investigated. This research looks at three existing stretcher loading systems (ramp/winch, easi-loader and tail lift) and evaluates the forces required of the ambulance workers to load and unload the stretchers and patients.

Figures 1-3 show the three types of stretchers and loading systems evaluated within this research. The loading/unloading systems are very different and exert varied loading requirements on the ambulance workers musculoskeletal system. We evaluate the differences in the performances of these three systems from the ambulance worker's perspective. This is evaluated by both experimental and analytical techniques. We also ascertain the risk of injury to the musculoskeletal system by comparison of measured forces with safe loading limits. The experimental part of the research has been carried out in three of the UK's Ambulance Trusts; East-Midlands Ambulance Service, Two-Shires Ambulance Service and East- Anglia Ambulance Service who collectively currently use vehicles with the three above mentioned stretcher loading systems.

Figure 1: Falcon 6 Stretcher (used for Ramp & Tail Lift)

Figure 2: Ramp and Tail Lift Loading Systems

Figure 3: Easi-Loader 35A Stretcher (Direct Loading into the Ambulance at Normal Height)

The systems studied are not the only types of stretchers and ambulance loading systems used by the Ambulance Trust; however they are widely used. Therefore it is anticipated that the results of this research can provide widely applicable guidelines to the ambulance trusts.

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Materials and Methods

We have followed the objectives of the research through both experimental and analytical methods. The methods are integrated at some points as the input data for the kinematic analysis is derived from the experiments. Finally the results obtained by these methods are compared to provide validation for the methods applied. A brief description of each technique used in the research is as follows:

Experimental

A) Force measurements

Measurement of forces that the ambulance workers applied to the stretchers for the loading/unloading operations is collected at three UK ambulance trusts. The loading/unloading operations were performed on flat concrete surfaces at the ambulance stations. It should be noted that the forces could be increased if the conditions were not as in the ideal test environment (inclines or rough surface/terrain).

Force measurement was achieved by using a load cell in the arrangement shown in figure 4. The signal cable was connected to a strain gauge indicator (full bridge) which was connected to a Pico-scope. This was then plugged into a laptop which produced voltage-time curves on software associated with the Pico-scope (voltage was proportional to force, converted via a calibration factor).

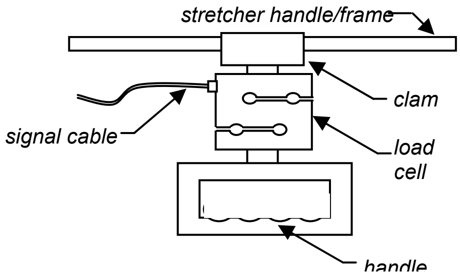

Figure 4: Load Cell Arrangement to Measure Force

B) Video recording

Two digital video cameras were set up perpendicular to each other (one aimed at the rear of the ambulance, the other aimed at the side of the ambulance). This enabled the stretcher motion to be recorded effectively (the ambulance obscured the view as the stretcher was loaded inside but the field of view the other camera could pick it up because it had a different viewing angle). Marker points of standard intervals were placed on the floor and around the test area to enable displacement-time information about the stretcher to be derived. The video of stretcher motion was analyzed and data points of stretcher displacement, front handle angle, back handle angle and stretcher angle with the surface were derived every second. This data is then used as input data for the kinematic analysis.

Kinematic analysis

Mathematical analysis, of the three systems is required to support the experimental measurements. Video observation has been used to identify the main phases of the loading and unloading tasks for each system. Synchronized video observation and force measurements results have been used to specify the crucial phases within the task. Kinematic analysis is performed for each phase of the loading and unloading of all three systems. The applied force by the ambulance workers is estimated for each phase.

The phases of motion considered for each system is as follows (reverse for unloading):-

Ramp and Winch

- Flat travel
- Mounting the ramp
- On the ramp
- Dismounting the ramp
- Flat travel

Easi-Loader

- Flat travel
- Engage wheels on ambulance floor
- Lift and raise undercarriage
- Push into ambulance

Tail Lift

- Flat travel (on ground)
- Encountering ramp (almost instantaneous)
- Front wheels on tail lift (assume flat travel)
- Rear wheels encounter ramp (almost instant.)
- On tail lift (assume flat travel)
- No force while raising tail lift
- On tail lift (assume flat travel)
- Flat travel (in ambulance)

The kinematic model results are compared with experimental results to show the reliability of the method. With the model validated, it can be used to derive optimization in the design and task performance.

Evaluation of the task load on the ambulance worker

Previous research by Snook and Ciriello [1, 2] suggest force limits for manual handling for pushing and pulling operations. The research makes load measurements from standard loading positions. Loading limits are measured based on personal perceptions of the test subjects of maximum exertion. The test subjects judged their own feelings of fatigue or exertion and changed the levels of force or size of the weights accordingly. The experimenter controlled the other task parameters which standardized loading conditions. The limits introduced by this method for pulling and pushing operations are reported in first column of table1.

Table 1: Pushing and Pulling Force Limits.

	Snook et al [1,2]	**BS EN 1005-3 [3]**
Pushing	243 N (110 N)*	200 N x 0.8^{+}
Pulling	247 N (113 N)*	145 N x 0.8^{+}

*Derived from standard data [1] using the following assumptions:-
Force limit safe for 75% of female population, Force applied at waist height Frequency every 30 minutes, Initial force not in brackets, sustained force in brackets assumes this can be interchanged for highest force. +Multiplied by a velocity factor because the pushing/pulling tasks involve movement.

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A second set of limits has been extracted from a report for the Health and Safety Executive [3]. This report reviews many different British Standards and quotes safe force limits for pushing and pulling from BS EN 1005-2 [4]. It looks at muscular strength limits and determines force limits for safe operation based on the population and task characteristics. The set limits of pulling and pushing obtained by this study is presented in second column of table 1.

Results & Discussion

Loadings exerted by ambulance worker 1 (AW1) and ambulance worker 2 (AW2) are described in this section (figure 5). Figure 6 (a-f) shows the results of the measurements and kinematic analysis.

Estimated forces from the kinematic analysis and recommended safe force limits are presented as well for all the systems (Apart from the ramp & winch figure 6 (c)). The forces measured and calculated for the three systems of loading and unloading is compared to the safe limits reported in table 1.

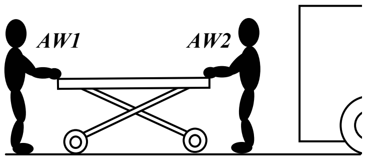


Figure 5. Definition of Ambulance Worker 1 & 2

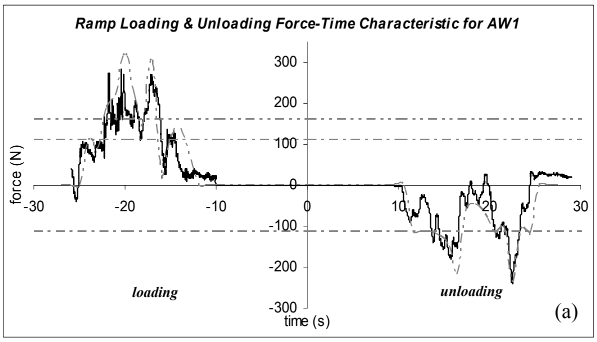


Figure 6(a): Ramp loading/unloading for AW1

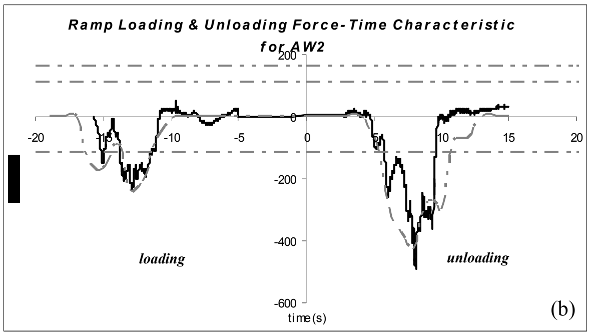


Figure 6(b) Ramp loading/unloading for AW2

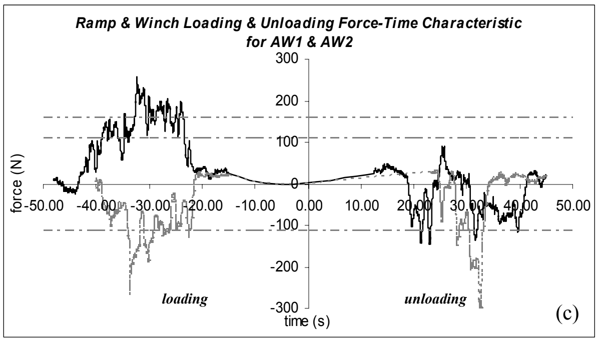


Figure 6(c): Ramp & Winch loading/unloading for AW1 and AW2

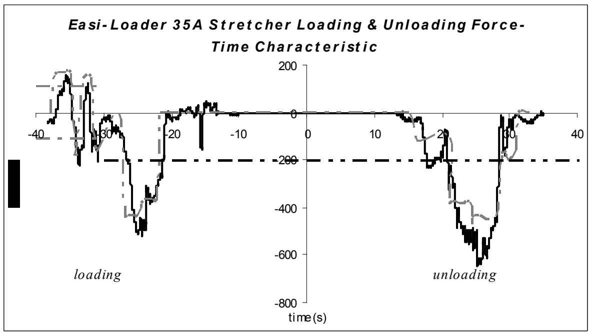


Figure 6(d) Easi-loader loading/unloading for AW1 (One worker applying force for this system)

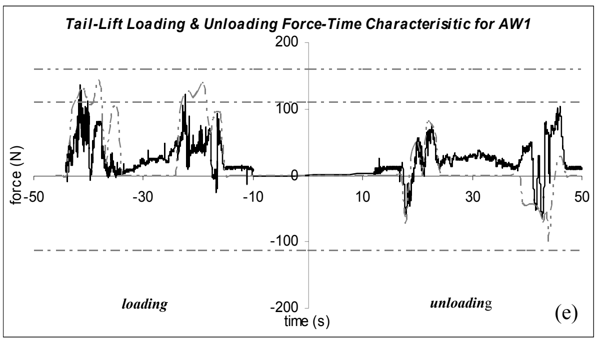


Figure 6(e) Tail-lift loading/unloading for AW1

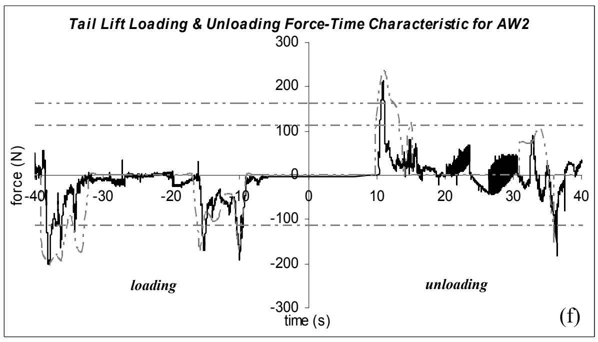


Figure 6(f) Tail-lift loading/unloading for AW2

Key ———	***Measured Data / (AW1 for Ramp & Winch 6 (c))***	—·—	***Safe Limits (Snook et al [1,2] Pushing, +ve & Pulling, -ve)***
- - - -	***Calculated Data/ (AW2 for Ramp & Winch 6(c))***	—··—	***Safe Limits (BSEN1005-2 [4] Pushing, +ve & Pulling, -ve)***
(a-c ramp loading, d easi-loader & e-f tail lift)		▬ · · ·	***Safe Limits (Snook[2] Carrying)***

Figure 6. Force-Time Characteristics for Ambulance Stretcher Loading-unloading Systems

Figure 6a and 6b shows the forces applied by AW1 and AW2 respectively when using the ramp loading system. During the loading operation AW1 applies greater force in comparison to the AW2 in ascending the ramp. The condition is reversed during stretcher unloading whilst AW2 exerts forces of around 400N to ensure that the stretcher and patient travel down the ramp in a controlled manner. For unloading AW1 mainly provides force during the flat travel phase of stretcher motion at the beginning and end of the stretcher's motion. Relatively little force is exerted by AW1 during ramp decent. The most critical task in the system seems to be descent of the stretcher controlled by AW2. The analytical results are in fair agreement with the experimental results.

Figure 6c shows the forces exerted by AW1 and AW2 when the ramp and winch is used. Loading/unloading forces are reduced considerably for both workers. However, the time of loading/unloading is increased significantly. This might not be acceptable for seriously injured patients when time is critical.

Figure 6d shows the force applied by a single ambulance worker when using the easi-loader stretcher system. Loading/unloading for the easi-loader stretcher is performed by only one ambulance worker. The stretcher is maneuvered so that one end rests in the ambulance the other end is supported by AW1 who lifts and pushes it to slide the stretcher into the ambulance (AW2 folds the stretcher undercarriage during the loading operation). The forces involve lifting in addition to pushing and pulling. Safe loading limits have been shown for carrying from Snook et al [1, 2] data on this graph (carrying loading limit 210N). The forces peak at around 600N for when the stretcher is lifted to facilitate folding the undercarriage. The kinematic model predicts the measurements very well (Kinematic analysis underestimate the peak lifting forces. This is mainly due to ignoring the vertical acceleration that occurs during lifting). Although the forces involved in this stretcher type were higher than the others it should be noted that the mode of loading (lifting not pushing/pulling) is different therefore is not directly comparable with the other measurements.

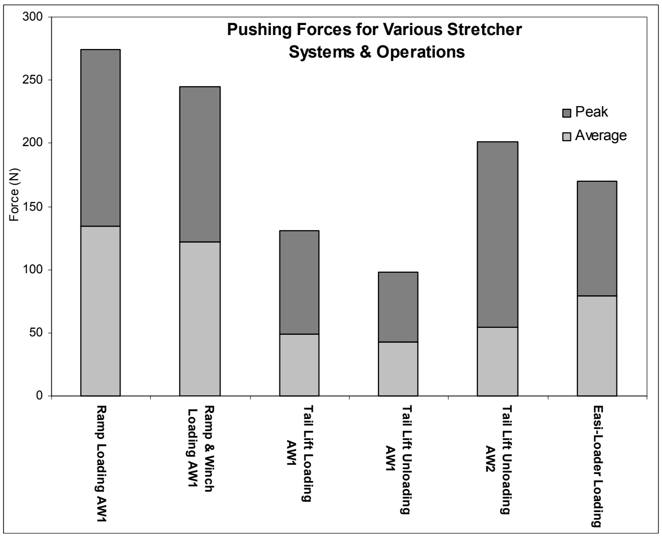
Figure 6e and 6f show the forces applied by AW1 and AW2 respectively for the tail lift operation. Forces are significantly less than that of the ramp loading system peaking at around 100N for AW1 and around 200N for AW2. It should be noted that the time for loading/unloading has approximately doubled compared to that for the ramp system. It can be concluded that when an element of the system is automated such as the case of using winch or tail-lift, the time of the task is increased whilst the requirement of the applied load is reduced.

The forces must be compared with the reference data from known safe loading levels to determine whether the loading on the ambulance workers is safe. Average and peak loading forces are shown in figure 7. In all cases the peak loading levels exceed the safe limits recommended by Snook et al [1, 2] (including carrying for the easi-loader stretcher). Loading levels recommended by BSEN1005-2 [4] are also exceeded by all the loading cases apart from AW1 using the tail-lift system. Even on the tail lift system AW2 exceeds the recommended safe loading levels for pulling. The easi-loader system involves a lifting operation. This is a different mode of loading compared to pushing and pulling applied to other systems. The safe limit data for lifting is different from pushing and pulling limits; therefore the easi-loader system is not included in figure 7.

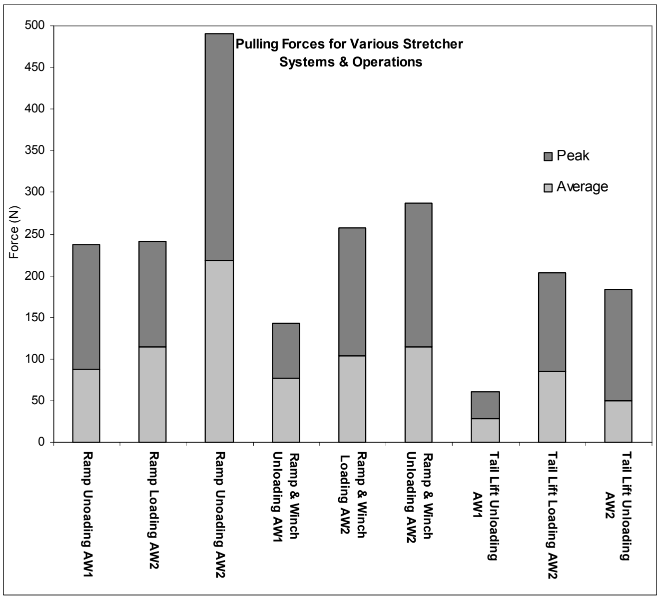
From the reference data available it can be concluded that ambulance workers are at risk when performing loading and unloading operations. AW2 must exert greater loading so it is anticipated that they are at greater risk of injury. Average loading levels are within the safe limits of both sets of reference data for most loading cases. Average loading levels exceed safe limits for the ramp loading system for AW1 when pushing to load the stretcher with and without the winch and for AW2 when unloading the stretcher without the winch.

BS1865 [5] for ambulance stretchers states that the maximum burden on any personnel during loading and unloading should not exceed half of the total weight of patient and stretcher. At the same time it is recommended that the time of exposure needs to be minimized. A preferred system requires optimal ergonomic position with reduced back bending posture. The measurements for the easi-loader system show that the peak force is around 630N for lifting. This is far beyond the recommendation of BSI explained above. Half the combined weight of the stretcher and the patient is 540N.

Comparison of the forces measured with the limits from the reference data is valid as a first estimation. However there are limitations to the application of the reference data for the evaluation of the three systems under study. The reference data set limits for cases where standard postures were used. This is not exactly the same posture as those adopted by the ambulance workers. Also the data has been generated from personal perception of maximum loading limits which may be very different from the force levels required to produce mechanical failure in the human musculoskeletal system. A better estimation of the limits could be achieved by adapting a known failure mechanism and a method to calculate or measure the force levels required for failure under similar conditions to that of stretcher loading/unloading. From past research [6] it has been observed that the most common injury sustained by ambulance workers is low back injury, Waters et al [7] state that failure of the L5/S1 disc is most common and will occur at compression force levels greater than 3.4kN. This could be used as the failure mode. Research by Chaffin et al [8, 9] has produced computational models to evaluate L5/S1 disc compression forces based on biomechanical principles. This suggests that further work should focus on estimating the failure criteria for back injury for specific loading cases of each of the three stretcher loading systems.



(a)



(b)

Figure 7: Average and Peak Loading on the Ambulance Workers for Various Stretcher Types and Operations
(a) Tasks involving pushing forces (b) tasks involving pulling forces

From the kinematic analysis it can be shown that there are a number of factors that could be used to reduce the forces associated with pushing/pulling the stretchers. Firstly if the stretcher mass is reduced the forces will be reduced proportionally. Reduced friction (wheel friction) will in some cases reduce the forces and in some case increase it. The force application angle has significant effect on the forces. (See figures 8, force application angles of less than 25° are suggested). This could be achieved by stretcher handle redesign.

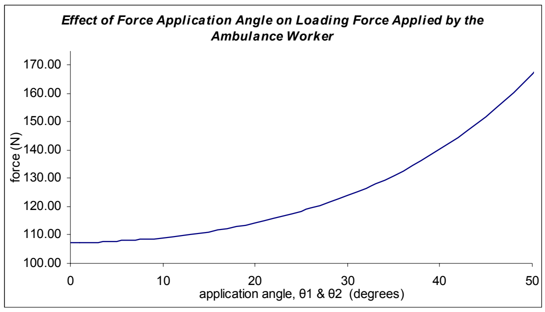


Figure 8: The Effect of Force Application Angle.

Conclusions

Peak loading forces are around 300N & 400N for ramp system, 100N & 200N for tail-lift system and 600N the easi-loader system (AW1+AW2 respectively). Current reference data shows that the loading and unloading systems are not in the safe limits. Comparison of the systems from the ambulance workers perspective and the time required for completing the task is made.

Kinematic analysis has been used to estimate the forces. The model estimated agrees very well with the measured values. Suggestions for loading reduction include:-

- Reduce stretcher mass
- Reduce maximum force application angle to 25°
- Improve ambulance worker training to ensure that the load is evenly shared

Reference data used in this research as the safe limits can be considerably improved. Further work is suggested to build on research by Chaffin et al [7, 8] to produce loading reference data based on the failure mode of the L5/S1 disc (common injury for ambulance workers).

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