Evaluation of manual handling tasks involving the use of carry chairs by UK ambulance personnel

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Evaluation of manual handling tasks involving the use of carry chairs by UK ambulance personnel

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The emergency carry chair is an important manual handling aid, used by UK ambulance services as the primary method for transporting patients up and down stairs and into the ambulance.

8 ambulance personnel performed 4 simulated handling tasks that commonly involved the use of the carry chairs: transporting a patient up and down stairs, lifting a patient into the back of an ambulance, wheeling a patient up a $10^\circ$ ramp, and negotiating a kerb. Force, posture, and anthropometric data were combined into a biomechanical model to predict the risk of injury to the low back and the physical demands imposed on operators.

Lifting the chair from a low level was found to expose the foot-end operator to a high risk of low back injury. High physical demands were also placed upon operators' arms. When transporting patients down stairs, means of supporting the weight of the patient and chair on the stairs provides one promising control measure for reducing the risk of injury to the low back and upper body. However, when transporting patients up stairs the benefits are much smaller and the task remains physically demanding. Versatility was reported to be a key requirement for chairs, and several workplace factors, such as confined spaces, were found to limit situations in which more recently developed chairs could be utilised.

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EXECUTIVE SUMMARY

OBJECTIVES

The emergency carry chair is an important manual handling aid, used by UK ambulance services as the primary method for transporting patients up and down stairs and into the ambulance. Within the past few years, new designs in carry chair have emerged that claim to offer significant benefits by removing the need to support the full weight of the patient and chair. The purpose of this study was to evaluate patient handling tasks involving the use of emergency carry chairs. The aims of this study were:

1. To determine the musculoskeletal loads that operators are exposed to when performing these tasks; and
2. To investigate how carry chair designs and workplace factors impact on the safety of handling procedures performed by ambulance personnel.

MAIN FINDINGS

When carrying a patient up and down stairs, the operator at the head-end position of the chair was found to exert more force than the operator at the foot-end position. However, the risk of low back injury appeared greatest at the foot-end position, as operator force exertion was combined with forward trunk flexion. In particular, the activity of lifting the chair from a low level exposes the foot-end operator to a high risk of low back injury.

High physical demands were placed upon operators’ arms when carrying a seated patient up and down stairs. A considerable percentage of the working population may have insufficient strength to hold the load close to the body and maintain an upright trunk posture during the task. This increases the risk of musculoskeletal injury.

Neither of the two chairs involved in this study offered a single, optimal solution for reducing the risk of musculoskeletal injury to ambulance personnel in the full range of circumstances where seated patients may need to be transported. When transporting patients down stairs, means of supporting the weight of the patient on the stairs provides one promising control measure for reducing the risk of injury to the low back and upper body. However, when transporting patients up stairs the benefits are much smaller and the task remains physically demanding.

Versatility was reported to be a key requirement for emergency chairs in the field, and a number of additional workplace factors, such as confined spaces, or uneven stair landings were found to limit situations in which more recently developed chairs could be utilised. Currently, ambulance personnel may still need to carry seated patients in these particular ‘high risk’ environments.

Lifting a seated 70 kg patient directly into the back of an ambulance poses a high risk of low back injury to ambulance personnel. In comparison, the risk of injury to the low back was greatly reduced when ambulance personnel wheeled the patient up a low-gradient ramp. Nonetheless, in some instances where there are heavy patients and/or steeper ramps, wheeling a seated patient into an ambulance will not reduce the risk of musculoskeletal injury sufficiently and alternative systems of loading a patient will be required.
RECOMMENDATIONS

There is an urgent need to improve the designs of chairs that offer mechanical assistance in the transportation of patients up and down stairs. In particular, improving the versatility of more recently developed chairs is thought to be a primary driver for greater implementation across front-line A&E crews. In this respect, there appears to be a need for chairs that can negotiate narrow landings, and chairs that can either support the weight of the patient on the stairs, or in the presence of certain environmental risk factors such as confined spaces or uneven terrain, serve as a light, carrying alternative.

Some manufacturers are working more closely now with some ambulance services on future carry chair design and there is a greater awareness that risk management and health and safety in the design is a significant factor in purchasing decisions of this nature. Nonetheless, advances in emergency chair design might be facilitated through a collaboration of stakeholders that is led by a central representative body such as the Ambulance Service Association (ASA).

In the meantime, there are certain situations where ambulance personnel must carry seated patients. However, efforts should be made to limit the extent of patient carrying that occurs on stairs and reduce the risk of musculoskeletal injury. This can be achieved with the development of safer systems of work. These may include operational protocols to manage the transport of seated patients, deployment of specialised vehicles and equipment to respond to situations that involve particularly high-risk handling and collaboration with local agencies.

In the long term, mechanical handling aids that actually lift the patient and chair up each step need to be implemented for those ambulance personnel that routinely transport patients up stairs. Further research is required to evaluate the musculoskeletal loads imposed on ambulance personnel and any additional risk factors that arise when using such chair designs.

Vehicle purchasing programmes should promptly phase out A&E and PTS vehicles that require ambulance personnel to lift or carry seated patients into the back of the vehicle. Where vehicle purchase orders specify the use of ramps as the primary system of patient loading, efforts should be made to select ramps with the lowest gradient, whilst still complying with aspects of EN 1789 (2000). In many circumstances, the task of loading a patient into an ambulance should be supported with alternative systems of work (e.g. using a mechanised tailgate lift, a stretcher loading system or a ramp in combination with a winch). However, an evaluation of these systems of loading was beyond the scope of this project.
1 INTRODUCTION

1.1 ACCIDENT AND INCIDENT DATA

Epidemiological studies would suggest that ambulance staff represent a group of high-risk workers susceptible to health problems and early retirement due to these illnesses (Rodgers, 1998; Safas, 1993; Turnbull et al., 1992). Rodgers (1998) identified that the three most common causes of early retirement were due to musculoskeletal disorders/injuries, circulatory disorders, or mental disorders. Musculoskeletal disorders/incidents accounted for 41% of all early retirements.

A recent survey of accident and incident data collated from six UK ambulance service Trusts by the Ambulance Services Working Group (Working Group of the Health Service Advisory Committee) showed that between 30 and 51% of all recorded incidents (not just RIDDOR reportable) involved the moving/handling of loads and resulted in some form of musculoskeletal injury. The mean incidence rate was 178 per 1000 employed, representing an 18% risk of musculoskeletal injury due to the moving/handling of loads. Where accident data could be subdivided according to Accident and Emergency crews (A&E) and Patient Transfer Service (PTS) staff, 90% of accidents were assigned to A&E staff. Analysis of 1039 incidents identified three main tasks linked to accident/injury causation: the use of carry chairs; the use of stretchers; and patient transfers (e.g. floor-to-bed, bed-to-chair).

1.2 PREVIOUS WORK PRACTICE ANALYSES OF PATIENT HANDLING TASKS

A review of the scientific literature suggests that there are few studies that have investigated the manual handling practices adopted by ambulance personnel. Even fewer have attempted to study the risks associated with lifting and carrying patient chairs, often referred to as ‘carry chairs’ or ‘stairchairs’ in North America.

In a Dutch survey, Doormaal et al. (1995) found that ‘getting a patient’ was reported to be the most strenuous task performed by ambulance personnel. They were observed to perform this task for 9 – 10% of their 8-hour day shift and 6 – 7% of their 8-hour night shift. During this period, time-sampled postural observations were made using the Ovako Working posture Analysing System (OWAS; Karhu et al., 1992). OWAS uses a five-digit coding system, allowing an observer to describe, over a period of time, the whole body posture, force application and activity of the worker in the field. An assessment chart is used to classify the likely severity of the postural load according to an Action Category (AC), describing the level of urgency with which corrective measures are required (Table 1).

<table>
<thead>
<tr>
<th>Action Category (AC)</th>
<th>Likely Level of Harm</th>
<th>Level of Urgency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No harm</td>
<td>No corrective measures required</td>
</tr>
<tr>
<td>2</td>
<td>Slight harm</td>
<td>Corrective measures in the near future</td>
</tr>
<tr>
<td>3</td>
<td>Distinct harm</td>
<td>Corrective measures as soon as possible</td>
</tr>
<tr>
<td>4</td>
<td>Severe harm</td>
<td>Corrective measures immediately</td>
</tr>
</tbody>
</table>

OWAS showed that personnel adopted postures classified as AC 3 or AC 4 3 – 5% of the time during non-emergency calls, and 18 – 19% of the time during emergency calls. A
biomechanical analysis suggested that the shoulders and ankles of personnel were subjected to high biomechanical loads when carrying on stairs. However, the authors failed to quantify this or discuss the characteristics of the task, load or work environment that might contribute to the musculoskeletal loading.

Birtles and Boocock (2003) conducted a field survey of the manual handling operations of three UK ambulance service Trusts, with particular emphasis on their use of carry chairs. The study combined results from a questionnaire survey, observations and self-reported manual handling documentation. The carry chair was reported to be used for 38% of patient transfers. This was more frequent than use of a stretcher or other patient carrying device, and more frequent than having a patient walk to the ambulance. Residential properties were the primary location of carry chair use (71%), while the most commonly performed handling tasks involving carry chairs were: negotiating kerb stones (80% of carry chair incidences); moving on steep slopes (50%) and descending stairs (50%). However, these results should be interpreted with caution, as a response rate of only 5% was obtained. Ambulance personnel perceived the most difficult handling tasks involving carry chairs to be: ascending and descending spiral staircases; manoeuvring in confined spaces; and pushing chairs on grass and gravel surfaces.

There are a few studies that have quantified the risks of musculoskeletal injury associated with various patient lifting, carrying and transfer tasks, some of which have touched upon the use of carry chairs. Lavender et al. (2000a, 2000b) conducted a laboratory study of five of the most ‘frequently performed strenuous emergency rescue tasks’ carried out by emergency service personnel (firefighters who were cross-trained paramedics) in Chicago, USA. This included a task referred to as a stairchair lift and carry, believed to be similar to a UK carry chair. The study described working postures and the forces applied by ten two-person teams during each simulated task. For the stairchair task, subjects were required to transport a patient dummy and stairchair weighing 56.6 kg down the stairs and around a landing. Estimates of static forces using a hand-held dynamometer suggested that 38% and 62% of the load were supported by the foot-end operator (FEO) and head-end operator (HEO), respectively. Despite this, greater arm flexion by the FEO increased the moment acting on the spine, resulting in L5/S1 spinal compression forces that were 37% greater than the HEO on average. Whilst postural and biomechanical data is reported for the different phases of the carry, this is based upon estimates from static force measurements. Additionally, the study provides no indications as to the possible effects arising from variations in chair design, or differences in the physical attributes of the handlers.

McGill et al. (1990) (Canadian study) investigated the musculoskeletal loads on the back while performing ten simulated patient handling tasks. One task was described as ‘lifting a chair (typical institutional frame chair with plastic seatpan) with a patient sitting in it’ by four ‘Emergency Medical Attendants (EMAs)’. A static biomechanical model provided a method by which to investigate the influence of EMA height, gender, patient weight and stoop-squat posture on spinal compression and shear forces. For the chair lift (patient weight = 82 kg), compression forces for the HEO were shown to exceed the NIOSH (1981) ‘maximum permissible limit’ (MPL) when lifting the chair, and exceeded the ‘action limit’ (AL) when carrying the chair up the stairs.

In an unpublished report by Collins (1999), two methods of loading a carry chair into an ambulance were studied using a Lumbar Motion Monitor (LMM): walking up the steps of the ambulance; and lifting directly into the ambulance. A 3% difference was found in the probability that the methods were a member of the ‘high risk group’. Nonetheless, Collins concluded that ‘the second method of loading significantly reduced the risk factors and should be advocated in all ambulance services who use these methods of loading carrying chairs’.
1.3 ANALYSES OF RECENT DEVELOPMENTS IN CARRY CHAIR DESIGN

Only within the last few years has there been a radical change to the basic design of the carry chair with the introduction of specially designed wheeled-based systems for manoeuvring up and down stairs. These new handling aids claim to offer significant benefits over the traditional method of lifting and carrying a seated patient, by removing the need for handlers to lift and support the full weight of the patient and chair. However, a lack of wide-scale acceptance and implementation within the ambulance service seems to suggest that they incur other unforeseen risks.

Fredricks et al. (2002b) (USA study) investigated the biomechanical stresses placed on ambulance personnel while transporting a patient down a flight of stairs using different designs of carry chair. Using a hand-held dynamometer to measure loads, the L5/S1 spinal compression force on the HEO and FEO (when walking backwards) were estimated to be, on average, 48% and 53% greater than that experienced by the FEO when facing forwards. Thus, chairs that allowed the FEO to descend the stairs facing forwards reduced the biomechanical stresses placed on this handler. However, safety and clinical implications of the FEO being unable to maintain visual eye contact with the patient were not discussed. In addition, one model of carry chair (Stryker Stair Pro), which used the stairs to support the weight of the victim and chair rather than the handler, was found to reduce the L5/S1 spinal compression forces and relative risk of low back injury (Fredricks et al., 2002b). However, any implications of other workplace factors to the health and safety of ambulance personnel and the patients were not discussed.
2 AIMS AND OBJECTIVES

2.1 AIMS

The purpose of this study was to evaluate patient handling tasks involving the use of emergency carry chairs. The aims of this study were:

(1) To determine the musculoskeletal loads that operators are exposed to when performing these tasks; and

(2) To investigate how carry chair designs and workplace factors impact on the safety of handling procedures performed by ambulance personnel.

2.2 OBJECTIVES

To achieve these aims, the study adopted the following objectives:

(1) Measure the dynamic forces exerted by ambulance personnel when performing simulated patient transfer tasks using 2 emergency carry chairs in 4 different workplace scenarios;

(2) Measure the movement and postures of ambulance personnel when performing these handling tasks;

(3) Use biomechanical modelling techniques to estimate musculoskeletal loads imposed on ambulance personnel when performing these tasks; and

(4) Gather qualitative data on performing these tasks when other risk factors are present.
3 METHODOLOGY

3.1 INTRODUCTION

The study combined biomechanics measures and subjective ratings of perceived exertion to assess the manual handling tasks performed by ambulance personnel. Measurements taken for the biomechanics analysis were ground reaction forces during lifting, handle forces during pushing/pulling, postures and anthropometrics. Informal interviews were also conducted to gather information on aspects of chair design and task performance where other risk factors may be present.

3.2 SAFETY CONSIDERATIONS / ETHICAL APPROVAL

Primary consideration was given to participant safety and important steps were taken to ensure safe lifting conditions during the experiment:

- A pilot study was performed before the main study;
- Participants completed some health screening questions before participation;
- The tasks were realistic and represented normal work activities;
- Participants were informed of any risks and permitted to withdraw from the experiment at any time.

The experimental procedure was approved by HSE’s Research Ethics Committee.

3.3 EXPERIMENTAL DESIGN

3.3.1 Independent variables

To minimise treatment order bias, participants were randomly allocated to a counterbalanced order of independent variables. There were 3 categories of independent variable: simulated tasks; emergency chair model and operator position.

Simulated tasks

This study investigated 4 simulated tasks:

(1) Descend / ascend stairs with a narrow 180° landing

This task was shown to represent a common handling task performed by both A&E and PTS ambulance personnel when transferring a patient to and from a domestic dwelling. Birtles and Boocock (2003) found that transport up/down stairs was required in just over 50% of A&E patient transfers involving the use of carry chairs. A wooden staircase was constructed (Figure 1) to simulate a narrow set of stairs and allow an unobstructed view of task performance. The staircase was constructed to conform to Building Regulations and BS 5395-1 (2000). The staircase had a clear width of 80 cm and consisted of 9 steps, each with a step rise of 15.5 cm and a step going of 28.0 cm. The pitch of the staircase was 29°. A 180° landing, with a stair clear of 80 cm, was marked out on the floor with cable protector to simulate a narrow landing.
Ambulance personnel were requested to perform the tasks within this boundary wherever possible.

Figure 1: Stairs constructed to simulate stair ascent / descent. A 180° landing, 80 cm wide, was marked out on the floor.

(2) Lift into an ambulance

This task represented the direct lift of a seated patient into the back of an ambulance. This task is common when using older ambulances that are not equipped with either a ramp or a tailgate lift for loading seated patients. A platform was constructed to simulate the tailgate of an ambulance (Figure 2). The platform was 75 cm high from the ground, specified by BS EN 1789 (2000) as the maximum allowable loading height to and from an ambulance.

Figure 2: Platform constructed to simulate the direct lift of seated patient into the back of an ambulance
(3) Wheel up into an ambulance

This task represented wheeling a seated patient up a ramp and into the back of an ambulance. A 27 cm high platform was constructed to simulate the floor of an ambulance that can be lowered with air suspension. A 152 cm long ramp was attached to the platform (Figure 3). The angle of the ramp was 10°. BS EN 1789 (2000) specifies a maximum loading angle of 16°, although also recommends that the loading height be kept as low as possible. Measurements at an ambulance Trust station found that ramp angles typically varied between 10° - 13° when the air suspension of the ambulance was lowered.

![Figure 3: Ramp and platform constructed to simulate wheeling a seated patient up into the back of an ambulance with lowered air suspension.](image)

(4) Negotiate a kerb

This task was also shown to represent a common handling task performed by both A&E and PTS ambulance personnel. Birtles and Boocock (2003) found that negotiating kerbs was required in about 80% of A&E patient transfers involving the use of carry chairs. A 16 cm high wooden platform was constructed to simulate the kerbstone (Figure 4). A 1.5 cm bump was constructed on the edge of platform with cable protector to simulate possible uneven surfaces on the kerbstone and differentiate the kerb task from a single-step stair task.

![Figure 4: Kerb constructed to simulate ascent / descent of a kerb.](image)
**Emergency chairs**

Two different models of emergency chair were involved in the study:

(1) **Model 1:** This chair incorporates wheel-based technology, a tension belt and adjustable brake to support the load of the patient and chair on the stairs. This removes much of the need for lifting. The weight of the chair was measured to be 135 N (13.8 kg)

(2) **Model 2:** This chair is considered to represent one of the most common types of chair design in regular use throughout the UK ambulance service. This involves the ‘traditional’ method of lifting and carrying a seated patient up / down a flight of stairs. The weight of the chair was measured to be 93 N (9.5 kg)

The chairs were loaded with a simulated patient mannequin, with a weight of 692 N (70.6 kg). This weight represented the 47th percentile weight of a 18 – 64 year old British adult or 52nd percentile weight of a 65+ year old British adult (50:50 mixed gender population).

**Operator position**

(1) **Head-End Operator (HEO):** The participant holding the top handles of the chair, close to the patient’s head.

(2) **Foot-End Operator (FEO):** The participant holding the bottom handles of the chair, close to the patient’s feet.

**3.3.2 Dependant variables – measurement methods**

To minimise any measurement learning bias, participants were given the opportunity to familiarise themselves with the task prior to undertaking any form of measurement. Each dependent variable was then measured twice, to provide some measure of consistency whilst not over-exerting the participants.

**Force measurement**

To determine the forces that ambulance personnel exerted during the tasks, 3 types of force measurement technique were utilised:

(1) **Force Platform Measurement:** Participants performed a series of lifts standing on one of two Kistler force platforms (type 9281B), connected to two 9865B charge amplifiers. Data were output via a 12-bit A/D card fitted to a Pentium Pro PC with 64 MB of RAM operating version 3.11 of the Bioware force platform software (Kistler Instrumente AG, Winterthur, Switzerland). The charge amplifier range was set to 10000 pC/10V. Data was collected at a sampling frequency of 500 Hz for a period of 20 seconds.

Prior to testing, incremental 25 kg loads were applied to each force platform to check the factory calibrations of the vertical force measuring components, up to a maximum of 175 kg. The need for multiple force platform arrangements did not allow the platforms to be fixed to a proper installation surface. Despite this limitation, fairly high linearity and accuracy were evident, with deviations of 0.1 % and 0.2 % for platforms 1 and 2 respectively.
Vertical ground reaction forces (Fz) were extracted to determine: the peak lifting force exerted during the lift and the mean static force exerted when holding the chair and patient in a standing position.

(2) **Unidirectional Hand Force Measurement:** Ambulance personnel ascended and descended the staircase with a unidirectional load cell attached to the HEO handle of Chair Model 1. The load cell was connected through a serial cable to a 2500 N Mechmesin Advanced Force Gauge (AFG). Data were output via a serial extension cable to a Pentium laptop with 192 MB of RAM operating version 1.05 Mechmesin Dataplot software (Mechmesin Limited, Horsham, UK). The load cell and AFG were factory calibrated. The sampling frequency was limited to 10 Hz. The load cell extended the HEO handle by 15 cm, although this was rectified by resetting the adjustable handle height of the chair.

To minimise the effects of shear loading on the load cell, the load cell was orientated so that it was parallel to the forearms of the participant when performing the task on the stairs. Each participant performed one familiarisation trial and two measurement trials. Peak and mean forces were extracted from the data to determine the peak force and sustaining force that the HEO exerted when ascending and descending stairs.

(3) **Tri-axial Hand Force Measurement:** Following the main study, further tri-axial (Fx, Fy & Fz) hand force measurement was undertaken at the HSL laboratory. In the manner demonstrated by ambulance personnel on video, 4 HSL staff replicated the kerb tasks, ramp task and, with Model 1 only, the stair ascent and descent task. Two MC3A tri-axial force transducers (Advanced Mechanical Technology, Inc) were inserted into the frames of the chairs at both ends, as close to the handles as possible (Figure 5 and 6). Efforts were made to minimise any alterations to the position of the handles. The force transducers were connected via cables to MSA-6 Strain Gage Amplifiers. Data were output via an A/D board (National Instruments) to a Pentium laptop with 192 MB of RAM operating version 3.04 of in-house data acquisition software (DAQStud, HSL, UK).

Prior to testing, incremental 25 kg loads were applied to each force transducer to check the factory calibrations of the vertical and horizontal force measuring components. Depending on
the force anticipated, calibrations were checked for loads up to either 50 or 75 kg. Moderate linearity and accuracy were evident with maximum deviations of 2.3% for the HEO handle. At the FEO handle, a deviation of 0.1% was evident for the vertical component, and a deviation of 5.4% was evident for the push/pull component.

Peak and mean resultant forces were extracted from the data to determine the peak force and mean force that the HEO and FEO exerted when ascending/descending stairs, negotiating the kerb and wheeling the chair up the ramp.

**Posture measurement**

Two industrial Lumbar Motion Monitors (LMM) were used to measure simultaneous 3D thoracolumbar kinematics of each participant. The LMM used four potentiometers to measure the instantaneous position of the spine relative to the pelvis. Position data was sampled at 60 Hz, transmitted to an A/D converter and recorded on a microcomputer. Data output was transmitted through either a telemetry unit or cable to a Pentium laptop with 192 MB of RAM operating Ballet 2.0 software (Biodynamic Solutions Inc, Ohio State University, USA). The data was then processed to calculate the position, velocity and acceleration of the spine in the sagittal and frontal plane of motion.

Two JVC digital video recorders (GR-DVP3 and GR-DVL767EK) were used to capture trunk and extremity posture for input into biomechanical analysis. The cameras were arranged to provide the best orthogonal views to the sagittal and frontal plane of both participants. Video recordings were synchronised to the LMM output using a foot-operated light switch and visual indicator of trial number.

**Subjective information**

Following task performance at either the HEO or FEO position, participants were asked to provide a Rating of Perceived Exertion (RPE) (Appendix A). Borg (1982) showed RPE to be a valid method for describing general perceptual variations of physical exertion. Each participant was assigned to a different experimenter and was instructed to point to their measure of RPE and avoid verbal communication. In this way, discussion and competition between participants was avoided.

Participants were also asked to discuss and provide feedback on:

1. The model of chair preferred for each task, and reasons for this preference;
2. Differences between task performance in the study and typical task performance in the field; and
3. Implications of other risk factors on task performance.

### 3.4 PILOT STUDY

A pilot study was undertaken prior to the main study to determine if the experimental protocol was suitable and reliable. The suitability of the tasks, the instructions issued to subjects, the reliability of the measuring techniques, the roles of the researchers and the safety procedures were all examined. HSL staff volunteered to act as participants for this phase of the study.
As a result of the pilot study, the number of measurement trials for each task was reduced from three to two, in order to reduce the extent of manual handling that participants were asked to undertake during the testing. Measurement of static and dynamic vertical lifting force from unfixed force platforms was deemed to be a reasonable approach for this study. A longer handle was attached to the unidirectional load cell to improve grip when measuring HEO hand forces of Model 1. The unidirectional load cell was deemed unsuitable for measuring FEO hand forces. It was realised that subsequent tri-axial force measurement at HSL would provide a better measure of HEO and FEO hand forces when using Model 1.

3.5 MAIN STUDY

3.5.1 Participant recruitment

To undertake the study, HSE sought the cooperation and involvement of employers and ambulance personnel of a UK ambulance Trust. The Trust approached had previously incorporated both chair models into its fleet of ambulances. Thus, participants were equipped with formal training and practical field-based experience in using both chair models. The Head of Clinical Education and the Health and Safety Manager approached staff from local ambulance stations to find suitable and willing volunteers. To facilitate recruitment, HSL ergonomists set up their test laboratory at a Territorial Army Centre, centrally located within the Trust area.

Participants attended this test location in groups of two, at a time and date that was convenient to both of them and the Trust. The majority of ambulance personnel volunteered outside of working hours, during a scheduled day off. Testing took approximately 5 – 6 hours, and typically included a mid-morning break and lunch break. Ambulance personnel were not paid or given financial incentive to participate in the study. However, a small honorarium was offered to participants to cover costs associated with travel, as some participants journeyed more than 100 miles to volunteer.

3.5.2 Instruction and preparation of the subjects

Participants attended the test session in the clothing and footwear that they normally wore for work. In an introductory briefing, the purpose, general protocol and safety instructions for the experiment were explained to each participant. A written set of instructions and a consent form (Appendix B and C) was signed by each participant in the presence of at least two research colleagues to indicate that the participant was fully aware of the requirements and the possible health risks.

A 10-minute warm-up routine was carried out at the start of each session. This involved 5 minutes of light cardiovascular exercise (skipping rope), designed to increase cardiac output and blood flow to the skeletal muscles, increase core and intra-muscle temperature without inducing local muscle fatigue, and generally increase levels of psycho-physiological arousal. Cardiovascular warm-up was followed by 5 minutes of specific stretching exercises related to the lifting tasks in this experiment.

A LMM was sized, calibrated and then attached to the back of each participant using the adjustable waist belt and shoulder harness. LMM function was assessed by viewing the instantaneous positional output as the participant bent forwards, backwards, sideways and twisted. Adjustment of LMM sizing was found to take a considerable amount of time, as the ‘large’ LMM size setting struggled to accommodate the trunk length and circumference of some of the largest ambulance personnel.
Reflective markers (lightweight tennis table balls coated in retro-reflective paint) were attached to external body landmarks overlying the joint centres of the wrist (head of ulna and radius), elbow (midway between the lateral epicondyle of the humerus and the radial head), shoulder (acromion process), hip (greater trochanter), knee (10 mm inferior to the lateral tuberosity of the femur) and ankle (lateral malleolus). Preferred attachment for the markers was to the skin, although in wearing normal ambulance work clothing, this was not possible for the lower extremities.

### 3.5.3 Overall study protocol

Following instruction and preparation, participants performed a series of lifts of the Model 2 chair, while standing on the force platforms. Participants performed lifts with the force platforms in 3 arrangements, as depicted in Figures 7 – 9. Participants were instructed to communicate with each other and perform the lifts in a controlled and co-ordinated manner. Participants were offered an opportunity to familiarise themselves with the lift. For each arrangement, they then performed four lifts, each acting as the HEO and FEO on two occasions. At the top of the lift, participants were instructed to hold the chair for a 3 second period to determine the static force exerted by each operator.

Natural recovery periods were designed into the protocol. While experimenters rearranged the positions of the platforms, another experimenter recorded anthropometric measures of the participants. Weight, stature, shoulder height, elbow height, hip height, knuckle height and knee height were recorded for each participant, using the definitions of Pheasant (2001). Measures of the participants’ dominant and non-dominant handgrip strength were also taken, using a SAEHAN hand dynamometer. The form used to record these anthropometric and strength measures, along with subsequent RPE and qualitative information, is provided in Appendix D.

Participants then performed the task simulations, which formed the primary activity of the main study. Participants performed four trials of each task, acting as the HEO and FEO on two occasions each. Participants were randomly allocated to a counterbalanced order of chair, task simulation, and operator position to minimise any effect of treatment order bias.

For each task simulation, the following general protocol was adopted. The task simulation was described and, if requested, clarified and demonstrated by the experimenters. Participants were reminded that at no time were they expected to significantly overexert themselves. Participants
were also urged to tell experimenters if they felt the task was beyond their capabilities, they experienced any difficulties or discomfort during the task or more time was required to become familiar with the simulation. Participants were also reminded to perform the task in a smooth controlled manner and to plan, communicate and coordinate the task with their partner as trained. Participants were then given an opportunity to ask questions and become familiarised with the task. As the tasks represented commonly encountered manual handling situations, participants typically opted for just one practice attempt during the familiarisation period.

Following task familiarisation, participants were asked to stand in a neutral posture at their prescribed position on the chair. Once data logging commenced, participants were instructed to begin the task whenever ready. During the trials, experimenters monitored each task carefully to ensure tasks were performed safely and correctly and trailing cables did not present a tripping hazard. At the end of the trial, participants were reminded to return to a neutral posture until the recording equipment was stopped and data files were saved. After performing two trials at either the HEO or FEO position, RPE measures were recorded.

Following performance of the 4 task simulations, the patient mannequin was transferred to the other chair model, and the trials were repeated. Following the last task simulation, an informal interview was conducted to collect qualitative information.

### 3.5.4 Participants used in the study

8 males volunteered for the study. Although participants were not excluded on the basis of gender in the experimental design, female ambulance personnel were not available to volunteer for the study. Table 7 summarises the anthropometric, demographic and hand grip strength characteristics of the group. Figure 10 shows each participant’s stature and weight as a percentage of the British 16 – 64 year old population. The group represented the upper quartile of this population in both stature and weight.

#### Table 2: Summary of participant anthropometric, demographic and grip strength information

<table>
<thead>
<tr>
<th>Variable (units)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>38.5</td>
<td>9.2</td>
<td>27 – 52</td>
</tr>
<tr>
<td>Stature (mm)</td>
<td>1812</td>
<td>47</td>
<td>1751 – 1876</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>93.9</td>
<td>13.6</td>
<td>77.2 – 122.5</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>28.6</td>
<td>3.9</td>
<td>23.9 – 35.8</td>
</tr>
<tr>
<td>Dominant hand grip strength (kg)</td>
<td>54.7</td>
<td>12.1</td>
<td>42.0 – 78.7</td>
</tr>
<tr>
<td>Non-dominant hand grip strength (kg)</td>
<td>54.8</td>
<td>11.1</td>
<td>45.3 – 70.7</td>
</tr>
</tbody>
</table>

7 of the 8 participants were right hand dominant. Handgrip strength was converted into percentile values, using U.S. normative data for males and females (Crosby et al., 1994). For the dominant hand, grip strength corresponded to the 60th percentile (SD: 22%). For the non-dominant hand, grip strength corresponded to the 64.9 percentile value. (SD: 20%). von Restorff (1994) proposed that hand-grip strength was an important descriptor of load carriage performance, particularly predicting whether the bearer was likely to be limited by local muscle fatigue. Mean handgrip strength measures suggest that participant load carriage performance would reflect reasonably typical capabilities of the working population.
Participants did not report any occurrences of previous musculoskeletal injury that they felt would affect their ability to perform the tasks safely and effectively. No incidences of back pain were reported within the six month period prior to this study.

Participants were diverse in both experience and clinical role within the ambulance service, as shown in Table 3. Participant experience in the ambulance service sector ranged from 3 to 29 years of service. On average, participants had 10 years of experience in the ambulance service. All participants were trained in using both models of chair. Mean field experience using Model 1 was 1.8 years, while mean field experience using Model 2 was 10 years.

### Table 3: Summary of participant experience

<table>
<thead>
<tr>
<th>Current Clinical Role</th>
<th>N</th>
<th>Mean Experience in Ambulance Service (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambulance Care Assistant</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Technician</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Paramedic</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Emergency Care Practitioner</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Clinical Educator</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>8</td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>

### 3.6 BIOMECHANICAL APPROACH USED IN THE STUDY

The biomechanical modelling approach used a commercially available 3D Static Strength Predictor Programme (The University of Michigan, 1993) to estimate the physical loads acting upon the human body. Inputs into the model were:

1. Anthropometric data
(2) Posture

Trunk and leg postures of ambulance personnel were defined using digital photographs and video. Arm postures adopted by the computer models were defined using inverse kinematics. This method uses the position of the hands relative to the feet to compute shoulder and elbow joint and segment data from a series of algorithms based on behavioural data. Arm postures were fine-tuned according to photographs if necessary.

(3) Force measurements

For analyses of stair tasks and tailgate lift tasks with Model 2 chair, force platform measurements were entered into the biomechanical model. Peak forces were entered into analyses of lifting tasks, while static forces were entered into analyses of carrying and lowering tasks. For analyses of the ramp task and kerb tasks, as well as the stair tasks with Model 1 chair, mean resultant tri-axial hand force measurements were entered into the biomechanical model.

Resultant force vectors were determined by reviewing the component forces and video recordings. For Model 1 stair tasks, HEO resultant hand force vectors were fixed at -65° from horizontal (lift and pull back) and FEO resultant hand force vectors were fixed at 40° from horizontal (push forwards and lift). For the kerb task, HEO resultant forces were fixed at -65° with Model 1 chair (lift and pull back), while all other force vectors were vertical. For the ramp task, HEO resultant hand force vectors were set at -65°. For the analysis, it was assumed that the total force was evenly distributed between both hands.

Outputs selected from the biomechanical model were:

(1) Low back compression force

Compression forces acting on the operator’s lower back are estimated, at the L5/S1 junction (the junction between the last lumbar vertebra and the sacrum of the spine). This location is considered to be where the greatest physical load is placed on the spine, and hence the site where spinal injury is most likely to occur. The National Institute of Occupational Safety and Health (NIOSH) in the U.S. reviewed literature and determined that:

- Tasks causing L5/S1 compression forces less than 3400 N offer a reasonable level of protection to most young, healthy workers (75% of women and 99% of men) (Waters et al., 1993).
- Tasks causing L5/S1 compression forces greater than 3400 N should be considered potentially hazardous to some workers (Waters et al., 1993).
- Tasks that cause L5/S1 compression values greater than 6400 N were considered to be unacceptable and hazardous to most workers (NIOSH, 1981).

(2) Resultant joint moments and percent capable

Resultant moments at the elbow, shoulder, torso, hip, knee and ankle joints are calculated using a static biomechanical model. The moments are presented in terms of ‘percent capable’, or the estimated percentage of the population with the strength
capability to generate a moment larger than the resultant moment. The percent capable is based upon several experimental studies of static strength where the duration of exertion last between 4 – 6 seconds (Chaffin et al., 1999). Population strength means depend upon gender and posture and were not stratified by gender or age. Although females did not participate in this study, it was possible to estimate percent capable for females, if one assumes that female ambulance personnel with similar stature would adopt identical postures to their male colleagues.

3.7 ANALYSIS

Data was processed using the standard and purpose-designed computer software described in Section 3.3.2. Following data processing, suitable parameters were entered into MS Excel spreadsheets. Subsets of the data were then exported into SPSS v12.0 for Windows for statistical analysis.

The SPSS ONEWAY procedure was used to carry out one-way analyses of variance (ANOVA) to examine the effects of emergency chair (Model 1 and Model 2) and operator position (HEO and FEO). Post-hoc analysis of means was carried out using the Tukey HSD test.
4 RESULTS

4.1 ASCENT AND DESCENT OF STAIRS

4.1.1 Force Measurement

Figure 11 shows the mean force exertions when lifting and holding the Model 2 chair and patient at the HEO and FEO position. Results are shown when lifting the chair on flat ground (or at the bottom of the stairs) and when lifting at the top of the stairs. Descriptive statistics of force exertions are provided in Appendix E.

Table 4 shows the mean, standard deviation (SD) and range in the proportion of total force exerted by the HEO and the FEO when holding the chair on stairs and on level ground. On average, the HEO exerted about 50% of the total force required to carry the chair and patient over flat ground and 55% of the force to carry on stairs. When holding the chair on the stairs, the HEO was found to exert a significantly greater proportion of force than the FEO (F = 64.642, p<0.005). However, a significant difference in force exertion was not found between the HEO and FEO when actually lifting the chair and patient.

Table 4: Proportion (%) of total force exerted by the HEO and the FEO when carrying the chair on level ground and stairs

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Level Ground</th>
<th>Stairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>51 %</td>
<td>3 %</td>
</tr>
<tr>
<td>FEO</td>
<td>49 %</td>
<td>3 %</td>
</tr>
</tbody>
</table>

Figure 12 shows the peak and mean forces exerted by the HEO and FEO when using Model 1 to ascend stairs and descend stairs. When ascending stairs, the mean force exertion of the HEO was about 41% of the total weight of the load (827 N). The mean force exertion of the FEO was about 21% of the total weight of the load. Differences between the HEO and FEO were
significant for mean force exertion (F = 64.642, p<0.0005) and peak force exertion (F = 13.589, p<0.005).

![Graph showing peak and mean forces exerted during stair ascent and descent]

**Figure 12: Peak and mean forces (N) exerted when using Model 1 to ascend and descend stairs**

During stair ascent, the mean force exerted with Model 1 was found to be significantly lower than the mean holding force of Model 2 on the stairs, at both the HEO and FEO position (F = 64.642, p<0.005). For the FEO position, the magnitude of peak force exerted with Model 1 was found to be significantly lower than the peak lifting force with Model 2 (F = 13.589, p<0.0005). A significant difference in the magnitude of peak forces at the HEO position was not found.

During stair descent with Model 1, the mean force exertion of the HEO was about 16% of the total weight of the load (827 N). The mean sustained force exertion of the FEO was about 15% of the total weight of the load. Thus, significant differences were not found between the HEO and FEO positions for peak or mean forces during stair descent. However, the mean force exerted with Model 1 was found to be significantly lower than the mean holding force of Model 2 on the stairs, at both the HEO and FEO position (F = 118.919, p<0.005). The magnitude of peak forces exerted with Model 1 were also found to be significantly lower than the peak lifting force on the stairs with Model 2, at both the HEO and FEO position (F = 28.699, p<0.0005).

However, it should be emphasised that while the magnitude of peak forces was reduced using Model 1, the frequency of peak forces was increased. With Model 1, peak forces were imposed on the operators with each step, as the chair wheels left the edge of the step until the time when the tension belt supported the load on the step. This can be seen in Figure 13, showing an example of the resultant force profile recorded at the HEO position during descent of 8 stairs with Model 1.
Concerns about the load capacity of the tri-axial force transducers prevented the measurement of dynamic peak forces that might occur with each step when carrying Model 2. Thus, it was not possible to comment on the relative magnitude, frequency or variability of peak hand forces that occur as ambulance personal carry patients up and down the stairs.

Using Model 1 to ascend stairs was reported to be a particularly strenuous task, with the mean magnitude of peak force approaching 66% the total weight of the load (range of 60 – 73%) at the HEO position. During stair ascent, no significant difference was found at the HEO position between the peak forces when using Model 1 and the peak lifting force with Model 2. Thus, with respect to force exertion, use of Model 1 to ascend stairs essentially changed the carry task up the steps, which typically involved a single lift, into a multiple sequence of equivalent lifts.

**4.1.2 Ratings of perceived exertion**

Figure 14 shows Ratings of Perceived Exertion (RPE) by ambulance personnel when ascending and descending stairs with both chair models. When ascending stairs, no significant differences in RPE were found between Model 1 and Model 2. When descending stairs, participants reported significantly lower RPE for the Model 1 FEO position ($F = 3.730, p<0.05$). There was a trend for participants to report lower RPE for the Model 1 HEO position as well, although the difference was not significant ($p>0.05$).
4.1.3 Posture analysis

Descriptive statistics of trunk postures measured with the LMM during stair ascent and descent are summarised in Appendix F. During stair descent and stair ascent, significant postural differences were only found in the sagittal plane of motion.

Forward bending

During stair descent with Model 1, maximum sagittal flexion was 15° on average at the HEO position and 30° at the FEO position. During stair descent with Model 2, maximum sagittal flexion was 13° at the HEO position and 43° at the FEO position. For Model 2, the maximum sagittal flexion, maximum sagittal range of motion, and maximum sagittal velocity of the FEO were significantly greater than that of the HEO (F = 9.235, p<0.0005; F = 7.493, p<0.005; F = 8.155, p<0.0005). This reflects the forward bending required by the FEO for the initial lift of the seated patient at the top and bottom of the stairs. When using Model 1, a lift was not required and individual technique had a greater influence on operator posture than any specific workplace factors, model of chair or operator position.

During stair ascent with Model 1, maximum sagittal flexion was on average 8° at the HEO position and 30° at the FEO position. For Model 2, maximum sagittal flexion was on average 18° at the HEO position and 45° at the FEO position. For Model 2, maximum sagittal flexion, range of motion and velocity of the FEO were significantly greater than that of the HEO (F = 10.693, p<0.0005; F = 7.738, p<0.005; F = 6.620, p<0.005).

Twisting and lateral bending

On average, twisting motion occurred within a range of about 10 – 16° for the HEO and FEO positions of both Model 1 and Model 2. This was inclusive of twisting to both sides. On average, lateral bending occurred within an inclusive range of 10° – 18°. Task observations suggest that lateral bending occurred occasionally to monitor foot placement on the steps. In addition, at the HEO position, lateral bending was evident when negotiating the landing with Model 2. At the FEO position, lateral bending was evident when reaching for the lower handles of the chairs. However, as with forward bending, it appears that individual technique and variation had a greater influence on operator posture, rather than the specific workplace factors, the models of chair or operator position.
4.1.4 Biomechanical analysis

Model 1

Figures 15 – 18 show examples of the postures adopted by ambulance personnel when using Model 1. Biomechanical analysis was undertaken for 4 components of the stair tasks:

1. Descent at the middle of the stairs;
2. Descent at the bottom of the stairs;
3. Ascent at the middle of the stairs;
4. Ascent at the bottom of the stairs.

Figure 15: Descent at middle of stairs

Figure 16: Descent at the bottom of the stairs

Figure 17: Ascent at the bottom of the stairs

Figure 18: Ascent at middle of stairs
Mean compression forces were obtained by entering mean force exertion values into the biomechanical model. Peak compression forces were obtained by entering the average peak force exertions. Combining mean and peak compression forces then provides a thorough indication of the cumulative low back load on the ambulance personnel during these tasks.

Figure 19 summarises the mean and peak low back (L5/S1) compression forces for two components of the stair descent task with Model 1. The NIOSH (1981) Back Compression Design Limit (DL: 3400 N) and Back Compression Upper Limit (UL: 6400 N) are shown on the charts. Table 5 summarises the mean and peak low back compression force values for stair descent and stair ascent with Model 1.

![Figure 19: Mean and peak low back compression forces (N) during stair descent with Model 1](image)

**Table 5: Peak and mean low back compression forces (N) during stair descent and stair ascent with Model 1. Standard deviations are shown in parenthesis.**

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Stair Descent</th>
<th>Stair Ascent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-Stairs</td>
<td>Bottom of Stairs</td>
</tr>
<tr>
<td></td>
<td>Peak</td>
<td>Mean</td>
</tr>
<tr>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1379 N</td>
<td>(539)</td>
</tr>
<tr>
<td></td>
<td>1122 N</td>
<td>(482)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3038 N</td>
<td>(461)</td>
</tr>
<tr>
<td></td>
<td>2134 N</td>
<td>(476)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

During stair descent, mean FEO low back compression forces were on average 90% greater than the HEO at the middle of the stairs and 97% greater than the HEO at the bottom of the stairs. Both mean and peak low back compression forces were significantly greater for the FEO compared to the HEO (F = 22.870, p<0.05; F = 40.413, p<0.0005). At the FEO position, low back compression forces were found to be significantly greater than at the bottom of the staircase compared to the mid-stair position (p<0.005). At the bottom of the stairs, mean and peak FEO compression forces were found to exceed the 3400 N design limit.
Figure 20 summaries the mean and peak low back (L5/S1) compression forces for two components of the stair ascent task.

During stair ascent, mean FEO low back compression forces were on average 59% greater at the bottom of the stairs and 78% greater at the middle of the stairs. Thus, mean and peak low back compression forces were found to be significantly greater for the FEO compared to the HEO ($F = 14.973, p<0.005$; $F = 24.573, p<0.0005$). FEO compression forces were greatest at the bottom of the stairs for the start of the stair ascent task ($p<0.005$). Low back compression force results in relation to Model 2 are presented at the end of Section 4.1.4.

Figure 21 shows the percentage of the male or female population with sufficient static strength to sustain moments about the elbow, shoulder, torso, hip, knee and ankle joints at the four components analysed for Model 1. The Strength Design Limit (SDL) is exceeded if the percent capable is below either 99% for men or 75% for women, while the Strength Upper Limit (SUL) is exceeded if the percent capable is below 25% for men and 1% for women.

For the HEO, moments about the joints were not found to exceed the SDL during stair descent. During stair ascent, moments at the hip and ankle were limiting factors at the HEO position.

For the FEO, mean moments at the FEO shoulder joint exceeded the SDL for females. It was predicted that about 60% of females would have sufficient static strength comparable to the moments about the shoulder joint of the FEO during stair descent. During stair ascent, the percentage of females with sufficient shoulder strength reduced to about 20%, as a result of greater force exertion in the forward and upward direction. For the lower body of the FEO, mean moments at the hip and knee joints exceeded the SDL for males and females. In particular, moments about the knee joints were increased at the bottom of the stairs as the FEO adopted a crouched posture.
Figure 21: Percentage (%) of male and female population with sufficient strength to generate moments about the major joints during stair tasks with Model 1.
**Model 2**

Figures 22 – 25 show examples of the postures adopted by ambulance personnel when using Model 2. Biomechanical analysis was undertaken for 4 components of the stair tasks:

1. The initial patient lift at the top (stair descent) or bottom (stair ascent) of the stairs;
2. The patient carry on the staircase;
3. The patient carry around the landing;
4. The final patient lower at the bottom (stair descent) or top (stair ascent) of the stairs.

Individual peak forces were entered into the biomechanical analysis for the lifting component of the stair tasks. Individual static forces were entered into the biomechanical analysis for the carrying and lowering components of the tasks. For the patient carry on the stairs and around the landing, the biomechanical analysis was only undertaken once and was assumed to represent both the stair descent and stair ascent. This was supported by review of video recordings.

Figure 26 summaries the low back (L5/S1) compression forces for four components of the stair descent task when using Model 2. The NIOSH (1981) Back Compression Design Limit (DL: 

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Figure 22: Lift / lower at top of stairs

Figure 23: Lift / lower at bottom of stairs

Figure 24: Carry on stairs

Figure 25: Carry around landing

---

27
3400 N) and Back Compression Upper Limit (UL: 6400 N) are shown on the chart. On average, when lifting the seated patient at the top of the stairs, HEO and FEO low back compression forces were found to be 3049 N (SD: 475 N) and 4129 N (SD: 640 N) respectively. Mean HEO and FEO low back compression forces were 2083 N (SD: 526) and 2035 N (SD: 321 N) when carrying the patient down the stairs, and 2030 N (SD: 672 N) and 2304 N (SD: 297 N) when negotiating the landing. Lowering the chair at the bottom of the stairs imposed average low back compression forces of 2662 N (SD: 736 N) and 4582 N (SD: 711 N) on the HEO and FEO respectively.

Mean FEO compression forces exceeded the design limit when lifting the seated patient at the top of the stairs and lowering the seated patient at the bottom of the stairs. In some cases, the design limit was also exceeded when negotiating the staircase landing. The lifting and lowering components of the stair descent task imposed significantly greater peak L5/S1 compression forces on the FEO compared to the HEO (F = 15.395, p<0.05).

![Figure 26: Mean low back compression forces (N) during stair descent with Model 2](image)

Figure 26 summarizes the low back (L5/S1) compression forces for four aspects of the stair ascent task when using Model 2. When carrying the patient on the stairs and around the landing, the biomechanical analysis was not able to differentiate the low back compression forces of stair ascent from stair descent. However, during the lift at the bottom of the stairs, peak HEO compression forces were 3292 N (SD: 932 N) and peak FEO compression forces were 5818 N (SD: 1083 N) on average. During the lower at the top of the stairs, average compression forces were 2337 N (SD: 396 N) and 3124 N (SD: 410) for the HEO and FEO respectively. These FEO compression forces exceeded the design limit and approached, or in some cases, exceeded the upper limit. In some cases, FEO compression forces also exceeded the design limit when lowering the patient at the top of the stairs. As with the stair descent, the lifting and lowering components of the stair ascent task imposed significantly greater peak L5/S1 compression forces on the FEO compared to the HEO (F = 29.981, p<0.0005).
Figure 27: Mean low back compression forces (N) during stair ascent with Model 2

Figure 28 shows the percentage of the male or female population with sufficient static strength to sustain moments about the elbow, shoulder, torso, hip, knee and ankle joints at the four components analysed for Model 2. When personnel carry the patient on stairs, mean moments at the HEO and FEO elbow joint exceeded the SDL and approached the SUL. The analysis programme predicted that less than 20% of females would have sufficient static arm strength to flex the elbows and keep the load as close to the body as possible during the patient carry. Mean moments about the HEO shoulder joint also exceeded the female SDL when carrying on the stairs and around the landing. During patient lifting / lowering, mean HEO and FEO moments about the elbow, torso and hip exceeded the SDL. Mean FEO shoulder moments also exceeded the SDL when lifting / lowering at the bottom of the stairs.
Figure 28: Percentage (%) of male and female population with sufficient strength to generate moments about the major joints during stair tasks with Model 2.
**Conclusions from the biomechanical analyses**

The following conclusions can be made from the biomechanical analyses of *stair descent*:

1. During stair descent, mean low back compression forces at the HEO position were found to be 46% lower when using Model 1. A significant difference was found between the mean compression forces at the HEO position of the two chairs (F = 22.870, p<0.05).

2. At the FEO position, mean low back compression forces were found to be 5% greater when using Model 1 at the middle of the stairs and 72% greater at the bottom of the stairs. Mean low back compression forces of the FEO were significantly greater when using Model 1 at the bottom of the stairs (F = 22.870, p<0.0005). Despite the reduction in force exertion, the increase in compressive force was primarily due to the crouched posture, the increased distance between the load and the FEO’s low back, and the direction of force application.

3. Model 1 eliminated the lifting and lowering components of the task. At the FEO position, these task components for Model 2 imposed substantially higher peak compression forces, which approached the 6400 N upper limit.

4. With Model 2, a significant increase in low back compression forces was not found when carrying around the landing. Low back compression forces around the landing were not compared between models of chair, as the operators could not operate Model 1 within the marked confines of the landing. However, with a slightly wider landing, perhaps 90 cm in width, it would be possible to wheel the chair around the landing. This would result in a considerable reduction in compression force compared to carrying the load around the landing.

5. The percentage of the male and female population with sufficient static arm strength to descend stairs with Model 2 was considerably reduced. Where discrepancy exists between the joint moments and the percent capable, an increased risk of musculoskeletal injury is predicted (Chaffin, 1979). Use of Model 1 to descend stairs resulted in mean joint moments that were more congruent with the strength capabilities of the male and female population.

Similar conclusions were drawn from the biomechanical analyses of *stair ascent*, as this essentially involved a reversal of task sequence. With Model 1, mean low back compression forces were reduced by 31% at the HEO position, although the finding was not significant for stair ascent. Mean FEO low back compression forces were 75% greater at the bottom of the stairs and 25% greater at the middle of the stairs.

**4.1.5 Additional qualitative information offered by participants**

For the stair descent task, 88% of participants preferred using Model 1. For stair ascent, 63% of participants preferred using Model 2. However, these results should be interpreted with caution as, with any small sample, individual preferences corresponded to large changes in percentage value. In addition, the sample represented a fairly homogenous group of large, strong males, and the weight of the simulated patient remained constant. Alterations in the anthropometric and strength characteristics of the group, and different patient weights may result in variations of chair preference.
For example, some participants indicated that equipment preference would also depend on the weight of the patient and the capability of their partner. Some participants felt that carrying a seated patient required more upper body strength. Thus, with heavier patients and/or less physically capable partners, a chair that supported a portion of the load on the stairs would be beneficial. It would allow rest periods when travelling up or down the stairs, as Model 1 could be held on the stairs by the FEO with fairly little effort.

Preference for a particular piece of equipment would also depend upon many other workplace factors than those investigated in the study. Participants mentioned that Model 1 was an effective piece of equipment for descending straight staircases with wide flat landings, a task evaluated in this laboratory study. It was also highly effective across paved surfaces, as the chair could be pushed on four wheels rather than two. However, participants constantly stressed the importance of equipment versatility in the ambulance service and mentioned several risk factors in the field that restricted the widespread use of Model 1:

1. Narrow spiral staircases, where the step going at the centre of the spiral was too narrow for the wheel of the chair to rest
2. Narrow staircase landings that did not provide sufficient room for the FEO to crouch on the landing when assisting the patient and chair down the final few steps (Figure 14). Ambulance personnel did not feel that the HEO should ascend or descend any steps without the additional physical assistance and control provided by the FEO.
3. Stepped landings that had insufficient space to turn the chair
4. Long distances, particularly involving travel over gravel or grass, which tended to become caught beneath the wheels of the tension belt
5. Excessive distances between the ambulance and the injured person, where ambulance personnel may have to carry other equipment to the patient concurrently with the carry chair.

As a result of these additional risk factors in the workplace, ambulance personnel were reluctant to give up the traditional Model 2 carry chair, believing that this would reduce their ability to deliver care to patients in the wide variety of working environments encountered. Rather, ambulance personnel stressed a preference for a Model 1 and a Model 2 type chair, along with discretion to select the most effective equipment for the specific working environment, partnership and task. As with other equipment, selection would be based upon a personal risk assessment undertaken by ambulance personnel at the scene of the incident.

### 4.1.6 Results summary

The following results can be summarised from the study of the stair ascent and stair descent task. Caution should be exercised if generalising results to heavier patient weights, less capable or untrained operators or situations involving additional work factors.

1. When carrying the patient with Model 2, the HEO and FEO were found to exert a mean static force equivalent to 55% and 45% of the total weight of the load respectively. With Model 1, the HEO and FEO were found to exert a mean force of 15% and 16% of the total weight of the load.
2. While the magnitude of peak forces was reduced using Model 1, the frequency of peak forces was increased, as the operators moved the chair to each step. At the HEO
position, this was found to be particularly demanding during stair ascent, where average peak forces were equivalent to 66% of the total weight of the load.

(3) During stair ascent and descent, significant differences in posture were found primarily in the sagittal plane of motion. Use of Model 1 significantly reduced maximum sagittal flexion, range of motion and velocity by eliminating the lifting and lowering components of the task.

(4) During stair descent, mean low back compression forces of the HEO were 46% lower when using Model 1, although this benefit was not found at the FEO position. The predicted low back compression forces at the FEO position approached the 6400 N Back Compression Upper Limit when lifting and lowering the patient seated in Model 2.

(5) The percentage of the male and female population with sufficient static arm and upper body strength to carry or lift a patient seated in Model 2 was considerably less than for Model 1. Use of Model 1 to descend and ascend stairs resulted in mean joint moments that were more congruent with male and female capabilities.

(6) For the stair descent task, the majority of participants preferred Model 1 and felt it was an effective tool on straight stairs with wide landings and over paved surfaces. However, participants highlighted the importance of equipment versatility in the ambulance sector and felt that, in the presence of certain workplace factors, manual handing tasks of seated patients were better carried out with the traditional carry chair.
4.2 LOADING PATIENT INTO AMBULANCE

4.2.1 Force measurement

Figure 29 shows the peak lifting force and static holding force exerted by the HEO and FEO when lifting the seated patient seated on to the tailgate with Model 1 and Model 2. Descriptive statistics of force exertions are provided in Appendix E.

![Force Exertion Chart](image)

**Figure 29:** Peak lifting and static holding forces (N) exerted by the HEO and FEO when lifting the patient on to the tailgate

For both Model 1 and Model 2, the HEO was found to exert significantly greater force than the FEO when holding the chair for the tailgate lift (F = 25.353, p<0.0005). Table 6 shows the relative contribution of the HEO and the FEO to the total static force exerted when holding the chair.

| Table 6: Proportion of total static force (%) exerted by the HEO and the FEO when lifting Model 1 and Model 2 onto the tailgate |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Operator Position** | **Model 1** |             |             | **Model 2** |             |             |             |
|                       | **Mean** | **SD** | **Range** | **Mean** | **SD** | **Range** |
| HEO                  | 56 %    | 7 %   | 41 – 63 % | 59 %    | 2 %   | 56 – 62 % |
| FEO                  | 44 %    | 7 %   | 37 – 59 % | 41 %    | 2 %   | 38 – 44 % |

Figure 30 shows the initial pulling force on flat ground and the sustained pulling force when wheeling the seated patient up the ramp with Model 1 and Model 2. For both chairs, the sustained force exerted by the HEO when wheeling the patient up the ramp was significantly less than the static force exerted when guiding the chair onto the tailgate (F = 25.252, p<0.0005). For example, with Model 2, the mean sustained force on the ramp was 44% less than the static holding force at the HEO position, and 18% less than the static holding force at the FEO position.
4.2.2 Ratings of perceived exertion

Figure 31 shows mean HEO and FEO ratings of perceived exertion for the two ambulance loading tasks. With Model 1, the FEO reported significantly lower RPE when wheeling the patient up the ramp (F = 8.496, p<0.05) and there was a trend for the HEO to report lower RPE as well. With Model 2, the HEO and FEO reported significantly lower RPE when wheeling the seated patient up the ramp (F = 8.496; p<0.05).

4.2.3 Posture analysis

The trunk postural variables measured with the LMM are summarised in Appendix F. Results are only presented for Model 2, as this represented the most commonly used chair by the UK ambulance Trusts for ambulance loading tasks. The model of chair was not found to have a significant effect on operator posture for ambulance loading tasks. Significant postural
differences between the ambulance loading tasks were found only within the sagittal (forward bending) plane of motion.

**Forward bending**

Wheeling the patient up the ramp, HEO maximum sagittal flexion and maximum sagittal range of motion were significantly less than that of the HEO and FEO when crouching to hold the handles for the tailgate lift task \(F = 43.967, p<0.0005; F = 170.170, p<0.0005\). On average, maximum sagittal flexion was 54° for the HEO and 50° for the FEO during the tailgate lift. On average, maximum sagittal flexion was 13° for the HEO when wheeling the patient up the ramp. Maximum sagittal velocity and acceleration were also significantly less for the ramp task compared to that exhibited by the HEO and FEO when lifting the seated patient on to the tailgate \(F = 61.312, p<0.0005; F = 13.622, p<0.0005\).

**Twisting and lateral bending**

Twisting and lateral bending were limited during the ambulance loading tasks. Mean twisting range of motion did not exceed 10° (inclusive of both sides), while mean lateral bending did not exceed about 13°. During the tailgate lift, there was a trend for the FEO to exhibit a greater degree of twisting and lateral bending than the HEO. This may have occurred when trying to check that the wheels of the chair cleared the edge of the tailgate floor. However, individual variation on posture negated a significant finding.

4.2.4 **Biomechanical analysis**

Measurement of force and posture revealed only slight differences between chair models during ambulance loading tasks. Thus, biomechanical analysis was only undertaken for Model 2, as this represented the most commonly used chair in UK ambulance Trusts. Figures 32 – 34 show examples of the postures adopted by ambulance personnel for the biomechanical analysis.

Figure 35 summaries the low back (L5/S1) compressive forces for these three components of the ambulance loading tasks. The NIOSH Back Compression Design Limit (DL: 3400 N) and Back Compression Upper Limit (UL: 6400 N) are shown.

On average, peak compression forces at the start of the tailgate lift were 8055 N (SD: 309 N) for the HEO and 6103 (SD: 806 N) for the FEO. At the top of the lift, as the chair was carried onto the tailgate, compression forces were found to reduce, on average, to 2421 N (SD: 427 N) for
the HEO and 1697 N (SD: 284 N) for the FEO. However, when wheeling the patient up the ramp, L5/S1 low back compression forces at the HEO position were found to be 1129 N (SD: 375 N) on average. Low back compression forces at the FEO position were not determined for the ramp task, as participants felt that the physical requirements of the task were suitable for one-person.

The method of loading a seated patient into the ambulance had a significant effect on participant low back compression force (F = 263.423, p<0.0005). Wheeling the patient up the ramp resulted in significantly reduced low back compression forces compared to both the HEO and FEO at the start of the tailgate lift, and the HEO at the top of the tailgate lift (p<0.0005). Wheeling the patient up the ramp resulted in compression forces that were 86% and 82% less than those imposed on the HEO and FEO at the start of the tailgate lift, and 53% less than those imposed on the HEO at the top of the tailgate lift.

![Figure 35: Mean low back compression forces (N) during ambulance loading tasks](image)

Figure 35: Mean low back compression forces (N) during ambulance loading tasks

Figure 36 shows the percentage of the male or female population with sufficient strength to generate moments about the elbow, shoulder, torso, hip, knee and ankle joints at the three positions of the ambulance loading tasks. The Strength Design Limit (SDL) is exceeded if the percent capable is below either 99% for men or 75% for women, while the Strength Upper Limit (SUL) is exceeded if the percent capable is below 25% for men and 1% for women.

At the start of the tailgate lift, mean moments at all joints exceeded the SDL, while hip moments of at the HEO position were predicted to violate the SUL. At the top of the tailgate lift, mean moments at the elbow, shoulder and hip exceeded the SDL. It was predicted that less than 20% of the female population would have sufficient arm strength to carry the patient and chair on to the tailgate. In addition, shoulder and torso strength was also found to be a limiting factor for the tailgate lift task.

When wheeling the patient up the ramp, only mean hip moments exceeded the SDL. Otherwise, mean moments about the joints were more congruent with the physical strength capabilities of the working population.
4.2.5 Results summary

The following results can be summarised from the ambulance loading tasks:

1. When wheeling the patient up the ramp, force exertion was significantly reduced. The mean sustained force on the ramp was 44% less than the static holding force at the HEO position, and 18% less than the static holding force at the FEO position.

2. Ambulance personnel reported significantly greater perceived exertion during the tailgate lift task compared to the ramp task when using the most common model of chair.

3. During the tailgate lift and ramp task, significant differences in posture were found primarily in the sagittal plane of motion. Maximum sagittal flexion was 50 - 54° on average at the start of the tailgate lift, but only 13° at the HEO position during the ramp task. Sagittal velocity and acceleration were all greater during the tailgate lift compared to the ramp task.

Figure 36: Percentage (%) of male and female population with sufficient strength to generate moments about the major joints during ambulance loading tasks.
Wheeling the patient up the ramp imposed significantly lower L5/S1 compression forces on ambulance personnel compared to the tailgate task. Wheeling the patient up the ramp resulted in compression forces that were 86% and 82% less than those imposed on the HEO and FEO at the start of the tailgate lift, and 53% less than those imposed on the HEO at the top of the tailgate lift.

In many cases, at the start of the tailgate lift, predicted low back compression forces exceeded the 6400 N Back Compression Upper Limit, for ambulance personnel acting as both the HEO and the FEO. Based upon this criterion for musculoskeletal injury, the task is considered to be hazardous to most workers.

At the start of the tailgate lift task, mean moments at all joints exceeded the Strength Design Limit, while hip moments at the HEO position were predicted to violate the Strength Upper Limit. When wheeling the patient up the ramp, mean moments about the joints were more congruent with the physical strength capabilities of the working population.
4.3 DESCENT OF A KERB

4.3.1 Force measurement

Figure 37 shows the peak forces exerted by the HEO and FEO when using Model 1 to descend the simulated kerb. On average, for Model 1, the peak force exertion of the HEO was about 52% of the total weight of the load (827 N). The peak force exertion of the FEO was about 40% of the total weight of the load. For Model 2, the peak force exertion was about 47% of the total weight of the load (785 N) at the HEO position and 50% at the FEO position. However, with substantial variation measured amongst operators, significant effects of chair models or operator position were not found in the magnitude of peak force exertion.

![Force measurement graph](image)

**Figure 37:** Peak forces (N) exerted by the HEO and FEO during kerb descent with Model 1 and Model 2

4.3.2 Ratings of perceived exertion

Figure 38 show the mean and standard deviations in RPE for the kerb descent task.

![Ratings of perceived exertion graph](image)

**Figure 38:** Mean ratings of perceived exertion for kerb descent task
Mean RPE results were relatively low, with participants not reporting exertion above the ‘light’ category. This possibly reflects the fairly short duration of force exertion as the chair was lowered. The mean duration of ‘considerable’ force exertion (beyond that required to support or push the chair on even ground) was 3.1 seconds (SD: 0.7 seconds) on average for Model 1 and 3.5 seconds (SD: 0.8 seconds) on average for Model 2. The model of chair and operator position were not found to have a significant effect on ratings of perceived exertion.

4.3.3 Posture analysis

Descriptive statistics of the LMM postural variables measured during the kerb task are summarised in Appendix F. Only results of kerb descent are presented, as this was believed to be the most common direction of travel over the kerb during patient transport to the ambulance. Due to individual postural variation, few significant effects of the chair model or operator position were found.

**Forward bending**

With Model 1, FEO maximum sagittal flexion was found to be significantly greater than HEO maximum sagittal flexion ($F = 5.700, p<0.005$). On average, maximum HEO sagittal flexion was measured to be only $8^\circ$, while FEO flexion was measured to be $30^\circ$. A similar effect was not found with Model 2, where maximum sagittal flexion of the HEO was measured to be $16^\circ$ on average.

For Model 2, maximum sagittal velocity was found to be significantly greater at the FEO position compared to the HEO position ($F = 5.632, p<0.005$). However, this finding was likely to describe FEO movements to assume the lifting position, rather than the period of force application, during which sagittal motion was fairly slow and controlled.

**Lateral bending and twisting**

Twisting and lateral bending were limited when descending the kerb. The average range of twisting motion (inclusive of both directions) was about $10^\circ$ for the HEO and $12^\circ$ for the FEO. The average range of lateral bending was about $10^\circ$ for the HEO and $15^\circ$ for the FEO. With Model 2, maximum lateral velocity was found to be significantly greater at the FEO compared to the HEO position. This could be explained by the FEO having to bend to the side of the Model 2 chair to view the wheels and ensure a smooth and controlled descent. This may not be necessary with Model 1, where the belt remains in contact with the kerb.

4.3.4 Biomechanical analysis

Figure 39 and 40 show typical postures adopted by ambulance personnel during the kerb descent task with Model 1 and 2 respectively. Biomechanical analysis was undertaken at one position, as the chair wheels were lowered from the kerb to the ground. Due to the short duration of the task, peak compression forces were entered in the model for the analysis, as an indication of worst case scenario for this patient weight.

For the analysis, many of the postures adopted by ambulance personnel at the FEO position could not be replicated with the biomechanical model. For example, one participant knelt on one leg, while another participant exhibited extreme knee flexion and supported their elbows on top of their legs. Such postures had to be excluded from the analysis, which resulted in a sample of only 6 participants for the FEO position.
Figure 41 shows the results of the low back (L5/S1) peak compression forces. The model of chair and operator position was found to have a significant effect on low back compression forces ($F = 62.408, p<0.0005$) of ambulance personnel.

![Figure 39: Kerb descent with Model 1](image1)
![Figure 40: Kerb descent with Model 2](image2)

**Figure 41: Mean low back compression forces (N) during kerb descent task**

HEO L5/S1 compression forces were predicted to be 1746 N (SD: 407 N) for Model 1 and 2771 N (307 N) for Model 2, both of which were below the 3400 N Back Compression Design Limit. With Model 1, low back compression forces at the HEO position were 37% lower compared to Model 2 ($F = 62.408, p<0.0005$). FEO L5/S1 compression forces were predicted to be 4064 N (SD: 516 N) for Model 1 and 4358 N (SD: 406 N) for Model 2. Compression forces differed by less than 1% at the FEO position, and with both chairs, were between the Design Limit and the 6400 N Back Compression Upper Limit. With both Model 1 and Model 2, these FEO low back compression forces were found to be significantly greater than HEO compression forces ($p<0.0005$).

Figure 42 shows the percentage of the male or female population with sufficient strength to generate moments about the elbow, shoulder, torso, hip, knee and ankle joints when using...
Model 1 and Model 2 to descend the kerb. At the FEO position, results for Model 1 and Model 2 were similar, with the Strength Design Limit (SDL) exceeded by mean FEO moments at the elbow, shoulder, torso, hip and knee. At the HEO position, mean moments exceeded the SDL at the elbow, shoulder, hip and ankle for Model 1, and additionally at the torso for Model 2.

Figure 42: Percentage (%) of male and female population with sufficient strength to generate moments about the major joints during kerb descent task

4.3.5 Results summary

The following results can be summarised for the task of negotiating a kerb:

(1) Participants perceived the kerb task to be fairly ‘light’, possibly due to the brief 3 seconds of force duration.

(2) The stooped posture and fairly high peak force exertions exposed the FEO to significantly greater low back compression forces. These forces were above the 3400 N Back Compression Design Limit and indicated that this task would be hazardous for some workers. Use of Model 1 chair reduced the compression forces imposed on the HEO by about 37%; however, no effect was found at the FEO position.
5 DISCUSSION

5.1 EFFECT OF CHAIR MODEL ON THE PHYSICAL DEMANDS OF STAIR DESCENT

Results of this study and a similar study (Fredericks et al., 2002b) suggest that, during stair descent, the physical demands imposed upon ambulance personnel and the risk of injury to the low back are lower with chairs that support the weight of the patient on the stairs.

5.1.1 Head-end operator position

At the HEO position, the mean force exerted when descending the stairs with Model 1 was found to be 69% less than the mean force exerted to hold the patient and chair. Even the magnitude of the peak forces was found to be 30% lower than the mean force exerted to hold the patient and chair. In addition, participants tended to report lower ratings of perceived exertion when using Model 1. Some participants indicated that they would have provided a greater RPE value for the carrying task with Model 2 if the staircase had been longer, as was typically the case in the field. These findings were corroborated by Fredericks et al. (2002a), who showed that using a chair that supported the weight of the patient on the stairs resulted in lower RPE along with force exertions that were 90% lower than those applied to the chairs that required carrying.

As a result of the lower force exertion, the biomechanical analysis showed that the mean low back compression forces were reduced by 46% at the HEO position with Model 1. Similarly, Fredericks et al. (2002b) reported that, where the stairs supported the weight of the patient and chair, compression forces imposed on the HEO were reduced by 33 – 51% depending on the design of the chair. Birtles and Boocock (2003) reported that for patient transports involving the use of a carry chair (38%), the task of descending stairs was performed on about one half of incidences. Thus, in reducing the low back compression forces imposed on the HEO during stair descent, the daily cumulative load on ambulance personnel could be reduced substantially.

In this study, participants represented the upper quartile in stature and weight for the British working adult population. Thus, it is difficult to determine whether the information collected from this study would describe task performance by other groups of ambulance personnel; for example, females or shorter males. If females were to perform the task in the same manner as the study participants, the static strength prediction programme predicts arm strength to be the limiting factor for the HEO when carrying patients down stairs. Specifically, it predicted that, for a 70 kg patient, less than 20% of females would be able to sustain moments at the elbow joints necessary to keep the handles of the chair at waist height and close to the body. Where discrepancy exists between the joint moments and the percent capable, an increased risk of musculoskeletal injury is predicted (Chaffin, 1979). Additionally, if ambulance personnel possessed insufficient arm strength to carry the patient down the stairs, it is predicted that their elbows would extend, arms would straighten and the handles of the chair would be lowered to about hip level. The low handle height could obstruct walking down the steps, place increased physical stress on the shoulders and back, compel the HEO to adopt a stooped upper body posture and shift the bearer’s centre of gravity further over the edge of the stairs. This would increase the musculoskeletal loads imposed on the HEO considerably, as well as the risk of injury to both the chair bearers and the patient. In contrast, where the weight of the 70 kg patient and chair was supported by the stairs, this study predicted that more than 80% of males and females would have sufficient strength about the major joints to descend stairs at the HEO position.
Chairs that support the weight of the patient on the stairs reduce the risk of low back injury to the HEO and allow the stair descent task to be performed within the physical capabilities of a greater percentage of the working population.

5.1.2 Foot-end operator position

In contrast to the HEO position, little biomechanical benefit was found at the FEO position with respect to low back compression forces. These were found to be 5% greater when transporting the patient at the middle of the stairs, and 72% greater at the bottom of the stairs. This is unexpected considering that the mean force exerted when using Model 1 was found to be 64% less than the mean force exerted when holding the patient and chair. In addition, participants reported significantly lower ratings of perceived exertion when using the chair that supported the weight of the patient on the stairs. It appears that this increase in compression force was primarily due to the trunk flexion required to reach the foot-end handles, which were positioned low and close to the patient’s legs. In this case, the weight of the handler’s upper body imposed the majority of the compression force upon the lower back.

However, this study has also shown low back compression forces to be greatest at the FEO position when lifting the chair from the floor to waist height, rather than when carrying the patient down stairs. Mean low back compression forces were found to be about 4600 N at this position, which falls between the Back Compression Design Limit and the Upper Limit. However, the 70 kg simulated patient only represented the 47th percentile weight for the British adult population, and it is likely that ambulance personnel frequently carry much heavier patients down the stairs. Where the task involves lifting the chair and patient, extensive sagittal velocity and acceleration were also evident at the FEO position, and this would further increase the risk of injury, beyond that which the biomechanical model can predict (see Section 5.6 for limitations of the biomechanical model). As a result, lifting a seated patient from floor to waist height would be hazardous to some workers and should be examined carefully. In this respect, chairs that support the weight of the patient on the stairs and eliminate the lifting and lowering component of the task to reduce the peak low back compression forces and the risk of low back injury at the FEO position.

Eliminating the lift component of the task would also reduce the risk of injury that might arise if a patient becomes uncooperative, unbalanced, aggressive, or in anyway shifts the centre of gravity of the load. Such changes to the characteristics of the load could impose unpredictable physical loads on any ambulance personnel carrying the patient at this moment. Implications for participant and patient safety render it difficult to investigate such risk factors quantitatively. However, when transporting patients down stairs, the likelihood and consequences of such physical stresses could be quite high. In such instances, a chair that supports the weight of the patient on the stairs could alleviate much of the additional physical demand suddenly imposed upon the operators. In addition, with the chair supported against the stairs, transport down the stairs could be interrupted to attend to the patient’s needs and address the additional risks. When carrying the chair and patient, the operators must continue transporting the patient to a landing before the chair can be lowered and such risks can be addressed.

One method of reducing the musculoskeletal loads at the FEO position could be to extend the foot-end handles away from the patient’s feet. This may have been the case for the study undertaken by Fredericks et al. (2002b), which found a reduction of 44 – 53% in low back compression force when using a chair that supports the loads on the stairs. However, lengthening the foot-end handles would also increase the landing space required at the bottom of the staircase. In this study, the FEO was unable to perform the task within the marked boundary of the 80 cm wide landing (Figure 43) and wider landings would be required to wheel the chair around in the landing (Figure 44). Fredericks et al. (2002b) found compression forces
to be about 838 N (SD: 385 N) when wheeling the chair around a landing. However, Fredericks et al. (2002b) noted that ‘negotiation of the 90° degree landing was a particularly hazardous task’, and identified ‘the need to develop stair chairs that could easily manoeuvre in tight situations’. Uneven landings present a further obstacle, limiting the amount of space in which to turn the chair. This study agrees with that conclusion, as the benefit of a chair that supports the weight of the patient on the stairs would only be optimised if it could be used regularly within confined spaces.

![Figure 43: Unable to operate within the landing boundaries](image)

![Figure 44: Negotiating the landing if sufficient space were available](image)

5.2 EFFECT OF CHAIR MODEL ON THE PHYSICAL DEMANDS OF STAIR ASCENT

During patient transport up stairs, participants’ RPE suggest that supporting the weight of the patient on the stairs may not provide the same psychophysical benefit as that when moving down stairs. The non-significant finding in RPE was believed to reflect the magnitude of peak force exertions when using Model 1.

At the HEO position, the mean force was 21% less than the static holding force, while the peak force exerted was 27% greater than the static holding force. Stair ascent at the HEO position was found to be particularly demanding, as the mean magnitude of these peak forces approached 66% of the total weight of the load (range of 60 – 73%). A significant difference was not found at the HEO position between the peak forces exerted when using Model 1 to ascend stairs and the peak force exerted when lifting the patient seated in Model 2. Thus, with respect to force exertion, use of Model 1 to ascend stairs essentially changed the carry task up the steps, which typically involved a single lift, into a multiple lifting task.

When using Model 1, mean low back compression forces were reduced by 31% at the HEO position. However, this was not found to be significantly different from low back compression forces when carrying the patient on stairs. Despite using trained ambulance personnel in this study, individual technique appeared to have a large influence on posture in addition to task-based factors. This suggests that more comprehensive manual handling training may be
required, possibly involving postural feedback with video, to promote upright postures when using chairs such as Model 1.

During stair ascent, the main benefit of chairs that support the weight of patient on the stairs may be the reduction in the moments about the major joints and the corresponding increase the ‘percent capable’. Tasks in which strength is a limiting factor should be thought of as putting ambulance personnel at risk for overexertion-type injuries (Chaffin, 1979). Thus, where ambulance personnel have insufficient arm strength to carry a patient up the stair safely, chairs that support the weight of the patient on the stairs may be preferred. When travelling up the stairs with a 70 kg patient, more than 80% of males and females are predicted to have sufficient strength about the major joints to ascend stairs at the HEO position.

At the FEO position, mean low back compression forces were 75% greater at the bottom of the stairs and 25% greater at the middle of the stairs when using Model 1. Again, this appears primarily due to forward trunk flexion required to reach the foot-end handles of the chair, as the mean force exerted with Model 1 was 51% less than the mean force exerted to hold the patient and chair. The average peak forces exerted with Model 1 were only 20% less than the mean force exerted to hold the patient and chair.

At the FEO position, it was predicted that some female operators could have insufficient shoulder strength to generate shoulder moments required when using chairs that support the weight of the patient on the stairs. The large predicted shoulder moments appear to reflect the complex direction of force application. In the biomechanical model, the angle of force exertion was set to 40° from horizontal, which represented a combination of lifting and forward pushing to keep the belt in contact with the edge of the stairs. Where insufficient pushing force was applied, the belt could be lifted off of the stairs when travelling up each stair, placing additional physical demand on the operators. However, rather than adopt a semi-prone (neutral) grip at the middle of the handle, during stair ascent, most participants were observed to grasp the base of the handles with a supine (underneath) grip. This suggests that participants may have actually applied force in a more vertical direction, more indicative of a true lifting / lowering task. Unfortunately, it was not possible to measure the precise direction of force application during the main study. If a substantial horizontal pushing force at the FEO position is imperative to the safety of the task, to ensure that the belt of the chair remains in contact with edge of the step, the limited predicted female shoulder strength for this combination of posture and direction of force application should be considered.

When transporting patients up stairs, supporting the weight of the patient on the stairs may increase the percentage of the workers with sufficient strength to perform the task. However, it appears that the transport of patients up stairs remains a fairly physically demanding task. In the long term, mechanical handling aids that actually lift the patient and chair up each step may be required for the stair ascent task. However, the involvement of such additional chairs was beyond the scope of this study.

Analysis of the stair ascent task highlights that selection of the most effective piece of equipment for patient transport depends upon the specific characteristics of the patient, ambulance personnel and the work environment. Ambulance personnel stressed a preference for a traditional carry chair as well as a chair that supports the weight of the patient on the stairs. Rather than impose one model of chair on ambulance staff, ambulance personnel reported that risk could be controlled more effectively with worker discretion and training in personal risk assessment and manual handling technique. One ambulance Trust appears to have implemented a successful trial to equip all front line A&E and PTS vehicles with both models of chair. However, other ambulance Trusts report barriers to implementing this control measure, primarily citing that there is insufficient space to store an additional chair within many
ambulances. Until an optimal chair design emerges for the ambulance service, the risk of musculoskeletal injury to ambulance personnel should be reduced with the implementation of safe systems of work (see Section 5.5).

5.3 **EFFECT OF A RAMP ON THE PHYSICAL DEMANDS OF LOADING A SEATED PATIENT INTO AN AMBULANCE**

Several measures indicate that wheeling a patient into the ambulance can significantly reduce the risk of injury to the low back compared to lifting a seated patient into the ambulance. When wheeling the patient up the ramp, force exertion was significantly reduced. With the traditional carry chair, the mean sustained force on the ramp was 44% less than the static holding force at the HEO position. In addition, with the ramp, ambulance personnel did not have to accelerate the patient and chair from floor level to the height of the tailgate. As a result, this not only eliminated the peak force exertion of the lifting component, but also reduced the risk of injury that might arise due to unpredictable characteristics of the patient load, such as a shift in the centre of gravity during the lift. The reduced force exertion was supported by significantly lower ratings of perceived exertion when wheeling the seated patient up the ramp.

In reducing force exertion and eliminating the lift from floor level, wheeling the patient up the ramp imposed significantly lower low back compression forces on ambulance personnel compared to the tailgate lifting task. In many cases, at the start of the tailgate lift, predicted low back compression forces exceeded the 6400 N Back Compression Upper Limit, for ambulance personnel acting as both the HEO and the FEO. Based upon this criterion, the lifting a 70 kg patient into the back of the ambulance is considered to involve a high-risk of low back injury. If the weight of the patient were greater than 70 kg, low back compression forces and the risk of injury would be even greater. Upper body strength was also found to be a limiting factor for all major joints during the tailgate lift, a further indication of a risk of musculoskeletal injury. Where the height of the ambulance tailgate is lower than 75 cm, the low back compression forces of the HEO may be reduced slightly for a 70 kg patient. However, the low back compression forces of the FEO should remain fairly constant, as regardless of the tailgate height, the lift would always occur from floor level.

In contrast, wheeling the patient up the ramp resulted in mean S1/L5 compression forces of only 1122 N at the HEO position. This was 86% and 82% less than those imposed on the HEO and FEO at the start of the tailgate lift, and 53% less than those imposed on the HEO at the top of the tailgate lift. When wheeling the patient up the ramp, mean moments about the joints were more congruent with the physical strength capabilities of the working population.

Nonetheless, the risk of musculoskeletal injury associated with pulling a seated patient up a ramp into the ambulance should not be neglected. Psychophysical data (Snook and Ciriello, 1991) suggest that forces exerted when pulling the 70 kg patient up a 10° ramp would be deemed acceptable by about 90% of males and 75% of females. The effects of ramp gradient were beyond the scope of this study. However, initial measurements suggest that resultant force exertions could increase by a further 25% when wheeling a 70 kg patient up a ramp with an angle of 15°. This would be deemed acceptable by about 75% of males and 25% of females. Where force exertions exceed the psychophysical capability of the worker, an increased risk of musculoskeletal injury is predicted. In addition, the risk of slipping would increase while pulling the patient up the ramp. Where heavier patients and/or steeper ramps can increase the required pulling force up the ramp beyond a level that some ambulance personnel are capable of exerting safely, alternative systems of loading the patient into the ambulance are required to reduce the risk of musculoskeletal injury further.
5.4 EFFECT OF CHAIR MODEL ON THE PHYSICAL DEMANDS OF NEGOTIATING A KERB

Participants exerted a considerable amount of force to negotiate the kerb. However, the brief 3-second duration of force exertion may have led participants to perceive the physical demands of the task to be fairly ‘light’.

Nonetheless, at the HEO position, low back compression forces were found to approach the 3400 N Design Limit when using a traditional carrying chair. Use of the chair that supported the weight of the patient and chair on the edge of the kerb was found to reduce HEO compression forces significantly by 37%. At the FEO position, compression forces were found to exceed the 3400 N Back Compression Design Limit, which indicated that this task would be hazardous for some workers. However, the model of chair was not found to have an effect on the low back compression forces imposed on the FEO. The risk of acute musculoskeletal injury could be much greater at the FEO position if the stooped posture of the operator is coupled with much greater forces exertions that might arise with a heavier patient.

Kerbs were found to be a particularly frequent obstacle encountered by ambulance personnel during the transport of seated patients (Birtles and Boocock, 2003). Thus, the task of negotiating a kerb will contribute to the cumulative load imposed upon the FEO, which over the course of a day seems to exceed the load imposed on the HEO due to repeated lifting below waist height or even at floor level. Low back compression forces imposed upon ambulance personnel were found to be similar to those of stairs tasks, and although short in duration, appropriate attention and training should be given to minimise the risk of acute musculoskeletal injury with these frequently encountered obstacles.

5.5 DEVELOPMENT OF SAFE SYSTEMS OF WORK FOR HANDLING SEATED PATIENTS

Regardless of whether a chair that supports the weight of a patient on the stairs can be incorporated into front-line vehicles, ambulance Trusts should still take other proactive measures to reduce the risk of musculoskeletal injury from seated patient handling. These measures will need to focus on the development and evaluation of safer systems of work. For example, additional personnel should be called in to assist with those patient transports that an ambulance crew have identified will involve a high-level of manual handling risk. Dedicated vehicles with specialised equipment may need to be deployed as well, to assist with operations, where the risk of musculoskeletal injury cannot be controlled sufficiently with additional personnel. Several Trusts are currently piloting the design and deployment of such specialised vehicles and equipment. These systems of work need to be supported with effective training of ambulance personnel to identify high-risk handling operations, use specialised equipment and handle patients in teams of more than two people. In addition, these systems of work need to be managed strategically to ensure that crews can obtain support quickly and consistently and that such systems can function under most emergency pressures.

As an assessment of manual handling tasks involving the use of carry chairs, this study compared two systems of manually loading a seated patient into the back of an ambulance: lifting a seated patient directly into the ambulance and wheeling a seated patient up a ramp and into the ambulance. However, where there is a greater level of manual handling risk than that simulated in this study, wheeling a patient up a ramp and into the ambulance may not reduce the risk of musculoskeletal injury sufficiently. In these circumstances, alternative systems of
loading a patient into an ambulance are required. These could include the use of a mechanical tailgate lift system, a winch, or other stretcher-based systems for loading a patient into the ambulance. However, investigation of these systems of work was beyond the scope of this study.

The Ambulance Service Association (ASA) has produced a National Policy and Strategy Framework on safer handling, which suggests broader initiatives to support safer handling by ambulance personnel. These include clinical protocols (“Can you walk?”), purchase, maintenance and replacement programmes for equipment, vehicle design projects, and collaboration with local agencies such as care homes and councils on patient handling issues.

5.6 LIMITATIONS OF THE STUDY

When using biomechanical models as a predictor of the risk of musculoskeletal injury, there are several limitations with both the University of Michigan model and the NIOSH guidelines (1981) that should be recognised:

(1) The NIOSH guidelines relate only to lifting in the sagittal plane and the spine may be much more vulnerable under trunk twisting or extreme flexion. Although significant trunk twisting was not observed during the simulations, it is likely that such posture could be adopted when carrying seated patients in the field, particularly where there are severe space constraints.

(2) Ambulance personnel perform a range of other patient handling tasks, many of which have been shown to be above the 3400 N Back Compression Design Limit and some above the 6400 Upper Limit (Marras et al., 1999; Lavendre et al., 2000b). Performance of these tasks may then predispose ambulance personnel to a greater risk of injury when carrying patients down stairs. It may be inappropriate to assume that ambulance personnel can be protected by criteria designed for ‘healthy workers’.

(3) The biomechanical model and guidelines do not take repetitive or sustained exertion into consideration, such as the exertion of carrying patients down stairs. However, most chronic low-back pain has been found to be the result of cumulative exposure and degeneration over time. The extent to which compression forces should be reduced for sustained exertions has not yet been determined, although Genaidy et al. (1993) has suggested that tolerance limits should be reduced to about 60% of the predicted compression strengths.

(4) The biomechanical analysis was restricted to an analysis of static postures and therefore cannot consider the dynamic components of the movement. This was not regarded as a major limitation as many of the postures, such as those observed when holding the traditional chair or using the recent chair, occurred in a slow, controlled manner and were considered to be quasi-static. However, the lifting elements of the various tasks did involve dynamic components, characterised by high sagittal accelerations. In these instances, inertial effects during the first acceleratory phase of the lift can increase the spinal compression forces considerably. In this study, L5/S1 compression forces determined for the lifting components of tasks should be interpreted as underestimations.

These limitations should emphasise that for manual handling tasks involving the use of carry chairs, where dynamic lifting and sustained carrying is involved, there is a need to reduce the
low back cumulative exposure of ambulance personnel regardless of whether the mean compression forces exceed the NIOSH Back Compression Design Limit.

The physical demands of the tasks may also be underestimated through the selection of participants. In excluding people who have previously suffered back pain, and involving a degree of self-selection in the recruitment process, this study may have involved participants that were more physically capable of performing the tasks than the actual population of ambulance personnel. In this study, participants tended to represent the upper quartile of the British working population in terms of both stature and weight and females were not represented in the group. Based upon the performance of the participants, limiting strength factors for the task can be determined to give some insight into whether the task can be performed safely by a greater percentage of the workforce, including, for example, females. Although it was possible to estimate the percentage of the working population for which arm strength may be a limiting factor, it was not possible to observe how this might affect whole body posture, nor estimate low back compression forces for such a person. It was also not possible to describe how participants with reduced physical capability may perceive the exertion of the tasks.

As a result of these limitations, any absolute risks of musculoskeletal injury described in this study should be interpreted as an underestimation, rather than an overestimation.
6 CONCLUSIONS

This study has principally shown the following:

(1) When carrying a patient up and down stairs, the operator at the head-end position of the chair was found to exert more force than the operator at the foot-end position. However, the risk of low back injury appeared greatest at the foot-end position, as operator force exertion was combined with forward trunk flexion. The activity of lifting the chair from a low level has the potential to expose the foot-end operator to a high-risk of low back injury.

(2) Participants of this study represented the upper quartile of the British adult working population in terms of both stature and body weight, which suggests that this study may overestimate the physical capabilities of many UK ambulance personnel. In particular, high physical demands were placed upon the operators’ arms when carrying a seated patient up and down stairs. A considerable percentage of the working population may have insufficient arm strength to hold the load close to the body and maintain an upright trunk posture during this task. Where discrepancy between the physical demands of the task and worker capability is predicted, there is an increased risk of musculoskeletal injury. Thus, additional information is required on how the physical demands of the task are perceived by ambulance personnel that were not represented in this study (e.g. females, short males).

(3) Neither of the two chairs involved in this study offered a single, optimal solution for reducing the risk of musculoskeletal injury to ambulance personnel in the full range of circumstances where seated patients may need to be transported.

(4) When transporting patients down stairs, means for supporting the weight of the patient and the chair on the stairs provides one promising control measure for reducing the risk of low back injury to ambulance personnel. This control measure also reduced the physical demands placed on the upper body and should increase the percentage of workers with sufficient arm strength to perform the task.

(5) When transporting patients up stairs, the benefits of supporting the weight of the patient on the stairs are much smaller and the task remains physically demanding.

(6) Versatility was reported to be a key requirement for emergency chairs in the field, and a number of additional workplace factors, such as confined spaces, or uneven stair landings were found to limit situations in which more recently developed chairs could be utilised. As a result, ambulance personnel may still need to carry seated patients in these particular ‘high risk’ environments.

(7) Lifting a seated 70 kg patient directly into the back of an ambulance poses a high risk of low back injury to ambulance personnel. As a comparison, the risk of low back injury was greatly reduced when ambulance personnel wheeled the seated patient up a low-gradient ramp. Nonetheless, wheeling a seated patient up a ramp does not reduce the risk of musculoskeletal injury sufficiently in some instances; for example, where heavier patients and/or steeper ramps can increase the required pulling force up the ramp beyond a level that some ambulance personnel are capable of safely exerting. In such circumstances, alternative systems of loading a patient into an ambulance are required to reduce the risk of musculoskeletal injury further. However, investigation
of alternative systems of loading a patient into an ambulance was beyond the scope of this study.

(8) Participants in this study did not perceive the physical demands of negotiating a kerb to be high due to the short duration of the task. However, this study found that peak low back compression forces imposed upon the ambulance personnel when negotiating a kerb were similar to those incurred when transporting a patient up or down stairs.
7 RECOMMENDATIONS

(1) There is an urgent need to improve the designs of chairs that offer mechanical assistance in the transportation of patients up and down stairs. In particular, improving the versatility of more recently developed chairs is thought to be a primary driver for greater implementation across front-line A&E crews. In this respect, there appears to be a need for chairs that can negotiate narrow landings, and chairs that can either support the weight of the patient on the stairs, or in the presence of certain environmental risk factors such as confined spaces or uneven terrain, serve as a light, carrying alternative. Some manufacturers are working more closely now with some ambulance services on future carry chair design and there is a greater awareness that risk management and health and safety in the design is a significant factor in purchasing decisions of this nature. Nonetheless, advances in emergency chair design might be facilitated through a collaboration of stakeholders that is led by a central representative body such as the Ambulance Service Association (ASA).

(2) Currently, there are certain situations where ambulance personnel must carry seated patients. However, efforts should be made to limit the extent of patient carrying that occurs on stairs and to reduce the risk of musculoskeletal injury. This can be accomplished by developing safer systems of work. For example, operational protocols should be developed for the management of specialised situations that incur a high level of manual handling risk. Additional personnel could be called in to assist in those patient transports that an ambulance crew have identified will involve a high-level of manual handling risk. Several Trusts are undergoing trials of specialised vehicles equipped with mechanical chairs and other equipment that could respond to these situations as well. These systems of work must be supported with effective training of ambulance personnel to identify high-risk handling operations, use specialised equipment and handle patients in teams of more than two people. In addition, these systems of work need to be managed strategically to ensure that crews can obtain support quickly and consistently and that such systems can function under most emergency pressures. The ASA has documented some broader initiatives for supporting safer handling such as clinical protocols (“Can you walk?”) and collaboration with local agencies such as care homes and councils on patient handling issues.

(3) In the long term, mechanical handling aids that actually lift the patient and chair up each step may need to be implemented for those ambulance personnel that routinely transport patients up stairs. Further research is required to evaluate the musculoskeletal loads imposed on ambulance personnel and any additional risk factors that arise when using such chair designs.

(4) Vehicle purchasing programmes should promptly phase out all A&E and PTS vehicles that require ambulance personnel to lift or carry seated patients into the back of the vehicle. Where vehicle purchase orders specify the use of ramps as the primary system of patient loading, efforts should be made to select ramps with the lowest gradient, whilst still complying with aspects of EN 1789 (2000). In many circumstances, the task of loading a patient into an ambulance should be supported with alternative systems of work (e.g. using a mechanised tailgate lift, a stretcher loading system or ramp in combination with a winch).
Although short in duration, the task of negotiating a kerb requires attentive execution and support from safe systems of work to minimise the risk of injury to the low back of ambulance personnel.
APPENDIX A: BORG’S (1982) RPE SCALE

Ratings of Perceived Exertion

Please **point** to the **number** on this scale that matches how **physically demanding** you feel the task is:

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>Extremely light</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Very light</td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Light</td>
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<tr>
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</tr>
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<td>15</td>
<td>Hard</td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Very hard</td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Extremely hard</td>
</tr>
<tr>
<td>20</td>
<td>Maximal Exertion</td>
</tr>
</tbody>
</table>
APPENDIX B: WRITTEN INSTRUCTIONS ISSUED TO PARTICIPANTS

EVALUATION OF MANUAL HANDLING TASKS INVOLVING CARRY CHAIRS

INSTRUCTIONS FOR PARTICIPANTS

The task: You will be provided with demonstrations of the task. These will involve correct procedures for using each of the carry chairs. You and your partner will work as a team to carry out each of the required handling tasks, varying your role as either the foot-end or head-end operator. You will be given plenty of opportunity to familiarise yourself with using the equipment. A ‘patient dummy’ weighing approximately 70 kg will be seated and secured to the chairs.

Safety precautions: If at any time you experience any difficulties then you must immediately tell the researcher who will be on hand to provide assistance. Listen and follow carefully the instructions provided. Before carrying out any of the activities, we will ask you to undertake some light warm-up exercises lasting 5 minutes.

Risks: The physical nature of the task may expose some people to a risk of muscle strain or sprain, pulled tendons, back pain or sprain, or hernia. Some people may also experience slight discomfort from muscle soreness. The risk of any of these occurring is small and every attempt will be made to prevent their occurrence. It is important to follow the safety procedures described.

Measuring procedures: A lightweight measuring device will be attached to your back and reflective markers attached to your clothes using adhesive tape/bandages. Video recordings will also be made of each activity. Information collected from these devices will be used to track the movement of your back and limbs during each task.

At the end of each handling task you will be shown two rating scales and asked to give a score for how hard you found each task.

To determine the forces you exert during each handling task, you will initially be asked to perform a series of lifts while either standing on force measuring platforms or holding a force measuring device.

Acknowledgement of what is required: I have read these instructions and I am aware of what the study involves and the associated risks. If at any time I wish to withdraw from the study, then I may do so.

Signature: .......................................

Date: ............................
APPENDIX C: CONSENT FORM

VOLUNTEER CONSENT FORM

TITLE OF PROJECT: Manual handling tasks involving the use of the emergency carry chairs

The volunteer should complete the whole of this sheet himself/herself.

Please initial as appropriate:

Have you read the information sheet? 
(Instruction For Participants) 

YES ...... NO ......

I give my consent to my participation in the study

YES ...... NO ......

I give my consent for my test results from my assessments by the HSL to be used for research purposes

YES ...... NO ......

I give my consent for photographs and video recorded during the study to be used for illustration purposes in HSE/HSL reports / journal articles

YES ...... NO ......

I understand that the HSL will only use my results in an anonymised way so that I am not able to be identified

YES ...... NO ......

I understand that inclusion in this study is voluntary and I am free to withdraw at any time

YES ...... NO ......

Volunteers should note that HSE has no legal liability to pay compensation for damage, loss or injury resulting from participation in this study in circumstances where there has been no negligence on the part of HSE

Signed..................................................Date..............................

(NAME IN BLOCK LETTERS)......................................................................

This study has been cleared to proceed by the HSE Research Ethics Committee. If you have any concerns over the conduct of the study, you may contact the Medical Secretary of the Research Ethics Committee directly on 0151 951 4555.

Signed..................................................Date: 7 May 2003

(Dr P Graham, Chair to the Research Ethics Committee)
APPENDIX D: DATA COLLECTION SHEET

EVALUATION OF MANUAL HANDLING TASKS INVOLVING CARRY CHAIRS

DATA COLLECTION SHEET

Participant ID #: ____________________ Group ID#: ____________________ Date: ____________________

DEMOGRAPHICS

Age: ____________________ Gender: ____________________

ANTHROPOMETRIC MEASURES

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<th>Measure</th>
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<th>with shoes</th>
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</thead>
<tbody>
<tr>
<td>Stature</td>
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<td>mm</td>
</tr>
<tr>
<td>Weight</td>
<td>kg</td>
<td>kg</td>
</tr>
<tr>
<td>Shoulder Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Elbow Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Knuckle Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Biacromial Breadth</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Iliac Crest Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Hip Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Knee Height</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Ankle Height</td>
<td>mm</td>
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</tr>
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</table>

STRENGTH MEASURES

Dominant Hand: ____________________

<table>
<thead>
<tr>
<th>Hand</th>
<th>kg</th>
<th>kg</th>
<th>kg</th>
</tr>
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<tbody>
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<td>Left</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
</tr>
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## RATINGS OF PERCEIVED EXERTION

<table>
<thead>
<tr>
<th>Task</th>
<th>Chair End</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stairs Ascent</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stairs Descent</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tailgate Lift</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerb Ascent</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerb Descent</td>
<td>HEO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FEO</td>
<td></td>
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## CHAIR PREFERENCE

<table>
<thead>
<tr>
<th>Task</th>
<th>Model 1</th>
<th>Model 2</th>
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<tbody>
<tr>
<td>Stairs Ascent</td>
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<td>Reason:</td>
</tr>
<tr>
<td>Stairs Descent</td>
<td></td>
<td></td>
<td>Reason:</td>
</tr>
<tr>
<td>Tailgate Lift</td>
<td></td>
<td></td>
<td>Reason:</td>
</tr>
<tr>
<td>Task</td>
<td>Model 1</td>
<td>Model 2</td>
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</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>---------</td>
<td>---------------</td>
</tr>
<tr>
<td>Ramp</td>
<td>Reason:</td>
<td></td>
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<td>Kerb Ascent</td>
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</tr>
<tr>
<td>Kerb Descent</td>
<td>Reason:</td>
<td></td>
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</tr>
</tbody>
</table>

ADDITIONAL COMMENTS
APPENDIX E: FORCE EXERTION RESULTS

Table 7: Peak lifting forces and static holding forces (N) exerted by HEO and FEO of Model 2 on level ground

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Lifting Force (N)</th>
<th>Static Holding Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>599 N</td>
<td>79 N</td>
</tr>
<tr>
<td>FEO</td>
<td>582 N</td>
<td>118 N</td>
</tr>
</tbody>
</table>

Table 8: Peak lifting and static holdings forces (N) exerted by HEO and FEO of Model 2 on stairs

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Lifting Force (N)</th>
<th>Static Holding Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>657 N</td>
<td>52 N</td>
</tr>
<tr>
<td>FEO</td>
<td>591 N</td>
<td>120 N</td>
</tr>
</tbody>
</table>

Table 9: Peak and mean forces (N) exerted by the HEO and FEO when using Model 1 to ascend stairs

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Force (N)</th>
<th>Mean Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. Dev</td>
</tr>
<tr>
<td>HEO</td>
<td>542 N</td>
<td>50 N</td>
</tr>
</tbody>
</table>

Table 10: Peak and mean forces (N) exerted by the HEO and FEO when using Model 1 to descend stairs

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Force (N)</th>
<th>Mean Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. Dev</td>
</tr>
<tr>
<td>HEO</td>
<td>301 N</td>
<td>86 N</td>
</tr>
<tr>
<td>FEO</td>
<td>244 N</td>
<td>76 N</td>
</tr>
</tbody>
</table>
Table 11: Peak and static forces (N) exerted by the ambulance personnel when lifting the patient onto the tailgate with Model 1

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Lifting Force (N)</th>
<th>Static Holding Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>769 N</td>
<td>190 N</td>
</tr>
<tr>
<td>FEO</td>
<td>610 N</td>
<td>135 N</td>
</tr>
</tbody>
</table>

Table 12: Peak and static forces (N) exerted by the ambulance personnel when lifting the patient onto the tailgate with Model 2

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Peak Lifting Force (N)</th>
<th>Static Holding Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>717 N</td>
<td>156 N</td>
</tr>
<tr>
<td>FEO</td>
<td>603 N</td>
<td>142 N</td>
</tr>
</tbody>
</table>

Table 13: Initial pulling force and sustained pulling force (N) exerted by the HEO when wheeling the patient up the ramp with Model 1 and Model 2

<table>
<thead>
<tr>
<th>Chair Model</th>
<th>Initial Peak Starting Force (N)</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>227 N</td>
<td>334 N</td>
<td>2 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>133 N</td>
<td>259 N</td>
<td>1 N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Peak forces (N) exerted by the HEO and FEO during kerb descent with Model 1 and Model 2

<table>
<thead>
<tr>
<th>Operator Position</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HEO</td>
<td>434 N</td>
<td>86 N</td>
</tr>
<tr>
<td>FEO</td>
<td>334 N</td>
<td>19 N</td>
</tr>
</tbody>
</table>
APPENDIX F: LMM KINEMATIC RESULTS
Table 15: LMM postural data recorded during stair descent with Model 1 and Model 2 chairs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Model 1</th>
<th></th>
<th>Model 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HEO</td>
<td>FEO</td>
<td>HEO</td>
<td>FEO</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Max Sagittal Flexion</td>
<td>deg °</td>
<td>14.9 (11.3)</td>
<td>0 – 37.4</td>
<td>18.1 (10.0)</td>
<td>5.4 – 36.1</td>
</tr>
<tr>
<td>Max Sagittal Range</td>
<td>deg °</td>
<td>29.1 (11.5)</td>
<td>13.1 – 45.9</td>
<td>43.2 (25.4)</td>
<td>8.9 – 73.0</td>
</tr>
<tr>
<td>Max Lateral Range</td>
<td>deg °</td>
<td>18.0 (8.9)</td>
<td>8.8 – 34.1</td>
<td>18.1 (10.0)</td>
<td>5.4 – 36.1</td>
</tr>
<tr>
<td>Max Twist Range</td>
<td>deg °</td>
<td>15.9 (5.4)</td>
<td>9.6 – 26.2</td>
<td>13.6 (5.7)</td>
<td>8.5 – 23.5</td>
</tr>
<tr>
<td>Avg. Sagittal Velocity</td>
<td>°/ sec</td>
<td>4.6 (1.0)</td>
<td>3.0 – 5.6</td>
<td>6.2 (3.5)</td>
<td>1.8 – 12.8</td>
</tr>
<tr>
<td>Max Sagittal Velocity</td>
<td>°/ sec</td>
<td>33.4 (9.2)</td>
<td>15.8 – 46.8</td>
<td>47.7 (22.1)</td>
<td>17.4 – 76.7</td>
</tr>
<tr>
<td>Max Lateral Velocity</td>
<td>°/ sec</td>
<td>31.2 (11.7)</td>
<td>17.3 – 53.7</td>
<td>32.8 (9.2)</td>
<td>20.5 – 45.1</td>
</tr>
<tr>
<td>Avg. Twist Velocity</td>
<td>°/ sec</td>
<td>3.8 (1.3)</td>
<td>2.5 – 6.2</td>
<td>3.0 (1.2)</td>
<td>1.7 – 5.1</td>
</tr>
<tr>
<td>Max Twist Velocity</td>
<td>°/ sec</td>
<td>29.1 (9.0)</td>
<td>18.1 – 44.1</td>
<td>27.7 (6.8)</td>
<td>20.4 – 38.6</td>
</tr>
<tr>
<td>Max Sagittal Accel.</td>
<td>°/sec²</td>
<td>201 (60)</td>
<td>117 - 309</td>
<td>223 (104)</td>
<td>102 – 363</td>
</tr>
<tr>
<td>Max Twist Accel.</td>
<td>°/sec²</td>
<td>190 (41)</td>
<td>142 – 247</td>
<td>198 (30)</td>
<td>163 – 247</td>
</tr>
</tbody>
</table>
Table 16: LMM postural data recorded during stair ascent with Model 1 and Model 2 chairs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>HEO Mean (SD)</th>
<th>Range</th>
<th>FEO Mean (SD)</th>
<th>Range</th>
<th>HEO Mean (SD)</th>
<th>Range</th>
<th>FEO Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Sagittal Flexion</td>
<td>deg °</td>
<td>7.8 (10.1)</td>
<td>-7.1 – 23.9</td>
<td>30.4 (22.0)</td>
<td>-1.1 – 60.1</td>
<td>18.1 (10.9)</td>
<td>2.1 – 30.4</td>
<td>45.7 (9.5)</td>
<td>27.7 – 59.4</td>
</tr>
<tr>
<td>Max Sagittal Range</td>
<td>deg °</td>
<td>22.1 (7.6)</td>
<td>13.1 – 37.9</td>
<td>43.4 (25.1)</td>
<td>8.9 – 73.3</td>
<td>30.5 (13.6)</td>
<td>18.4 – 51.9</td>
<td>58.0 (11.9)</td>
<td>45.5 – 84.3</td>
</tr>
<tr>
<td>Max Lateral Range</td>
<td>deg °</td>
<td>10.9 (3.6)</td>
<td>6.4 – 16.1</td>
<td>15.5 (9.3)</td>
<td>5.4 – 36.1</td>
<td>15.1 (2.4)</td>
<td>11.6 – 17.6</td>
<td>17.0 (5.5)</td>
<td>10.4 – 28.9</td>
</tr>
<tr>
<td>Max Twist Range</td>
<td>deg °</td>
<td>10.3 (4.1)</td>
<td>4.4 – 18.1</td>
<td>10.3 (4.3)</td>
<td>6.1 – 20.1</td>
<td>13.2 (7.6)</td>
<td>3.8 – 29.6</td>
<td>15.7 (6.1)</td>
<td>7.5 – 25.2</td>
</tr>
<tr>
<td>Avg. Sagittal Velocity</td>
<td>°/sec</td>
<td>4.1 (0.9)</td>
<td>3.0 – 5.5</td>
<td>6.7 (4.0)</td>
<td>1.8 – 12.8</td>
<td>4.4 (0.7)</td>
<td>3.0 – 5.5</td>
<td>5.8 (1.2)</td>
<td>4.3 – 8.3</td>
</tr>
<tr>
<td>Max Sagittal Velocity</td>
<td>°/sec</td>
<td>30.0 (10.1)</td>
<td>15.8 – 46.8</td>
<td>49.9 (23.1)</td>
<td>17.4 – 80.1</td>
<td>33.4 (10.0)</td>
<td>22.4 – 51.1</td>
<td>60.1 (15.2)</td>
<td>38.3 – 93.0</td>
</tr>
<tr>
<td>Max Lateral Velocity</td>
<td>°/sec</td>
<td>20.7 (5.7)</td>
<td>14.6 – 29.2</td>
<td>29.2 (8.8)</td>
<td>20.1 – 45.1</td>
<td>30.1 (5.6)</td>
<td>19.3 – 43.4</td>
<td>33.1 (11.0)</td>
<td>21.6 – 51.6</td>
</tr>
<tr>
<td>Avg. Twist Velocity</td>
<td>°/sec</td>
<td>2.9 (1.9)</td>
<td>0.8 – 6.2</td>
<td>2.3 (1.2)</td>
<td>1.5 – 5.1</td>
<td>2.7 (1.9)</td>
<td>0.8 – 6.9</td>
<td>3.1 (1.1)</td>
<td>1.9 – 4.6</td>
</tr>
<tr>
<td>Max Twist Velocity</td>
<td>°/sec</td>
<td>23.8 (8.6)</td>
<td>16.0 – 39.8</td>
<td>22.1 (6.3)</td>
<td>14.0 – 33.7</td>
<td>25.7 (15.6)</td>
<td>9.5 – 60.6</td>
<td>32.9 (9.3)</td>
<td>19.2 – 49.1</td>
</tr>
<tr>
<td>Max Sagittal Accel.</td>
<td>°/sec²</td>
<td>181 (63)</td>
<td>117 – 309</td>
<td>213 (82)</td>
<td>102 – 337</td>
<td>181 (41)</td>
<td>131 – 264</td>
<td>254 (122)</td>
<td>185 – 534</td>
</tr>
<tr>
<td>Max Lateral Accel.</td>
<td>°/sec²</td>
<td>146 (42)</td>
<td>95 – 203</td>
<td>180 (44)</td>
<td>119 – 233</td>
<td>213 (69)</td>
<td>146 – 314</td>
<td>211 (51)</td>
<td>128 – 278</td>
</tr>
<tr>
<td>Max Twist Accel.</td>
<td>°/sec²</td>
<td>161 (51)</td>
<td>107 – 235</td>
<td>159 (37)</td>
<td>115 – 217</td>
<td>184 (101)</td>
<td>86 – 417</td>
<td>213 (67)</td>
<td>125 – 335</td>
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</table>
### Table 17: Mean, standard deviation (SD) and range of LMM postural data for the tailgate lift and ramp tasks using Model 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Tailgate Lift</th>
<th>Ramp</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>HEO</td>
<td>Range</td>
<td>FEO</td>
<td>Range</td>
</tr>
<tr>
<td>Max Sagittal Flexion</td>
<td>deg °</td>
<td>53.6 (6.4)</td>
<td>49.2 – 66.2</td>
<td>49.6 (9.2)</td>
<td>40.5 – 61.4</td>
</tr>
<tr>
<td>Max Sagittal Range</td>
<td>deg °</td>
<td>62.9 (4.0)</td>
<td>58.4 – 68.5</td>
<td>59.8 (3.1)</td>
<td>55.3 – 63.5</td>
</tr>
<tr>
<td>Max Lateral Range</td>
<td>deg °</td>
<td>10.7 (3.3)</td>
<td>7.3 – 15.4</td>
<td>13.3 (3.6)</td>
<td>7.3 – 17.8</td>
</tr>
<tr>
<td>Max Twist Range</td>
<td>deg °</td>
<td>8.7 (2.5)</td>
<td>6.0 – 12.3</td>
<td>10.4 (3.9)</td>
<td>4.3 – 14.7</td>
</tr>
<tr>
<td>Max Sagittal Velocity</td>
<td>° / sec</td>
<td>69.8 (11.8)</td>
<td>57.1 – 88.8</td>
<td>62.1 (8.5)</td>
<td>48.1 – 72.0</td>
</tr>
<tr>
<td>Max Lateral Velocity</td>
<td>° / sec</td>
<td>18.6 (4.9)</td>
<td>13.3 – 26.2</td>
<td>25.1 (9.6)</td>
<td>13.1 – 39.1</td>
</tr>
<tr>
<td>Avg. Twist Velocity</td>
<td>° / sec</td>
<td>2.0 (0.6)</td>
<td>1.4 – 2.8</td>
<td>2.1 (0.6)</td>
<td>1.3 – 2.9</td>
</tr>
<tr>
<td>Max Twist Velocity</td>
<td>° / sec</td>
<td>18.4 (5.2)</td>
<td>13.7 – 27.9</td>
<td>26.5 (5.0)</td>
<td>19.6 – 34.0</td>
</tr>
<tr>
<td>Max Sagittal Acceleration</td>
<td>° / sec²</td>
<td>296 (93.8)</td>
<td>209 – 470</td>
<td>277 (47.3)</td>
<td>219 – 351</td>
</tr>
<tr>
<td>Max Lateral Acceleration</td>
<td>° / sec²</td>
<td>118 (31)</td>
<td>76 – 164</td>
<td>163 (49)</td>
<td>96 – 219</td>
</tr>
<tr>
<td>Max Twist Acceleration</td>
<td>° / sec²</td>
<td>140 (45)</td>
<td>101 – 216</td>
<td>193 (38)</td>
<td>142 – 245</td>
</tr>
</tbody>
</table>
Table 18: LMM postural data recorded during kerb descent with Model 1 and Model 2 chairs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Model 1</th>
<th></th>
<th></th>
<th>Model 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HEO</td>
<td>FEO</td>
<td></td>
<td>HEO</td>
<td>FEO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Max Sagittal Flexion deg °</td>
<td>7.8 (10.1)</td>
<td>-7.1 – 23.9</td>
<td>30.4 (22.0)</td>
<td>-1.1 – 60.1</td>
<td>16.4 (10.9)</td>
<td>0.6 – 32.0</td>
<td>38.9 (19.5)</td>
</tr>
<tr>
<td>Max Sagittal Range deg °</td>
<td>22.1 (7.6)</td>
<td>13.1 – 37.9</td>
<td>43.4 (25.1)</td>
<td>8.9 – 73.3</td>
<td>26.7 (7.8)</td>
<td>13.6 – 37.8</td>
<td>48.8 (17.6)</td>
</tr>
<tr>
<td>Max Lateral Range deg °</td>
<td>10.9 (3.6)</td>
<td>6.4 – 16.1</td>
<td>15.5 (9.4)</td>
<td>5.4 – 36.1</td>
<td>9.8 (3.1)</td>
<td>5.8 – 14.0</td>
<td>16.2 (6.5)</td>
</tr>
<tr>
<td>Max Twist Range deg °</td>
<td>10.3 (4.1)</td>
<td>4.4 – 18.1</td>
<td>10.3 (4.3)</td>
<td>6.1 – 20.1</td>
<td>7.7 (2.5)</td>
<td>4.4 – 12.0</td>
<td>12.3 (4.3)</td>
</tr>
<tr>
<td>Avg. Sagittal Velocity °/sec</td>
<td>4.1 (0.9)</td>
<td>3.0 – 5.5</td>
<td>6.7 (4.0)</td>
<td>1.8 – 12.8</td>
<td>4.0 (1.0)</td>
<td>2.6 – 6.0</td>
<td>6.6 (1.9)</td>
</tr>
<tr>
<td>Max Sagittal Velocity °/sec</td>
<td>30.0 (10.1)</td>
<td>15.8 – 46.8</td>
<td>49.9 (23.1)</td>
<td>17.4 – 80.1</td>
<td>27.2 (10.3)</td>
<td>16.9 – 47.7</td>
<td>58.2 (23.6)</td>
</tr>
<tr>
<td>Max Lateral Velocity °/sec</td>
<td>20.7 (5.7)</td>
<td>14.6 – 29.2</td>
<td>29.2 (8.8)</td>
<td>20.1 – 45.1</td>
<td>21.7 (3.8)</td>
<td>13.5 – 24.9</td>
<td>30.9 (8.2)</td>
</tr>
<tr>
<td>Avg. Twist Velocity °/sec</td>
<td>2.9 (1.9)</td>
<td>0.8 – 6.2</td>
<td>2.3 (1.2)</td>
<td>1.5 – 5.1</td>
<td>2.0 (0.9)</td>
<td>0.5 – 3.7</td>
<td>3.0 (0.9)</td>
</tr>
<tr>
<td>Max Twist Velocity °/sec</td>
<td>23.8 (8.6)</td>
<td>16.0 – 39.8</td>
<td>22.1 (6.3)</td>
<td>14.0 – 33.7</td>
<td>19.7 (6.6)</td>
<td>12.3 – 29.7</td>
<td>28.2 (6.7)</td>
</tr>
<tr>
<td>Max Sagittal Accel. °/sec²</td>
<td>180 (63)</td>
<td>117 – 310</td>
<td>213 (82)</td>
<td>102 – 337</td>
<td>161 (61)</td>
<td>104 – 269</td>
<td>246 (90)</td>
</tr>
<tr>
<td>Max Lateral Accel. °/sec²</td>
<td>145.6 (42)</td>
<td>95 – 203</td>
<td>180 (44)</td>
<td>119 – 233</td>
<td>141 (28)</td>
<td>99 – 169</td>
<td>199 (39)</td>
</tr>
<tr>
<td>Max Twist Accel. °/sec²</td>
<td>161 (52)</td>
<td>107 – 235</td>
<td>159 (37)</td>
<td>115 – 215</td>
<td>147 (49)</td>
<td>90 – 219</td>
<td>207 (54)</td>
</tr>
</tbody>
</table>
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