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HEALTH & SAFETY LABORATORY

A Comparison of Two Manual Handling Techniques Used Within the Mattress Manufacturing Industry.

HSL/2007/09

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EXECUTIVE SUMMARY

OBJECTIVE

The aim of this study was to compare two mattress handling techniques that are performed within the warehouse environments of bed manufacturers and to investigate if one technique places less stress on the musculoskeletal system, particularly on the low back, than the other.

METHODS

The two techniques used were:

(1) Overhead Technique: the mattress is lifted and held directly above the head with the load supported equally by both arms; and
(2) Side of Body Technique: the mattress is lifted and held to the side of the body, resting against the shoulder and side of the head, with the weight primarily supported by one arm located at the bottom of the mattress.

Mattresses may then be carried within the warehouse in either of these postures. Current manual handling training directs employees to use the Side of Body Technique, however, there is no evidence to suggest that this places less stress on the musculoskeletal system.

The two mattress handling techniques were simulated in the warehouse environment, and the data were collected using force plates, video recordings, ratings of perceived exertion scores and a questionnaire. 3-dimensional biomechanical modelling and Rapid Entire Body Assessment (REBA) of handling postures were also used.

FINDINGS

The findings indicated that both handling techniques place moderate levels of stress on the low back and the musculoskeletal system. Similar results were observed at the start of the lift, where the NIOSH Back Compression Design Limit of 3400 N was exceeded by some participants, thereby placing them at increased risk of low back injury. At the end of the lift when in the carry position, the Side of Body Technique resulted in a greater back compression force than the Overhead Technique due to the lateral bending of the trunk when holding the mattress asymmetrically. Perceived exertion ratings, REBA scores, and questionnaire data were unable to provide evidence that one technique is preferable to the other.

RECOMMENDATIONS

(1) On the basis of this analysis there does not appear to be any advantage in instructing employees to use solely one or the other of the two techniques. Alternating between the two handling techniques is recommended, as this will help different muscle groups to rest and recover over the course of the workday.
(2) Further investigation of lifting techniques at the start of the lift should be undertaken. One participant faced the mattress and tipped it off the conveyor prior to lifting it resulting in lower low back compression forces and increasing the estimated percentage of the population capable to perform the lift. However, as this was only performed by one participant further analysis of this technique is recommended.
(3) The results indicated that both handling techniques place the low back and musculoskeletal system under a moderate level of stress, therefore the industry should continue to focus on alternative methods of manual handling mattresses within the warehouse.

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1 INTRODUCTION

1.1 THE CONTEXT

The bed manufacturing industry has a high level of manual handling risks and is a concern for the Health and Safety Executive (HSE) (Stanley, 2005). Compared with other manufacturing industries within the United Kingdom a higher incidence rate of manual handling injuries occur within the mattress manufacturing industry, as illustrated in Figure 1. Process operators have been identified by Bomel (2005) as suffering from the greatest proportion of manual handling injuries. The majority of tasks involve manual handling of all types of mattresses and divan bases, and historically there has been a 'macho' attitude towards lifting and handling.

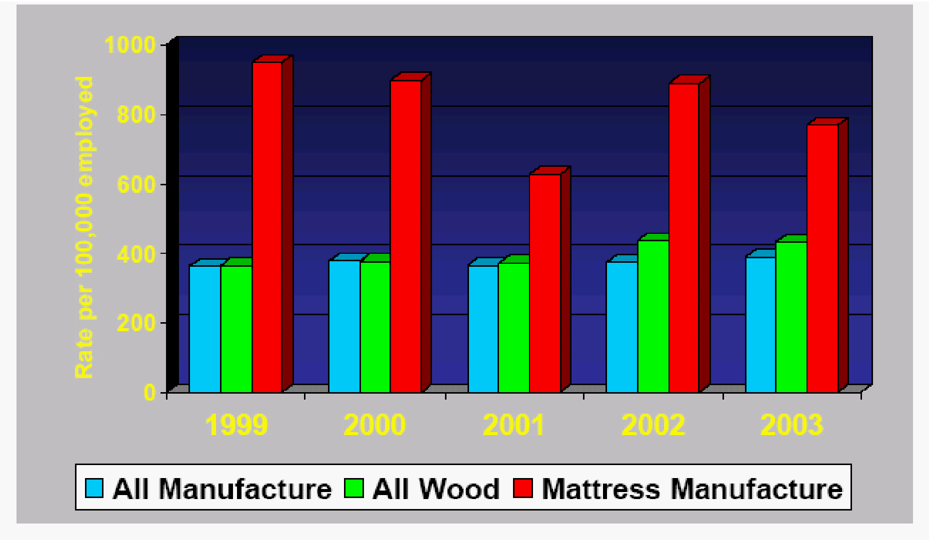


Figure 1. Manual handling accident incident rate in the mattress manufacturing industry compared to all manufacturing and wood manufacturing industries (Bomel, 2005).

The bed manufacturing industry employed 9,493 people in 2003, with 80 major, and over three day injuries attributed to manual handling (Bomel, 2005). The manual handling of mattresses and divan bases within the bed manufacturing industry is a widespread problem experienced within the United Kingdom (Stanley, 2005). In recent years, work systems have become more mechanised and a variety of manual handling aids have been introduced. However, there are still occasions, such as when loading vehicles, when manual handling activities continue to occur (Stanley, 2005). More recently the manual handling training within the bed manufacturing industry has instructed employees to carry mattresses at the side of the body compared to the traditional method of holding and carrying them above the head (Stanley, 2005).

1.2 BACKGROUND TO THE RESEARCH

An initiative was developed by HSE to work with the bed manufacturing industry in a partnership programme. This was a three year programme whereby manufacturers had an opportunity to work with the HSE, by attending workshops, drawing up action plans for risk reduction, and benefiting from advice and follow up visits. The aim was to lower the incidence of musculoskeletal injuries within the industry. An initial step was to commission the Health and Safety Laboratory (HSL) to perform an investigation. The aim was to identify and prioritise the tasks that pose the greatest risk to employees. Five different manufacturers of varying sizes were visited and five key tasks that expose employees to an increased risk of manual handling injury were identified. The five tasks were: divan assembly / dressing, mattress assembly, tape-edging, tufting, and handling in the warehouse / distribution areas. All of these tasks involve manual handling activities, such as lifting and lowering, carrying, pushing and pulling.

Industry statistics were obtained to help focus the investigation and were reported by individual companies to the HSE. Process operatives were identified as the group of employees reporting manual handling accidents most frequently (51%) (Bomel, 2005). Additionally, Bomel (2005) found that the accident statistics indicated that the weight and awkward manner of handling mattresses and divans was responsible for the majority of manual handling injuries. It is unclear however, if these injuries are acute or cumulative in nature. This research project specifically considers the handling of mattresses, as this is a prevalent activity performed within the warehouse. The handling of divan bases, although still awkward to handle, are lighter than mattresses, and were not considered for inclusion in this investigation. This latter activity should be the subject of a separate investigation, and is beyond the scope of this study.

Historically, the most common method of handling mattresses was to lift and carry them above the head, a method that still continues to be used to some extent today. Employers are now training their employees to carry and support the mattress at the side of the body, as this method attempts to keep the load horizontally closer to the body's centre of gravity (Stanley, 2005). Although handling mattresses at the side of the body is now a common method, no research has been undertaken to establish if this reduces the risk of musculoskeletal injury or the biomechanical load. It is the purpose of this research therefore, to compare the two techniques and to establish if one technique is preferable to the other.

The author has worked with the industry over the past 18 months and visited a number of manufacturers of various sizes. A good understanding of the industry and the activities that are performed within it has been obtained. As part of the preliminary investigation five different companies were visited; the activities performed and how they are performed were considered, along with possible factors, such as the increased use of mechanisation and handling aids, that could reduce the risk of musculoskeletal injury. These findings were documented and presented at three different workshops to bed manufacturers within England. This earlier work helped to establish the need for this research project and to develop:

(1) The statement of the problem;

(2) The research question; and

(3) The aim and objectives of the investigation.

1.3 STATEMENT OF THE PROBLEM

The majority of employers within the mattress manufacturing industry have implemented the use of handling aids where possible. However, handling of mattresses still occurs at various locations on the production line. One of the main areas of concern is within the warehouse environment as employees spend most of their working day handling mattresses and divan bases. Activities can include lifting mattresses off conveyors and carrying them to storage areas, or loading them into vehicles. These tasks can involve pushing and pulling, lifting and lowering, and carrying. Employees are being trained to handle mattresses and divans using the ‘side of the body’ technique compared with the more traditional ‘overhead’ technique, but many employees are still found using this latter technique. General manual handling guidelines indicate that keeping the load close to the body’s centre of gravity is preferable, and is the reason for the recommended change in lifting technique; however, there is little, or no evidence to indicate that handling a mattress to the side of the body reduces the risk of injury.

1.4 THE RESEARCH QUESTION

The following research question was the focus for the investigation:

Does manually handling a mattress at the side of the body place employees at greater risk of sustaining a musculoskeletal injury, particularly with regard to the low back, than one where the mattress is raised and held above the head?

1.5 OVERVIEW OF THE RESEARCH PROJECT

This research will cover the following areas:

(1) Chapter 2. This chapter will outline the specific aim and the objectives of the research project.

(2) Chapter 3. This chapter will present a review of the literature and discuss the background to the research and the specific problems found within the bed manufacturing industry. It will also outline the recognised risk factors associated with musculoskeletal disorders.

(3) Chapter 4. This chapter will outline and review the methodology that was used, the experimental design adopted, the study protocol, and data analysis that was performed.

(4) Chapter 5. This chapter will present the results from comparing the two handling techniques. The findings on force measurements, biomechanical analysis, postural analysis, psychophysical ratings of effort, and questionnaire analysis are reported.

(5) Chapter 6. This chapter discusses the findings of the study and the limitations that need to be considered when interpreting the results.

(6) Chapter 7. This chapter will draw conclusions and make recommendations that are based on the study findings. It also proposes potential areas for further research.

2 AIM AND OBJECTIVES

AIM

The aim of this study is to perform a comparison of two mattress handling techniques within the warehouse environment of a large mattress manufacturer. It seeks to establish if one technique places less stress on the musculoskeletal system, particularly the low back, compared with the other; and therefore, if employees are at a greater risk of sustaining a musculoskeletal injury.

OBJECTIVES

To achieve this aim, the following objectives were identified.

(1) Undertake a comparison of the ground reaction forces for the two techniques using force plates and use postural analysis and biomechanical modelling techniques to estimate the musculoskeletal loads imposed when performing the two handling techniques;

(2) Assess the perceived exertion of study participants for each of the two techniques using the Borg CR10 Scale, and obtain additional subjective information about the two techniques used, to establish which technique participants prefer and why; and

(3) Gather qualitative data from the study participants and the wider warehouse population about performing the two techniques and the handling activities they perform.

3 LITERATURE REVIEW

3.1 BACKGROUND

The aim of this review is to critically discuss the scientific literature that is directly relevant to this research project. The risk factors associated with musculoskeletal disorders (MSDs) will be reviewed particularly in relation to manual handling injuries and low back disorders (LBDs). Previous studies that have investigated the handling of heavy and awkward loads in warehouse and distribution environments will be considered, especially with regard to lifting and handling tasks that occur during the process of bed manufacturing.

The databases searched were: Pubmed, Medline, Ergonomics Abstracts Online, Healsafe, HSELINE, and OSHLINE. The following key words were used in the database searches: manual handling, material handling, furniture handling, low back disorders / pain, musculoskeletal disorders, work-related musculoskeletal disorders, asymmetrical handling, carrying loads on head and shoulders, biomechanical modelling.

This literature review discusses a variety of factors associated with manual handling and the influences of these factors on individuals, and in relation to the bed manufacturing industry. Within the literature, manual handling is also referred to as manual materials handling, however, for the purposes of this review it will be referred to as manual handling. The two major terms used to describe back injuries are: low back pain (LBP), and lower back disorders (LBDs). Furthermore, musculoskeletal injuries have been referred to as musculoskeletal disorders (MSDs), cumulative trauma disorders (CTDs), work-related musculoskeletal disorders (WRMSDs), and occupational musculoskeletal disorders (MSDs). A combination of these terms may be used throughout this literature review to describe the injuries that may be associated with manual handling work.

3.2 THE SIZE OF THE PROBLEM

3.2.1 General Injury Statistics

Work-related ill health is a widespread phenomenon with 2.2 million people being affected in Great Britain in 2003 / 4. One in four days absence are lost due to back pain resulting in approximately 6 million working days lost in 2001 / 2, with an average time off per person in excess on 20 days (HSE, 2005). Similar levels of back pain are represented within the working populations of the European Union and the United States (Frymoyer and Cats-Baril, 1991; Webster and Snook, 1994; WHO, 1995; Statistics Canada, 1995; Bernard, 1997; Guo *et al.*, 1999; Op De Beeck and Hermans, 2000).

Studies have shown that rates of LBDs vary between different industries, occupations, and by jobs within given industries or facilities; for example non-sedentary occupations have the highest prevalence rates (Hoogendoorn *et al.*, 1999). Occupational health surveillance data reviewed by Andersson (1997) have shown that that those who handle materials are at a much greater risk of LBD than those who work in occupations that require no lifting. This is supported by Paoli (1997) in the Second European survey on working conditions who identified that “slips / trips and falls” and “manual handling” are the main causes of accidents, with construction and manufacturing being the most frequently identified sectors where these accidents occur, and predominantly involve the male population. Marras (2000) stated that low back disorders are at epidemic levels and will continue to be one of “*society’s most significant non-lethal medical conditions*” (pp. 881).

3.2.2 Background within the Furniture Manufacturing Industry

Several authors have identified the furniture manufacturing industry as one that experiences problems associated with MSDs and work-related low back pain (Mirka *et al.*, 2002; Christensen *et al.*, 1995). Mirka *et al.*, (2002) identified that previous studies have predominantly focused on exposure to sawdust, chemical exposure, noise, and acute injury. However, in addition to these risk factors it is now recognised that furniture workers are also exposed to a number of occupational risk factors associated with low back injuries. Such risk factors may include, performing physically heavy work, that is highly repetitive, and can involve frequent lifting and bending, twisting, pushing or pulling, sustained awkward postures of the torso, and dynamic movements of the torso. These factors have also been identified when performing general warehouse work by Waters *et al*., (1998), who concluded that employees are exposed to a significantly increased risk of developing a LBD whilst lifting and twisting. Grant *et al*., (1997) found a high prevalence of back pain among workers in shipping departments where workers were loading wooden cabinets into trucks. They concluded that the risk of low back injury increased as the lifting duration increased; the ability to rest is reduced; or the product weights increase. Within the wood and furniture industry Christensen *et al.*, (1995) identified that MSDs constitute a major problem and concluded that there was an urgent need to identify the key risk factors. Furthermore, Mirka *et al.*, (2002) identified that there is a lack of literature specifically related to work-related musculoskeletal injuries and illness among furniture industry jobs, or, related to interventions aimed at the prevention of these disorders among these employees.

These studies have helped to identify common risk factors within the industry, such as the weight of loads, frequency of handling, awkwardness of handling, and the adoption of awkward postures.

3.3 MANUAL HANDLING RISK FACTORS

A number of studies have investigated the risk factors associated with manual handling such as Bernard (1997) and Op De Beeck and Hermans (2000). It is widely believed that MSDs, including those of the back, neck, and upper limbs, are multifactorial in origin and may be associated with both work, and non-work related activities. Frank *et al*., (1996) identified that manual handling activities expose the lower back to particular risk. Further, the development of LBP may be influenced by a number of physical and non-physical work-related factors that may simultaneously act on the human body and affect its biological functions.
Op De Beeck and Hermans (2000) developed a table that summarised the relationship and the strength of evidence for work-relatedness between back disorders and the risk factors that have been identified by past studies. They used the classification system of Bernard (1997) and Hoogendoorn *et al*., (1999); this is shown in Table 1.

Op De Beeck and Hermans (2000) classified the evidence for a relationship into one of three categories:

(1) Strong evidence of work-relatedness (+++): provided by generally consistent findings in multiple high quality studies;

(2) Evidence (++): provided by generally consistent findings in one high quality study and one or more low quality studies, or in multiple low quality studies;

(3) Insufficient evidence (+/0): only one study available, or inconsistent findings in multiple studies.

Traditionally, most epidemiologic studies have investigated physical risk factors, however, more recently Marras (2000) stated that investigating and trying to understand psychosocial risk factors is becoming increasingly important. In addition, Marras (2000) suggested that individual risk factors should also be considered if there is to be an increased understanding of why some people are at an increased risk of developing LBDs compared with others who are exposed to the same risk factors. Furthermore, how risk factors interact and the complexities of the relationships that exist between different risk factors are not fully understood.

Table 1. The work relatedness of low back disorders: overview of risk factors.

Category of Risk Factor	Risk Factor	Evidence
Physical factors	Heavy manual labour	++
	Manual material handling	+++
	Awkward postures	++
	Static work	+ / 0
	Whole body vibration	+++
	Slipping and falling	+
Psychosocial / Work Organisational Factors	Job content	+ / 0
	Work / time pressure	+ / 0
	Job control	+ / 0
	Social support	+++
	Job dissatisfaction	+++
Individual factors	Age	+ / 0
	Socio-economic status	+++
	Smoking	++
	Medical history	+++
	Gender	+ / 0
	Anthropometry	+ / 0
	Physical activity	+ / 0

(adapted from Op De Beeck and Hermans, 2000)

3.3.1 Physical Risk Factors and Biomechanical Considerations

Physical Risk Factors

Bernard (1997) found positive associations between a variety of risk factors and LBDs. Many of the occupational risk factors such as 1) lifting and forceful movements, 2) bending and twisting, 3) whole-body vibration, and 4) heavy physical work, were linked by a common theme, in that, they all placed the lumbosacral spine under high levels of stress.

Yeung *et al*., (2003) confirmed that lifting has been identified as one of the main risk factors for low back pain, and as a result, direct measurement techniques have been the main method for evaluating the risk exposure in different lifting conditions. Many investigations (Chaffin, 1974; Ayoub *et al*., 1983; Marras *et al*., 1993; and Waters *et al*., 1998) have shown significant associations between musculoskeletal injuries of the low back and the physical demands of the lifting activities. Gallagher *et al*., (2005) proposed that it the work is repetitive the stresses placed on the spine may be experienced several hundred times over the course of a typical workday. In addition, the National Research Council Report (1999) presented evidence that showed when the biomechanical load was reduced there was also a corresponding reduction in the prevalence of MSDs.

Keyserling (2000) identified three key factors associated with lifting. These are: 1) the amount of weight lifted, 2) the location of the load (e.g. horizontal hand distance from the lower back), and 3) body posture (e.g. forward bending of the trunk increases the load on the lower back).

Manual handling is an important risk factor in the development of LBDs (Bernard, 1997; Forde *et al*., 2002; Punnett and Wegman, 2004). However, Monnington (1997) reviewed the literature and found that fewer studies have been performed that have investigated asymmetrical handling as compared to symmetrical handling. Ayoub and Mital (1989) identified that asymmetrical handling is more common in industrial settings than symmetrical handling. This was also highlighted by Baril-Gingras and Lortie (1995) who studied handling techniques within a distribution centre. They investigated asymmetric handling operations involving objects that were not boxes as they had identified that the majority of research had considered handling displacements vertically upwards and symmetrical loads in the sagittal plane. They classified the objects into six categories (long objects, cylinders, tyres, large-volume objects, and other objects) which then were classified into a further twenty-six sub-categories. Furniture items such as sofas and mattresses were included within these subsequent categories. They found that handlers developed favoured handling methods depending on the item they were handling within the limits of the task. They concluded that further research is required to understand what employees perceived as the advantages of asymmetrical handling. They also concluded that future research comparing the techniques adopted by experienced and inexperienced employees could help to identify less hazardous handling strategies. Such findings could then be incorporated into manual handling training specific to the industry. The study by Baril-Gingras and Lortie (1995) is relevant to this research project as they identified that a greater understanding of employees handling choices and handling activities is required. Furthermore, additional studies into asymmetrical handling of non-standard loads and how this information should be incorporated into specific manual handling training are required.

Zwick *et al*., (1998) defined an asymmetrical load as "*a load carried on either side lateral to midline*" (pp. 62). Their study identified that handling of asymmetric loads caused unilateral and unbalanced use of the trunk muscles on the non-loaded side of the body. In addition, Pope *et al*., (1997) performed a study looking at occupational factors related to shoulder pain and disability. They found an increased risk of shoulder pain and disability in men who carry loads on one shoulder. They also found that factors concerning the environment and psychosocial factors, such as monotony, time pressure, high workload, and lack of autonomy, were related to the occurrence of shoulder symptoms, highlighting the multifactorial aetiology of shoulder pain. Furthermore, McGough *et al*., (1996) considered the mechanical properties of the long head of the biceps tendon, as it had been implicated as a major cause of pain in the shoulder, largely due to its long, complex anatomic course, that can leave it susceptible to acute injury or chronic degeneration. The investigations undertaken by Zwick *et al.*, (1998), Pope *et al.*, (1997), and McGough *et al.,* (1996) are relevant to this current investigation as mattresses are carried asymmetrically at the side of the body. Not only will this have an affect on the low back, but also on other parts of the musculoskeletal system such as the biceps in the lower arm when carrying mattresses at the side of the body which could potentially affect the shoulder resulting in pain or disability.

Monnington's (1997) literature review concluded that research into asymmetrical handling is limited and therefore a multi-disciplinary approach in future studies should be taken. This should incorporate psychophysical, physiological, and biomechanical methodologies, and would allow for a more accurate assessment of the affects of asymmetrical handling on the body.
Carrying mattresses on the head is common practice in the bed manufacturing industry. Several studies have been performed investigating load carriage on the head and have mainly been performed with African women and male porters. Results have shown that there are risks

associated with carrying loads on the head, particularly on the cervical spine (Jager *et al*., 1997; Heglund *et al*., 1995; Haisman, 1988). Jager *et al*., (1997) examined the degenerative changes in the cervical spine between carriers of loads on the head and individuals who did not carry loads on their head. A prevalence of degenerative change in the cervical spine of 88.6 % was observed for individuals who carried loads on their head, compared to 22.9 % for individuals who did not perform carrying tasks on their head. Such research is relevant to this research project as mattresses are frequently balanced on the head when carried and may place additional loads on the neck and cervical spine leading to degenerative changes.

Stanley (2005) investigated a range of activities occurring within the bed manufacturing industry and assessed the risk of injury associated with manual handling and upper limb injuries. The findings in relation to manual handling have helped to identify the risk factors associated with the task of manually handling mattresses within warehouses that this research project will focus on. These are identified in Table 2.

Table 2. Risk factors associated with the manual handling of mattresses (Stanley, 2005).

Risk Factors	
Task	***Repetition:*** Mattresses are handled repeatedly over an 8 hour workday.
	Frequency: Approximately 200 mattresses are handled per employee per day and employees have little control over the work rate.
	Posture: Activities involve forward bending twisting, reaching, lifting, lowering, and carrying. Spinal twisting and neck flexion are the main problems associated with holding the mattress at the side of the body, and raised arms, elevated shoulders and flexed wrists are associated with carrying above the head.
Load	***Weight:*** 11 – 61 kg, heavier mattresses (80 kg) will be handled by 2 employees.
	Awkward to handle: The bulk and size of mattresses makes them difficult to handle. There is a lack of handholds.
Environment	***Limited space:*** Mattresses are often handled in cramped spaces and may constrain posture (e.g. narrow aisles, loading vehicles).
	Temperature: Employees can be exposed to extremes of temperature (e.g. the warehouse gets very cold in winter; loading vehicles may be hot and humid in summer).
	Lighting: Generally good lighting levels exist apart from when working in the back of vehicles.
Individual	***Previous Injury:*** Individuals with previous musculoskeletal or low back injury may be predisposed to developing subsequent injury.
	Strength: Individual strength capabilities differ and handling heavier loads may place some employees at an increased risk of musculoskeletal injury.

Complexity of Causation – Biomechanical Considerations

A number of theories with regard to the development of musculoskeletal injuries that consider the physical, psychosocial, and individual risk factors and how they may interact have been developed.

McGill (1997) proposed that injuries and disorders develop when the biomechanical load placed on a tissue exceeds the tolerance limits of that tissue. If loads become excessive, such as when lifting heavy items, or if the tissue tolerance has decreased as a result of the aging process, or a cumulative trauma, then an injury or disorder may develop. Marras (2000) also stated that the tolerance levels to injury are not only affected by load level, but also by other factors such as repetition, time of day, and spinal posture when the load is applied. Furthermore, Marras (2005) suggested that individual and genetic factors and previous loading history or adaptation might also affect the load-tolerance relationship. In conclusion, Marras (2000) stated that assessing the causes of LBD and controlling the risk of injury is much more complicated than evaluating a single dimension of spine loading at a single point in time.

As part of the degenerative process, Marras (2000) proposed a sequence of events that is representative of one of the major pathways of LBD (Figure 2). It considers excessive loading that is generated by both external and internal forces that cause microfracturing of the vertebral end plates. Lotz *et al*., (1998) were also able to demonstrate how disc compression can initiate harmful disc responses that respond according to a dose-response relationship providing further evidence of cumulative trauma to the spine.

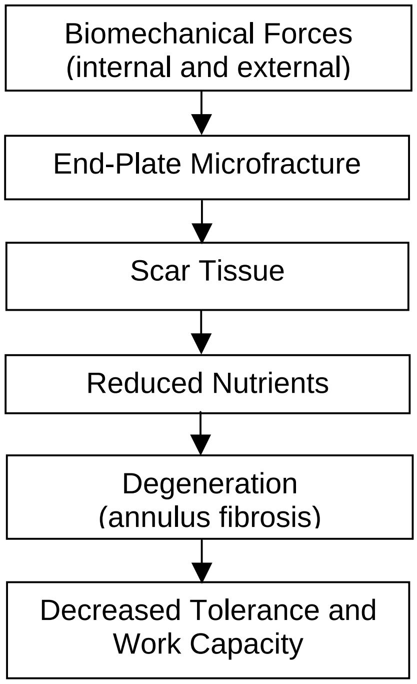


Figure 2. Sequence of events in low back cumulative trauma. (Marras, 2000).

Many authors have proposed a variety of theories associated with the development of musculoskeletal injury and LBDs. The theories proposed by McGill (1997) and Marras (2000) have helped to focus the research project on mattress handling as they provide a framework of injury causation that is cumulative in nature and is representative of the repetitive handling activities performed by warehouse personnel in the bed manufacturing industry.

Forces Acting on the Spine

Epidemiological evidence has found a strong link between heavy manual labour such as lifting, and LBDs (Bernard, 1997; Op De Beeck and Hermans, 2000). Marras (2000) identified that three types of forces or loading act on the spine; compression, torsion, and shear forces; outlined in Figure 3. He stated that spinal loading assessments must be capable of realistically assessing the loads that would be expected in the workplace in order to fully understand the causality and control the risk. Further, Keyserling (2000) stated that a compressive force acts on the lumbar spine in order to counteract the moments created by the load held in the hands, in combination with the body weight of the individual. This was also identified by Marras *et al.*, (1993) who stated that the load, multiplied by the distance it is being held from the body is a better predictor of the risk of back injury compared with considering an objects weight alone.

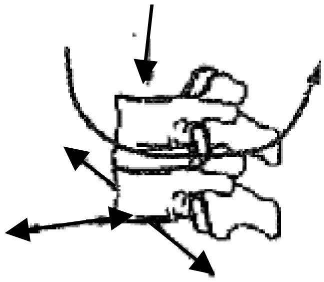


Figure 3. Three-dimensional loading occurring on the spine. (adapted from Marras, 2000)

Hutton and Adams (1982) proposed that degeneration of the lower back over time could result in the weakening of the disc. In addition, Hsiang *et al.,* (1997) identified that torsion had been identified as more recurrent and more detrimental than compressive forces in many situations. Furthermore, Gordon *et al*., (1991) found that a combination of flexion, rotation, and compression when performed repeatedly over 3 – 13 hours produced annular separation and the subsequent prolapse of the disc. However, Dolan *et al*., (1999) stated there is still some uncertainty over the extent of spine compression during vigorous activity.

These investigations have helped to identify how different spinal forces act on the spine and cause degeneration over a period of time when handling loads. The affect the mattress handling activity has on the compression forces acting on the spine was of particular interest within this research project.

3.3.2 Psychosocial Risk Factors

Psychosocial hazards have been defined by Cox and Griffiths (1996) as "*those aspects of work design, and the organisation and management of work, and their social and organisational contexts, which have the potential for causing psychological, social or physical harm*" (pp. 129 – 130).

The etiologic mechanisms of injury are still relatively poorly understood and the epidemiologic evidence may be somewhat conflicting. However, there is an increasing body of evidence outlining the role that psychosocial factors may play in the development of work-related MSDs. The studies reviewed by Bernard (1997) have provided inconsistent outcomes, however; he concluded that there might be some evidence to suggest that perceptions of intensified workload, monotonous work, limited job control, low job clarity, and low social support are associated with various work-related MSDs. Bernard (1997) concluded that these risk factors were found in a wide variety of work situations, were not restricted to specific jobs or work environments, and may represent generalised risk factors for work-related MSDs. Op De Beeck and Hermans (2000) also found that there is strongest evidence for a relationship between low social support, and low job satisfaction in the development of LBDs, but suggest that there is insufficient evidence for a relationship with job content, work / time pressure, and job control.

It is possible that a number of psychosocial factors work in combination to have an affect on the occurrence of LBP. Bongers and Hoogendoorn (2000) performed a prospective longitudinal study and found that low job satisfaction and low social support had the most positive associations with the occurrence of LBP and increased the perceived stress in the working environment. They also report that the most important psychosocial risk factors for predicting injury are high workload and low social support from colleagues or supervisors.

In addition to physical risk factors it was important to consider the impact of psychosocial factors within this research project and to establish if these risk factors are found within the warehouse environment.

3.3.3 Individual Risk Factors

Currently the most consistent associations have been found between LBDs and socio-economic status and previous medical history. There is some evidence of a relationship between age / years of employment and LBDs, but conflicting results exist for an association between LBDs, fitness, and smoking (Bernard, 1997; Op De Beeck and Hermans, 2000). In addition, Snook (2004) stated that the scientific evidence indicates that non-specific LBP is an age-related disorder that is affected by differences in occupation, genetics, and personal behaviour.

3.4 MANUAL HANDLING IN THE BED MANUFACTURING INDUSTRY

3.4.1 Incidence of Injuries within the Bed Manufacturing Industry

In 1994 the US Bureau of Labor Statistics reported data from private sector industries with the highest incidence rates of injuries and illnesses from overexertion resulting in days away from work. The mattress and bedspring manufacturing industry had an annual average employment of 31,000 employees, with an incidence rate of 233.5 overexertion injuries per 10,000 workers. These incidence rates are greater than those for ‘all manufacturing’ with an average employment of 18.319 million and an incidence rate of 83 overexertion injuries per 10,000 workers.

The HSE’s statistics for Great Britain in 2003 identify that an estimated 9,493 individuals were employed in the bed manufacturing industry (Bomel, 2005). This self-reported data collected by Bomel were used to generate statistics for the HSE based on reportable accidents and injuries from bed manufacturers within Britain. For 2003, a total of 80 manual handling injuries either major, or over 3-day injuries occurred. Table 3 shows the data gathered by Bomel (2005) from 1998 to 2003 on the manual handling incidence rates in the mattress manufacturing industry in Great Britain. This includes all manual handling accidents and not just those affecting the low back. An incidence rate of 761 per 100,000 people employed in Great Britain within the bed manufacturing industry was observed in 2003 (Bomel, 2005). Fluctuations of the incidence rate were observed and no pattern in the data is obvious. It would be useful to have details of the data from the 2003 / 04 year to establish if there is a continued decline in the incidence rate from the 2002 / 03 year, however, this is not currently available.

Table 3. Manual handling accident rates per 100,000 employed by HSE year* in the mattress manufacturing industry in Great Britain (Bomel, 2005).

Injury severity	HSE Year				
	1998/9	1999/0	2000/1	2001/2	2002/3
Major & O3D	862	894	614	862	761

* An HSE year begins in April and ends in March (Bomel, 2005).

An analysis of the data presented by Bomel (2005) showed that of the various occupations within the bed manufacturing industry, process operators suffer the largest proportion (51 %) of manual handling accidents. Handling and lifting activities caused the largest proportion of injuries with the weight and awkward manner of handling identified as principally responsible for causing these injuries. The torso and upper limbs are the areas primarily affected by manual handling accidents with 39.4 % of injuries affecting the back; 7.1 % affecting the neck; 5.4 % affecting the trunk; and 15.8% affecting the upper limbs, (Figure 4), (Bomel, 2005). The current research project comparing the two mattress handling techniques has focused on the low back due to the high number of back injuries within the bed manufacturing industry.

Lowering the accident rates within the mattress manufacturing industry is of importance to the HSE as part of the Musculoskeletal Priority Programme, which aims to reduce the rate of MSDs by 8 % by 2010. This programme is one of eight within the 'Revitalising Health and Safety' strategy. The overall aim of this strategy is to: 1) cut deaths and major injury accidents by 10 % by 2010; 2) reduce the rate of work-related ill health by 20 %; and 3) cut working days lost due to health and safety failure by 30 % (HSE, 2004).

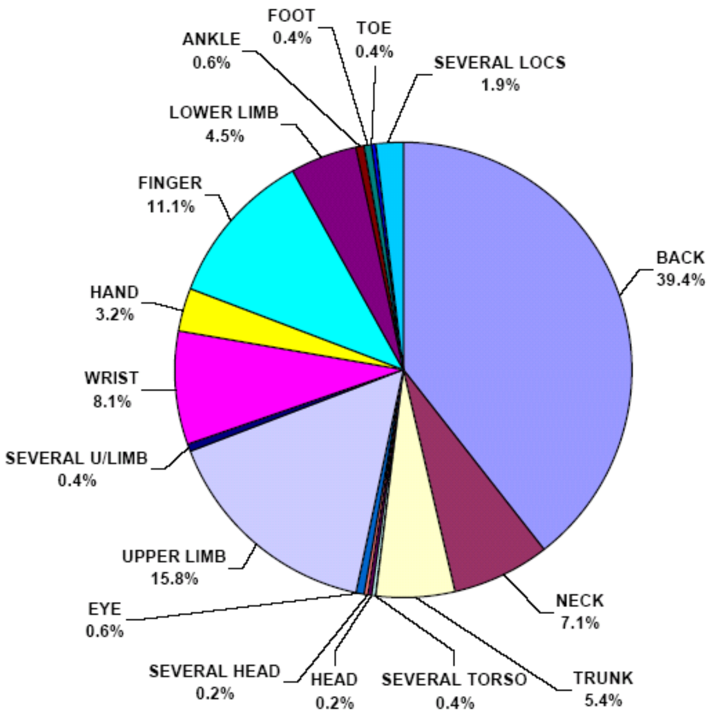


Figure 4. The affected body parts represented by proportion of major and over three day injury cases. (Bomel, 2005).

3.4.2 Previous Research in the Bed Manufacturing Industry

As part of the initial research into manual handling activities in the bed manufacturing industry commissioned by the HSE, a preliminary study was performed by the Health and Safety Laboratory (HSL), (Stanley, 2005). The aim of the investigation was to identify, and prioritise the tasks that pose greatest risk to employees in the bed manufacturing industry. Five different manufacturers of varying sizes were visited and five key tasks that exposed employees to an increased risk of musculoskeletal injury were identified, all of which contain various degrees of manual handling. The five tasks were: divan assembly / dressing (the wooden bases are stapled together and covered with fabric), mattress assembly (foam and padding is attached to the spring base), tape-edging (the mattress is stitched together), tufting (tufts or fabric buttons are pierced through the mattress which help to hold materials in place), and handling in the warehouse / distribution areas.

Stanley (2005) recommended that mechanisation or the use of handling aids such as conveyors and trolleys are beneficial as the primary means of avoiding or minimising the risks from manual handling that employees have to perform. In addition, Baril-Gingras and Lortie (1995), Grant *et al.*, (1997), and Stanley (2005) all identified that there were still situations particularly in warehouse areas and during truck loading where handling equipment is of limited use and employees will still have to manually handle items such as mattresses.

Wood and Andres (1995) observed mattress handling incidents when loading and unloading lorries. They reported that during loading, incidents occurred more frequently than during placement. They concluded that incidents formed an integral part of handling work and that greater analysis is essential to understand the risk factors associated with handling. They also identified that investigation into the choices made by handlers, that may include a specific handling technique and overall strategy should form the basis of a further investigation.

Stanley (2005) identified that a variety of manual handling training occurs across the manufacturers in the United Kingdom and its content varies considerably. However, the majority of health and safety managers advised that they are now training employees to lift and carry mattresses to the side of their body and not directly above the head. The aim is to keep the mattress as close to the individuals' centre of mass as possible, thereby minimising the stress on the lower back.

Employees were found to handle a wide variety of mattresses within the warehouse environment. Mattresses vary in weight and size and examples of approximate weights are shown in Table 4 (Stanley, 2005). The combination of weight and size make them difficult to handle, particularly as there are no specific handholds that operators can grip. Heavier mattresses will be handled by two employees who will decide when to ask their colleagues for assistance.

Table 4. Examples of standard mattress weights and sizes (Stanley, 2005).

Mattress size	Dimensions (cm) (length x width)	Weight range (kg)
Single	190 x 90	11 – 20
Double	190 x 135	15 – 50
King Size	200 x 150	20 – 80
Super King	200 x 180	50 – 100

Stanley (2005) observed that the tasks that warehouse operators perform involved repetitive handling of mattresses, commonly lifting them from conveyors, carrying them to storage areas or loading bays within the warehouse, and loading delivery vehicles. These activities involve pulling the mattress off a conveyor at approximately waist height and bending forward to lift it, often when the spine is twisted. Stanley (2005) identified that carrying distances vary depending on where individual mattresses are required. It was also identified that variation exists with regard to the amount of space available in the warehouse work environment across the industry. In addition, cramped environments can increase the difficulty of handling and potentially increase the risk of injury. Other factors such as poor floor conditions and uneven surfaces, extremes of temperature, particularly low temperatures during winter, and inadequate lighting levels may all contribute to the risk of warehouse employees developing musculoskeletal disorders (Stanley, 2005).

Summary

Investigators such as Stanley (2005), Baril-Gingras and Lortie (1995), and Grant *et al*., (1997) have identified that although mechanisation and the use of handling aids can eliminate or reduce the amount of manual handling warehouse employees perform, there are still circumstances whereby manual handling will occur; for example vehicle loading. Eliminating manual handling of mattresses is impossible and it is therefore important to establish if current manual handling training techniques are suitable and do not expose employees to excessive levels of risk of musculoskeletal injury. This research project will primarily focus on the low back, as Bomel (2005) identified that the back experienced the highest number of injuries compared with the rest of the body. Upper limb injuries also account for a high proportion of injuries within the bed manufacturing industry, however, Stanley (2005) concluded that warehouse employees are exposed to a lower risk of developing upper limb disorders, and is therefore outside the scope of this study. In order to evaluate the stress placed on the lower back when using the two handling techniques this research project used objective and subjective methodologies and these are discussed in the next chapter.

4 METHODOLOGY

4.1 INTRODUCTION

The reason for this research study is to investigate whether manually handling a mattress by holding it directly above the head results in an increased risk of injury to the worker compared with handling it at the side of the body.

This study has incorporated both objective and subjective methodologies suggested by many authors such as Monnington (1997), David (2005), Tracy (1998), and Op De Beeck and Hermans (2000). An overview of the research process and the methodologies adopted are shown in Figure 5.

This methodology chapter will describe the following:

(1) Methodologies selected for the current study;

(2) Safety considerations and ethical approval;

(3) Experimental design;

(4) Pilot study;

(5) Main study;

(6) Data analysis.

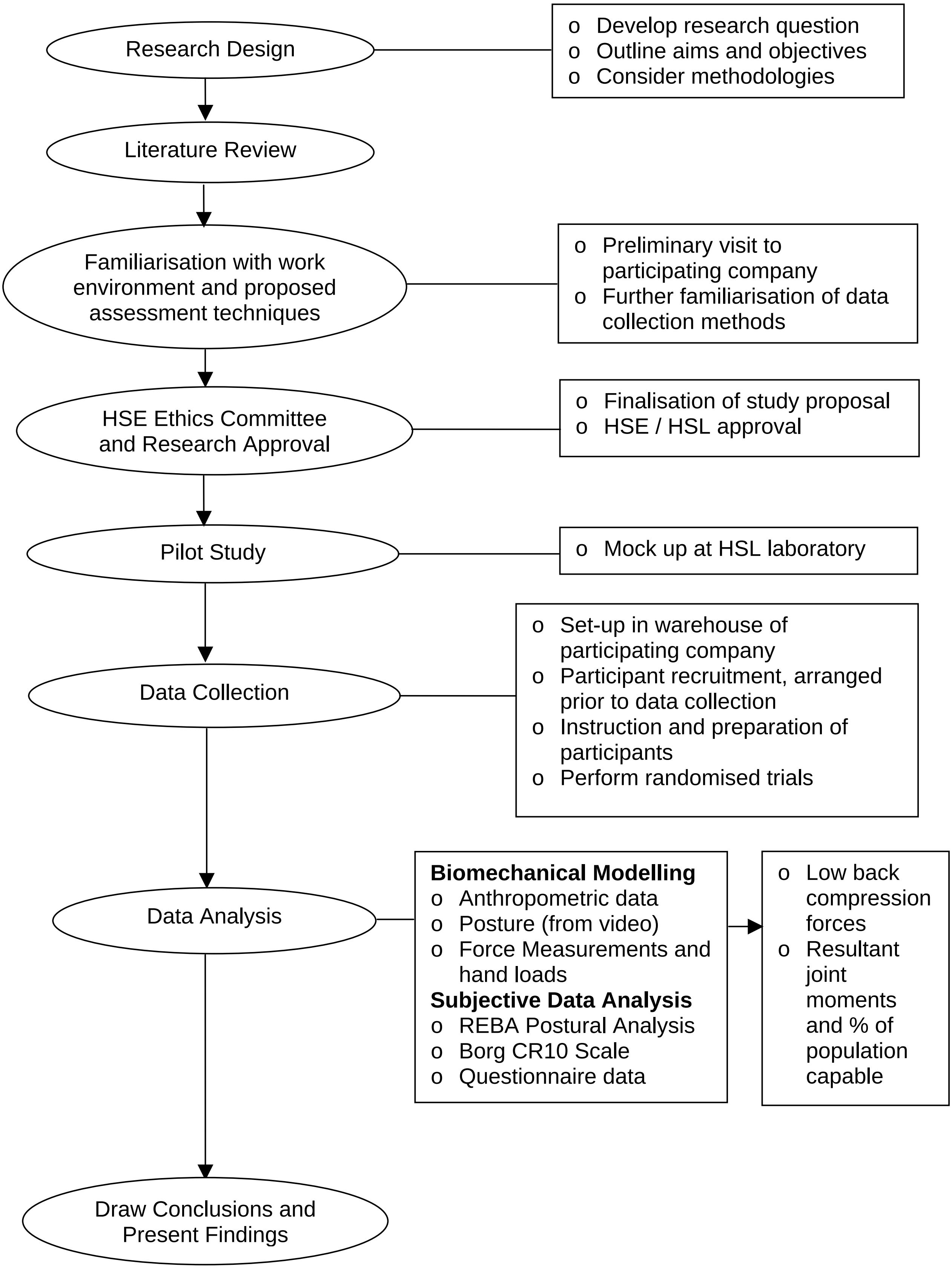


Figure 5. Flowchart showing the research stages.

4.2 METHODOLOGIES SELECTED FOR THE CURRENT STUDY

This section will describe the methodologies used and the reasons for their selection for this study. The following methods were primarily selected because the researcher was familiar with them and had previous experience using them.

4.2.1 Direct Measurement Techniques

The main measurement methods employed for this investigation involved the use of force plates, and biomechanical modelling. These are discussed in the following sections and were selected as they have been used successfully in other similar studies. For example, Ferreira and Stanley (2005) used force plates, video analysis, and biomechanical modelling techniques in an assessment of manual handling tasks involving the use of two ambulance carry chairs.

A range of other measurement techniques could have been employed such as the use of the motion tracking systems, lumbar motion monitors (LMMs), EMG, and hand force transducers, (Marklin and Wilzbacher, 1999; Dolan *et al*., 1999; Lindbeck, 1995; Ferreira and Stanley, 2005; Marras and Davis, 1998; Mirka *et al*., 2000; David, 2005), which were reviewed and would have provided an in-depth analysis of various components of the task. However, the investigator was unfamiliar with such equipment and decided that appropriate results could be obtained using the chosen methods rather than having to become familiar with, and competent in operating new equipment. Additionally, motion tracking systems and EMG are better suited for use in the laboratory and would not have been suitable for use in the field in this investigation. Other equipment such as the LMM can be difficult to use in the field and involve the use of complicated computer programs and data analysis.

4.2.1.1 Force Plates

Force plates were used in this investigation as they provide information with regard to the ground reaction forces acting on the foot, when standing, walking, or running. These forces are the most common type of force acting on the human body. A force plate is a measuring device, similar to a large set of weighing scales. However, the force vector is three-dimensional, consisting of one vertical component and two shear components (which act along the surface of the plate) (Winter, 1990). A force plate is connected to an electricity supply, an amplifier, and computer, therefore, when an individual is standing on, walking, or running across the force plate an electrical signal will be produced that is proportional to the force that is applied to it, and this can be recorded by computer. The ground reaction forces act on the feet and are transmitted through the body, therefore, changes in movement, or acceleration of a load will impact on the amount of force applied, for example when lifting a mattress.

Limitations

Force plates can be difficult to use outside of the laboratory due to their weight, and should be used on a well-constructed, level floor to ensure crosstalk is minimised (Kistler Instrumente AG, Winterthur, Switzerland). Lindbeck (1995) stated that difficulties also exist with ensuring subjects remain on the force plate during data collection. To overcome this, Lindbeck (1995) recommended only taking measurements for the brief periods when the feet are in contact with the surface of the plate.

Reasons for Selection

Force plates were chosen for use within this research project as the researcher had used them previously outside of the laboratory (Ferreira and Stanley, 2005) and was familiar in their use. It was also considered that the ground reaction force data would provide useful information about the loads experienced by the body and could be entered into the biomechanical model that would allow for comparisons to be made between the two mattress handling techniques.

4.2.1.2 Biomechanical Modelling

Tracy (1998) concluded that ergonomists most frequently use biomechanics to assess manual handling tasks. She indicated that biomechanics is best used as a comparative method, as the human body is a complex system and therefore all of the precise details cannot be provided by biomechanics. In addition Tracy (1998) suggested that biomechanics must also consider human variability for dimensions such as weight and stature, and the postures people choose when performing a task.

The Jack 3-Dimensional biomechanical modelling software (Version 5.0, 'Anthropometric Human and Environment Modelling Software', Simulation Solutions, 2005) was used within this study and is based on the 3-Dimensional Static Strength Prediction Program (3DSSPP) developed by the University of Michigan. It provides estimates of static lumbar disc compression force and moments at the L5 / S1 disc. It also provides estimates of muscle strength requirements needed to perform a specific task (Waters *et al*., 1998). The current research project used biomechanical models as a predictor of the risk of musculoskeletal injury. However, there are several limitations with both the University of Michigan model (used in Jack) and the NIOSH criteria outlined in the guidelines (1981) that should be recognised.

Limitations

(1) The Michigan model and guidelines do not take repetitive or sustained exertion into consideration, such as the repetitive handling of mattresses. Marklin and Wilzbacher (1999) advised that 3DSSPP should be used to assess the risk of acute injury and not that of cumulative trauma; the majority of chronic low back pain has been associated with cumulative exposure and degeneration over time. It has not yet been determined to what extent compression forces should be reduced for sustained exertions. Genaidy *et al*., (1993) suggested that tolerance limits should be reduced to approximately 60% of the predicted compression strength.

(2) The Michigan model is better suited to the analysis of static exertions, however, the mattress handling activity is a task that involves dynamic activities. Lindbeck and Arborelius (1991) stated that the inertial effects during the first acceleratory phase of the lift (e.g. immediately after lift-off) can increase the spinal compression forces considerably. Lavender *et al*., (2000) stated that the static postures modelled will provide some indication of the spine compression forces and estimated population strength capabilities, but may be underestimated as the acceleration and deceleration of joints when handling a load is not taken into account.

(3) The NIOSH criteria were developed using epidemiological and biomechanical evidence. Cadaver studies were used to predict the compression damage to spinal segments. This may be an unreliable predictor of the risk of injury when compared with in-vivo compressive forces experienced during work tasks. NIOSH (1981) recognised this limitation and estimated that 21 % of spinal segment specimens would fail at 3400 N, and therefore this limit may not protect the entire working population. Lindbeck (1995) outlined that forces below 3400 N represent only a nominal risk to employees, whereas forces greater than 6400 N are viewed as unacceptable, and require engineering controls. On the other hand, Leaman (1994) and Jager and Luttmann (1999) concluded that the epidemiological and biomechanical evidence that was used in setting the 3400 N limit has been shown to be inadequate and does not support a corresponding elevation in injury risk.

(4) The NIOSH guidelines (1981) with regard to lifting in the sagittal plane and the affects on the spine state that it is likely to be more vulnerable during trunk twisting, sideways

bending, or extreme flexion. Observations made prior to the study identified trunk twisting and sideways bending at the start of the lift, and sideways bending at the end of the lift when in the carry position for the Side of Body Technique. Therefore, the NIOSH criteria (1981) may underestimate the load placed on the back particularly at the start of the lift for both techniques, and at the end of the lift for the Side of Body Technique. The NIOSH (1981) guidelines were reviewed in 1991 and included methods for evaluating asymmetrical lifting tasks, but the additions made to the revised NIOSH lifting equation have not been added into the 3DSSPP software. Waters *et al.*, (1993) concluded that the limited scientific literature available that refers to asymmetric lifting shows a decrease in the maximum acceptable weight of 8 – 22 % compared with loads handled symmetrically in the sagittal plane.

(5) The resultant joint moments and percent capable estimations provided within the 3DSSPP program (and the Jack computer program) to determine the estimated percentage of the population who would be able to perform an activity based on the modelled posture, are based upon several experimental studies of static strength where the duration of exertion last between 4 – 6 seconds, and are based on United States populations (Chaffin *et al*., 1999).

Reasons for Selection

A biomechanical model was selected as one method for assessing the stresses placed on the musculoskeletal system to compare the two lifting techniques. Other biomechanical models could have been reviewed for use, however the author only had access to the 3DSSPP University of Michigan computer program or the Jack 3-dimensional computer program. The outputs are the same for both systems however, the Jack 3-dimensional computer program was chosen ahead of 3DSSPP as it allowed for greater flexibility when modelling postures, and forces could be entered to other parts of the body instead of just the hands.

The Michigan model is better suited to the analysis of static exertions and was not regarded as a major limitation when holding the mattress in the carry position at the end of the lift as this was done in a controlled and reasonably static manner. However, at the start of the lift a large degree of dynamic activity occurred when initiating the lift off the conveyor and could be controlled for by inputting the ground reaction forces into the model.

Lindbeck (1995) concluded that dynamic analyses may result in 1.2 to 3 times higher peak values of joint moments and compression forces than static analyses, depending on the biomechanical methods used and the tasks observed. In addition, Keyserling (2000) found that when compared with direct and indirect measurements of strain on musculoskeletal tissues for lifting tasks, consistent results were found with predictors from static biomechanical models with regard to the compressive forces acting on the lumbar spine. Therefore, the use of a biomechanical model was considered to provide a good estimation of the low back compression forces and the resultant joint moments for the mattress handling activities to allow for comparisons between the two techniques to be made.

Furthermore, concerns were raised in relation to the NIOSH criteria, and a review of the NIOSH (1981) guidelines occurred. The 1991 NIOSH review committee decided to maintain the 3400 N criterion of compressive force in the 1991 revised NIOSH lifting equation (Waters *et al.,* 1993). Therefore, the NIOSH compression limit of 3400 N offers a suitable cut-off point when examining the affects on the spine for comparing the two mattress handling techniques, and is not being used to define the absolute level of risk.

Measurement Techniques Adopted

Lindbeck and Arborelius (1991) identified that the start of the lift produces the greatest spinal compression forces. Therefore the dynamic component of the task, when the mattress is initially lifted off the conveyor, was considered by inputting the ground reaction forces into the biomechanical model at the start of the lift in order to provide a more realistic assessment of the weight of the load and allow for the dynamic accelerations. In addition, holding the mattress at the end of the lift in the carry position was done in a controlled and relatively static manner and therefore is suited to analysis using a biomechanical model. However, the ground reaction forces were also entered into the model for this component of the activity. The results obtained therefore provide a good estimation of the low back compression forces and the strength capabilities associated with the task. However, the biomechanical model does not take into account repetitive activities, of which, the mattress handling task is one, and therefore the absolute level of risk may be underestimated.

4.2.2 Observation Methods

4.2.2.1 Video Camera Recording

Martin *et al*., (2002) used a technique in a study on drum handling where posture data was obtained by using two digital video cameras set at 90 degrees to obtain perpendicular views of the work postures. Lindbeck (1995) used video cameras and body markers attached to the skin, over joint centres. He found that it became difficult to obtain accurate posture data particularly for large asymmetric movements as objects or other parts of the body may obstruct the view of the markers by the cameras. This limitation was considered within this research project as when the mattress was lifted from the conveyor it could block the view of body markers. This was established from observations of video footage of the handling task from previous site visits (Stanley, 2005). As a result, it was decided that the best places to position the cameras for this study were to the side of, and behind the participant. This would provide suitable views of the task and the body markers during the mattress handling trials. The analysis of the images would provide valuable postural details for use during biomechanical modelling.

4.2.2.2 Rapid Entire Body Analysis (REBA)

Hignett and McAtamney (2000) developed Rapid Entire Body Analysis (REBA) to assess the critical aspects of a task and the work postures associated with a job. REBA also considers the load weight, hand coupling, and the activity level. The results can be combined to produce a REBA score that indicates the level of musculoskeletal risk associated with the task. Initial reliability for inter-observer coding was reported to be promising, however, it has been identified that additional work is required to determine the validity of the tool (Hignett and McAtamney, 2000). Ferreira (2002) identified that REBA can be sensitive to small variations in postures. However, it was considered to be an acceptable tool to use within this research project as the researcher had used the tool previously, and it takes into account the posture of the whole body, the load being handled, and the grip on the load. This allowed for postural comparisons to be made between the two mattress handling techniques. REBA was used to assess the participants’ postures at the start of the lift and at the end of the lift when in the carry position, but was not used to provide an overall level of musculoskeletal injury risk.

4.2.3 Self Reports

Tracy (1998) advocated that the results of biomechanical analysis should not be used in isolation and identified that discomfort charts, and questionnaires are useful tools to help identify other factors of discomfort that force calculations cannot.

Furthermore, David (2005) identified that many types of self-reporting methods can be used to collect data on workplace exposure to investigate both physical and psychosocial risk factors.

Methods may include the use of questionnaires, interviews, and worker diaries. He also identified that other relevant additional information such as, demographic variables, reported symptoms such as pain and postural discomfort, and levels of subjective exertion can provide additional information about a work environment and the risk factors workers are exposed to, and how they contribute to the development of work-related MSDs. Therefore, Ratings of Perceived Exertion (RPE) and a questionnaire were used within the investigation.

4.2.3.1 Borg Psychophysical Assessment of Effort

Kilbom (1998) stated that Ratings of Perceived Exertion (RPE) scales have been used to a limited extent in industry, and gathering estimations of physiological load by subjective ratings is useful as this is easier than taking direct measurements. However, she stated that recent findings from field work indicated that in some circumstances previous experience and subject motivation may influence the ratings subjects provide. For example highly motivated subjects tend to underestimate their exertion.

Marklin and Wilzbacher (1999) performed an assessment of different work tasks within a warehouse. Four different assessment tools were used (NIOSH Lifting Equation, Static Strength Prediction Program (SSPP), the Lumbar Motion Monitor (LMM), and Borg's category ratio scale of psychophysical assessment of effort (CR10 scale). They found that the CR10 scale was applicable to all types of tasks of different intensities that were investigated and required the individuals to use verbal estimates such as "strong" or "weak" to describe the level of intensity they may experience. Marklin and Wilzbacher (1999) concluded that there were no limitations to the type of tasks that can be evaluated. For these reasons the use of the CR10 scale was considered to be a suitable tool for use when comparing the two mattress handling techniques.

4.2.3.2 Questionnaires

The questionnaire used within this research incorporated a Likert 5-point scale (Appendix H). Sinclair (1998) stated that the Likert's Summated Ratings Method, requires a subject to respond to every statement, stating whether or not they agree or disagree with it. Within this research project it was thought necessary to obtain information from the study participants and the wider warehouse population to gain insight into the jobs they perform and the related issues within the workplace.

Sinclair (1998) also suggested that a 'battery' of questions may be used to ensure consistency of results, however, due to time constraints this was not done in this study. It is suggested by Sinclair (1998) that subjects prefer the Likert scaling technique as it feels 'natural' and maintains their involvement. The Likert approach is also said to require less effort than when compared with other techniques when generating scales.

Summary

A range of methods were selected and adapted to provide data to answer the research question.

Force plates were chosen as they provide information on the ground reaction forces. These were input along with hand forces into the Jack biomechanical model. The biomechanical model, although based on static and infrequent handling activities, uses the NIOSH (1981) criteria (3400 N and 6400 N) to provide estimations of the low back compression forces and strength capabilities at the major articulation points within the body. In addition, REBA postural analysis was used to help identify high risk postures.

A questionnaire and the Borg CR10 scale of psychophysical effort were used to determine if participants preferred either technique or perceived one technique to require more effort than the other.

These methods allowed the two mattress handling techniques to be compared and provided an overall assessment of the differences to determine if one technique placed employees at an increased risk of musculoskeletal injury compared to the other.

4.3 SAFETY CONSIDERATIONS / ETHICAL APPROVAL

Primary consideration was given to participant safety and all necessary measures were taken to ensure safe lifting conditions during the experiment. In order to achieve this:

(1) The full experimental protocol was submitted to, and approved by HSE's Research Ethics Committee;

(2) A pilot study was performed at HSL prior to the main study;

(3) 'Request for Volunteer' leaflets were placed in the warehouse and canteen within the workplace that provided information about the study, the selection criteria for volunteers, and who to contact if employees wished to participate (See Appendix A). The exclusion criteria included that participants: 1) were not currently on 'light' or 'special' duties; 2) had not suffered from a back complaint in the last six months; 3) had not suffered any other muscle or joint problems that affect how they worked, within the last six months; and 4) were currently of general good health;

(4) Prior to commencing the trial, participants completed a health screening questionnaire (Appendix C);

(5) Participants were informed that the tasks were realistic and represented normal work activities;

(6) In addition, participants were informed of any risks and informed that they were permitted to withdraw from the study at any time.

4.4 EXPERIMENTAL DESIGN

4.4.1 Independent Variable

Simulated Task

Previous research undertaken by Stanley (2005) identified that the repetitive handling of mattresses within a warehouse exposed employees to an increased risk of musculoskeletal injury, particularly to the low back. This handling task was chosen as warehouse employees repetitively lift mattresses off the conveyor and carry them using either the Overhead or Side of Body Technique within the warehouse over the course of their entire workday. Current manual handling training instructs employees to use the Side of Body Technique but no research has been undertaken to determine if this technique reduces the risk of sustaining a low back, or musculoskeletal injury compared to the Overhead Technique. In order to make a comparison between the two techniques study participants were asked to perform a simulated lifting task that involved:

- *Lifting a double mattress off a conveyor into one of two carry positions.*

Techniques Adopted
Two different mattress handling techniques were evaluated during this study and are shown in Figure 6. Both techniques were performed by all eight participants.

(1) **Overhead Technique:** This technique required the participant to lift the mattress off the conveyor into the overhead carry position. The mattress was held above the head for approximately 5 seconds.

(2) **Side of Body Technique:** This technique required the participant to lift the mattress off the conveyor into the carry position at the side of the body. The mattress was held at the side of the body for approximately 5 seconds.

Overhead Technique **Side of Body Technique**

Figure 6. An example of the two handling techniques.

4.4.2 Dependant Variables: Measurement Methods
To determine the forces that warehouse personnel exert during the handling tasks, two types of force measurement technique were utilised 1) Force plate measurement, and 2) Hand force measurement.

4.4.2.1 Force Plate Measurement
Within this study, the force plates could be used effectively as they were placed in brackets with adjustable legs on the concrete warehouse floor. This enabled the legs to be adjusted to ensure the force plate was level and minimise any crosstalk. The force plates were then calibrated up to 100 kg to ensure that acceptable linearity and accuracy were achieved. The lifting task was a straightforward activity and the data was recorded for 30 seconds, therefore the study participants were able to keep their feet in contact with the force plate as suggested by Lindbeck (1995).

Measurement Techniques Adopted
Participants performed the series of lifts standing on a Kistler force plate, connected to a 9865B charge amplifier. Version 3.11 of the Bioware Force Plate software (Kistler Instrumente AG, Winterthur, Switzerland) was used to record the data. The charge amplifier range was set to 10000 pC / 10V, and data was collected at a sampling frequency of 100 Hz for a period of 30 seconds.

Calibration prior to the trials showed that high linearity and accuracy were evident, with a deviation of 1.06 %, from the factory calibrations.

To determine the forces that warehouse personnel exert during the handling tasks the force plate was used to obtain the ground reaction forces over a 30 second period. The vertical ground reaction forces (Fz) were extracted to determine:

(1) Peak force exerted at the start of the lift; and

(2) Mean force exerted at the end of the lift when holding the mattress in the carry position.

4.4.2.2 Hand Force Measurement

Within this study it was difficult to determine the hand forces that should be entered into the biomechanical model. The mattress handling task was broken down into two parts: 1) The start of the lift, and 2) The end of the lift. This was done for both techniques assessed.

Start of the Lift

At the start of the lift for both the Overhead and Side of Body Techniques similar postures were observed. It was difficult to determine what proportion of the load when initiating the lift from the conveyor was born by the lower arm. The decision made in relation to the load distribution born by the lower arm when initiating the lift, were made from reviewing previous video footage collected during the preliminary study by Stanley (2005). It was considered that the load being held in the lower arm was significantly greater than 50 %, but was not as much as 100 %. Therefore, following consideration of the video footage a subjective judgement was made by the researcher and a split of 80 % born by the lower arm and 20 % by the upper arm was decided, and was based on an approximation of the load distribution. Thus, 80 % of the ground reaction forces (less body weight) were entered into the biomechanical model for the lower arm and 20 % into the upper arm.

End of the Lift

The two mattress handling techniques required different methods of determining the hand forces that could then be entered into the biomechanical model when the mattress was held in the carry position at the end of the lift.

(1) **Overhead Technique:** When holding the mattress above the head at the end of the lift, it was assumed that an equal distribution of the load would be born in both hands. Therefore, the forces were equally divided and applied to both hands.

(2) **Side of Body Technique:** When using the Side of Body Technique the proportion of the load born by the lower arm needed to be assessed to determine the load that would be entered into the biomechanical model. This was determined by using a Mecmesin hand held dynamometer and attachment. Study participants were asked to hold the mattress in the carry position whilst the researcher placed the dynamometer under the mattress near where their hand was. The participant was then asked to slowly remove their hand but to keep their body posture the same. The study assistant helped to balance the mattress in position. This process was repeated twice and the measurements were recorded to ensure an acceptable level of consistency. An average of the two measurements was taken and the forces obtained were entered into the biomechanical model. The other proportion of the force was entered into the biomechanical model at the shoulder joint, as this is where the mattress rests when held in this position.

The methods of determining the hand load distribution for both the Overhead and Side of Body Techniques were considered to provide an effective and consistent measurement method to allow for comparisons to be made between the two handling techniques.

4.4.2.3 Subjective Measurement

Following the final trial of each of the two techniques participants were asked to provide their rating of perceived effort using the Borg CR10 scale. Each participant was assigned to either the researcher or the assistant and was instructed to point to their score and avoid verbal communication. In this way, discussion and competition between participants was avoided.

A questionnaire was administered to gather basic information about the job, and the psychosocial risk factors participants may be aware of.

In addition, participants were asked to discuss with the researcher and provide feedback on:

(1) The technique they preferred and their reasons for this preference;

(2) Differences between task performance in the study and typical task performance; and

(3) The implications of other risk factors on task performance.

The other warehouse employees received their questionnaires during the first data collection period in December. These were left with their line managers to distribute. An envelope was provided so that the completed questionnaire would remain confidential. Completed questionnaires were then returned to their line managers who then forwarded them to the researcher.

Summary
This research investigated one simulated task and made comparisons between the two handling techniques: 1) The Overhead Technique, and 2) The Side of Body Technique. A force plate was used to determine the ground reaction forces, and video footage captured the lifting trials. Hand force measurements were determined by reviewing the preliminary video footage and a hand held dynamometer was used to determine the proportion of the hand forces in the lower arm for the Side of Body Technique. The Borg CR10 scale was used to determine participant’s ratings of effort and a questionnaire was used to determine participant’s technique preferences and the presence of psychosocial risk factors.

4.5 PILOT STUDY

A pilot study was undertaken prior to the main study to determine if the experimental protocol was suitable and reliable. The force plates and surrounding wooden platform were set up in the laboratory at HSL and staff volunteered to act as participants for this phase of the study (Figure 7). It was unreasonable to ask these volunteers to lift mattresses, therefore the procedures and lifting actions were performed but no actual loads were lifted. The instructions issued to subjects, the reliability of the measuring techniques, the roles of the researcher and the assistant, and the safety procedures were all examined and reviewed.

As a result of the pilot study, it was decided that the front wooden platform would not be required, as the force plate would need to be pushed up close to the conveyor in the warehouse. It was initially thought that two force plates might be required following a review of video footage of warehouse employees lifting mattresses off the conveyor. As a result of the inability to fully simulate the lifting trials in the laboratory the wooden platform was constructed to allow for the position of the inner blocks to move and enable different force plate arrangements to be made as necessary. At this stage it was still unclear if one or two force plates would be required; this was determined following preliminary on-site trials.

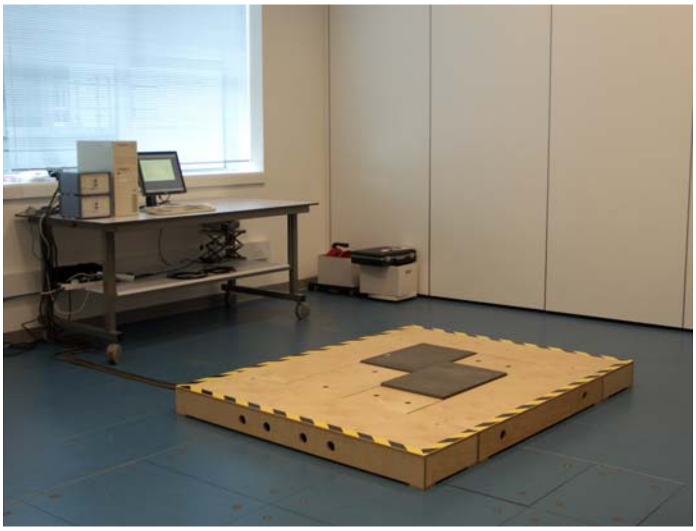


Figure 7. Force plates and computer set-up during pilot study.

4.6 MAIN STUDY

4.6.1 Participant Recruitment

A large mattress manufacturer was chosen following the commitment from both the Health and Safety representatives and the Warehouse Managers, who agreed to help provide volunteers. The company were willing to participate in the study and provide a suitable environment in which it could be undertaken.

Method of Recruitment and Number of Participants

Initially, posters were placed in the workplace informing staff members about the study, and if they were interested in participating that they should contact their line manager. The poster, shown in Appendix A, also outlined the following restrictions to participation including that they:

(1) Were not currently on ‘light’ or ‘special’ duties;
(2) Had not suffered from a back complaint in the last six months;
(3) Had not suffered any other muscle or joint problems that affect how they worked, within the last six months; and
(4) Were currently of general good health.

In addition to the posters, during team meetings line managers verbally informed their employees about the study and asked for volunteers to come forward and participate. These approaches yielded 8 male volunteers who matched the study criteria and were representative of the exclusively male warehouse population.

Testing took place within their normal work hours and took approximately 1.5 hours to complete. Participants were not paid or given any financial incentive for participating in the study.

Location

The study was performed in the warehouse where the participants normally work. It was decided that it would be too difficult to accurately simulate the tasks in the laboratory as a full-scale mock-up up of a conveyor or worktable, and a mattress would be required. The force plates had been used on-site before (Ferreira and Stanley, 2005) and it was concluded that this would be suitable for this study. In addition, this decision was made to ensure subject participation due to the distance participants would have to travel from the warehouse to the laboratory; approximately 2 hours.

The data collection was performed on two separate occasions in order to fit in with the company and to avoid months where the production demands were high, therefore 4 subjects completed the trials on the first occasion and 4 on the second occasion. A large conveyor runs the length of the warehouse and the equipment was set-up at one end of the conveyor that was not being used on both occasions (Figure 8).

Overhead Technique **Side of Body Technique**

Figure 8. Warehouse set-up showing the Overhead and Side of Body Techniques.

4.6.2 Overall Study Protocol

Figure 9 highlights the overall experimental process during the study trials.

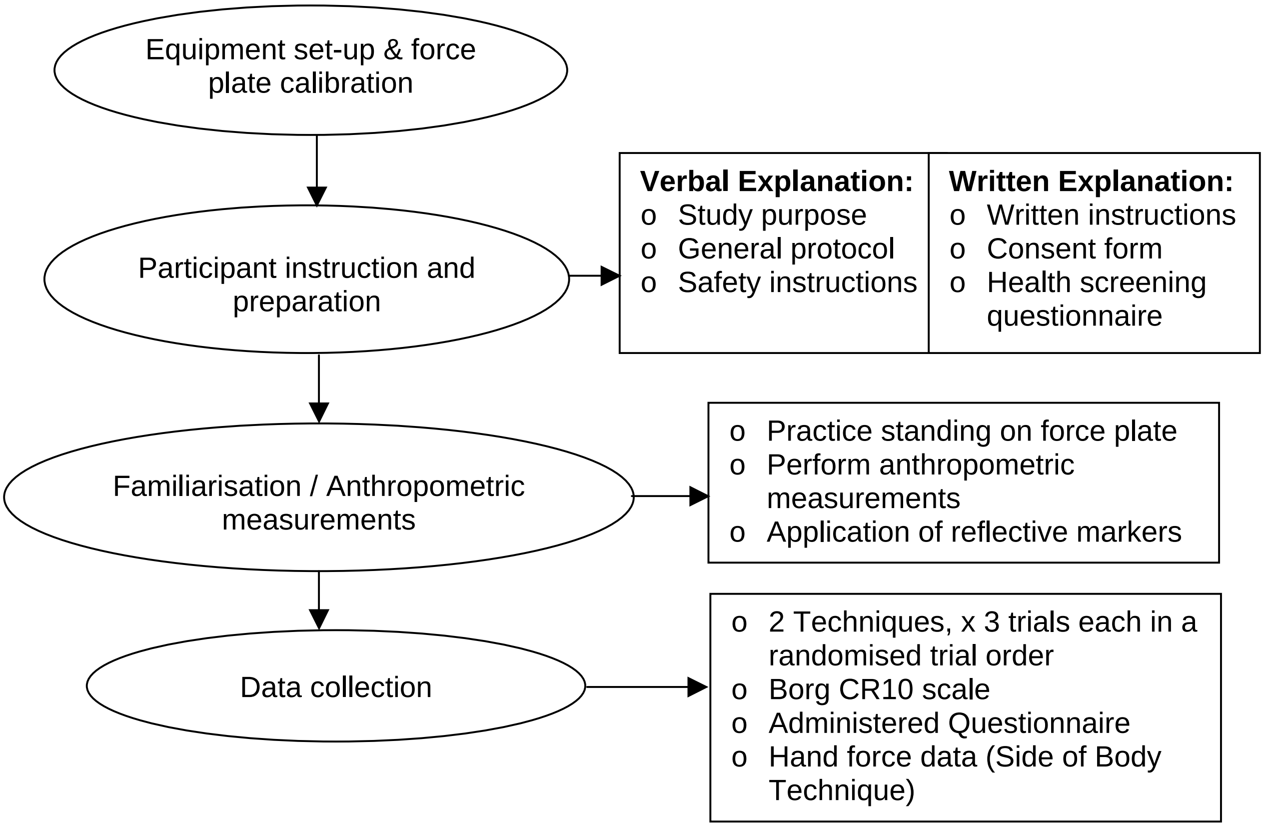


Figure 9. Experimental process during trials.

Equipment Set-up and Force Plate Calibration

The equipment was set-up in the warehouse prior to meeting the participants. This involved placing the force plates next to the conveyor and fitting the wooden platform around the force plates. The two video cameras were located, at 90-degree angles, one to the side of the conveyor, and the second behind the conveyor. A trial number board was used that could be viewed by both cameras to aid with identification of trial data and participants during the analysis phase. The force plates were connected to the computer and then they were calibrated. This was done using 25 kg calibrated weights and loading the force plates up to 100 kg to ensure that acceptable levels of linearity and accuracy were achieved. This procedure is outlined in Appendix B.

From previous observations from preliminary investigations (Stanley, 2005), it was anticipated that one force plate would be sufficient to perform the lifting trials, however, two force plates were taken in case required. On the initial data collection day one of the force plates was not working properly and therefore only one force plate could be used. This may have restricted the postures of participants slightly when performing the lifts, however, prior to the trials the participants were asked if one force plate allowed them to perform the lift as they would normally. All participants agreed that using one force plate allowed them to realistically perform the lifting trials. To ensure consistency, only one force plate was used during the second phase of data collection.

Participant Instruction and Preparation

Participants were already at work and therefore attended the test session in the clothing and footwear that they normally wear for work. The participants were tested in four groups, two at a time. An introductory briefing, including the purpose, general protocol, and safety instructions for the trials were explained to each participant. A written set of instructions, a health-screening questionnaire, and a consent form were signed by each participant in the presence of the researcher and the assistant to indicate that the participant was fully aware of the requirements and any possible health risks. The forms used are shown in Appendix C and D.

Participant Familiarisation and Anthropometric Measurement

Participants had already been working prior to testing, and a warm-up was considered to be unnecessary. However, a standardised familiarisation period of 5 minutes provided participants with the opportunity to ask the researcher any questions and to practice what was required in the trials. This familiarisation period required each participant to: 1) Step onto the force plate; 2) Lift the mattress off the conveyor into the carry position; 3) Hold the mattress there for approximately 5 seconds; 4) Lower the mattress back onto the conveyor; and 5) Step off the force plate. This was performed for both handling techniques. Whilst one participant was familiarising themselves with the task requirements and being supervised by the study assistant, the other participant was having their anthropometric measurements taken by the researcher. Upon completion of this the two participants swapped roles.

Measurements of the following anthropometric dimensions were taken: stature, weight, shoulder height, elbow height, knuckle height, hip height, iliac crest height, knee height, ankle height and biacromial breadth using a Harpenden anthropometer in the postures proposed by Pheasant (2001). The form used to record these anthropometric measures is provided in Appendix E. Reflective markers, to help identify joint centres during analysis, were then attached to external body landmarks overlying the joint centres of the wrist, elbow, shoulder, hip, knee, and ankle. The preferred attachment points for the markers were directly to the skin. As participants were wearing their normal work clothing this was not possible. To overcome this problem, markers were placed on the skin wherever possible. Otherwise, markers were mounted on Velcro straps that could be attached and secured to the limbs over the clothing at the joint centres. This still allowed for free movement. During the trials observations were made to ensure that the markers did not move from the exact position during the lifting task.

Data Collection

Following instruction and preparation, participants were reminded that if at any time during the trials they experienced any pain or discomfort, they should tell the researcher immediately. It was emphasized that they were entitled to withdraw from the study at any time. Additionally, at no time during the trials would they be expected to significantly overexert themselves. If they had any questions or needed additional time to familiarise themselves with the handling task, then they were asked to let the researcher know.

Each participant was asked to perform the simulated tasks involving a series of lifts while standing on the force plate. Six trials in total were completed with 3 lifts off the conveyor into the Overhead Technique carry position, and 3 lifts off the conveyor into the carry position for the Side of Body Technique. The lifting manoeuvre lasted for approximately 30 seconds each. A random trial order was used and is shown in Appendix F. Having participants perform the trials in pairs meant that they alternated to perform the two handling tasks with each other, therefore, allowing for rest periods between each trial. Recording the data from each of the trials into the computer also took approximately 30 seconds and this contributed to the rest period. Upon commencing trials the first participant was asked if they were ready to begin. Following that, each participant was asked prior to each trial if they were ready to continue.

The researcher would then instruct the participants:

(1) Which of the two techniques they would perform according to the trial order sheet (Appendix F).

(2) Once the researcher had commenced 'data logging' the participants were instructed to begin the task when ready.

(3) Once the participant was standing in the carry position for either the Overhead Technique or the Side of Body Technique the participants were instructed to hold the mattress for approximately 5 seconds to determine the static force exerted.

(4) Following this, they were instructed to lower the mattress back onto the conveyor and to step off the force plate, however, the lowering aspect of the trials was not considered for analysis.

Following the third trial of each technique, participants were asked to rate the level of perceived effort using the Borg CR10 Scale (Appendix G). The researcher completed this with each participant individually to avoid any conferring or competition between participants.

The hand force measurements at the end of the lift for the Side of Body Technique using the Mecmesin hand held dynamometer were then undertaken, following the methods outlined in Section 4.4.2.2.
At the end of all the trials the participants were individually asked about which technique they preferred (Appendix G) and a questionnaire was administered to them (Appendix H). The participants were then thanked for their time upon completion of the questionnaire and were able to return to their normal work activities.

Summary

Data collection occurred on two separate occasions with 4 participants on each occasion, 8 in total. Participants were recruited from within a large mattress manufacturer via posters outlining the exclusion criteria and the lifting trials occurred within an operational warehouse. The force plate and video cameras were set-up at a quiet end of the warehouse, next to the conveyor. Participants were informed of what was required of them prior to the trials and a period of familiarisation of the lifting activity occurred. Anthropometric measurements were taken for each participant prior to commencing the trials. A total of 6 trials were performed by each participant, 3 for each technique. Following the last trial for each technique the Borg CR10 scale was used and a questionnaire was administered.

4.7 ANALYSIS OF THE DATA

The data was analysed:

(1) At the start of the lift: This was defined as when the mattress was just raised from off the conveyor at the beginning of the lift; and

(2) At the end of the lift: This was defined as when the participant was holding the mattress in the carry position. For example, the position that would be used to carry the mattress within the warehouse.

Data analysis was performed for both techniques.

4.7.1 Biomechanical Data Analysis

The biomechanical modelling approach used the commercially available Jack Version 5.0, 'Anthropometric Human and Environment Modelling Software' (Simulation Solutions, 2005) to estimate the physical loads acting upon the human body.

Inputs into the Model

The Jack computer program allows for three different factors to be entered.
These included:

(1) Anthropometric data
(2) Posture
(3) Force measurements and hand loads

Postures were analysed using still photographs that were captured from video footage taken during the trials, using the DV Tools computer program. This program allows for a still image to be captured from video footage and saved within the computer hard drive. One of the three trials was assessed for each participant and technique at the start of the lift (mean forces at the start of the lift) and at the end of the lift (mean forces at the end of the lift) when in the carry position. These forces were input into the model after the individual participants body weight had been subtracted from the ground reaction forces data at the start and end of the lift. These images were used to assist in the modelling of the human figure in the Jack 3-dimensional environment.

Outputs Selected from the Biomechanical Model

(1) **Low back compression force:** The 'Low Back Analysis' within the 'Task Analysis Toolkit' of Jack was used. This estimates the compression forces acting on the participants lower back at the L5 / S1 junction, the junction between the last lumbar vertebra and the sacrum of the spine. This location is considered to be at greatest risk of injury as this is where the greatest load is placed on the spine. The National Institute of Occupational Safety and Health (NIOSH) in the U.S. following a review of the scientific literature proposed that:

(1) Tasks causing L5 / S1 compression forces less than 3400 N do not pose a risk to most young, healthy workers (75% of women and 99% of men) (Waters *et al*., 1993).

(2) Tasks causing L5 / S1 compression forces greater than 3400 N should be considered potentially hazardous to some workers (Waters *et al*., 1993).

(3) 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, trunk, hip, knee, and ankle were 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 (Chaffin *et al*., 1999).

One out the three trials for each of the two techniques was analysed for each of the 8 study participants. This method of selecting which trial to base the biomechanical models on occurred following observation of the video footage from both camera angles. The trial that provided the best view of the participants posture for each technique was selected. The start of the lift and the end of the lift, when in the carry position were analysed that provided a total of 32 data sets.

4.7.2 Additional Data Analysis

Data was entered into spreadsheets in Microsoft Excel 2000. This included:

(1) Ground reaction force data from the force plates;
(2) Anthropometric data;
(3) Low back compression data;
(4) Percentage of the population capable data;
(5) Borg CR10 scores; and
(6) REBA scores.

Subsets of the data for analysis were chosen. The ‘Chart’ function in Microsoft Excel 2000 was selected to show comparisons between the two techniques. Additionally, the ‘Data Analysis’ function in Microsoft Excel 2000 was used for statistical analysis. A paired t-test at $p < 0.05$ level of probability was used to examine the affects of the two handling techniques for the ground reaction forces and the lower back compression forces. A one-tailed Wilcoxon test was used to test the significance of the REBA postural analysis scores and the Borg CR10 scores, to establish whether a significant difference between the scores in the two techniques exists. This was done for the data collected at the start of the lift and at the end of the lift, in the carry position.

In addition, participant stature and weight were entered into the PeopleSize 2000 Professional computer program, Version 2.05. This allowed a comparison to be made of the participants' anthropometric dimensions with that of the British male 18 – 65 year old population.

The responses to the questionnaire that was distributed to the wider warehouse population were analysed using descriptive statistics.

Summary

Data was analysed bearing in mind the aim of the investigation, thus comparisons between the two techniques were performed. Ground reaction forces, less the participants body weight were entered into the Jack biomechanical modelling program and low back compression forces and resultant joint moments and percent capable estimations were the selected outputs used from the Jack biomechanical analysis. All data where possible, were entered into spreadsheets within Microsoft Excel. The mean, standard deviation, and range of the data were calculated, and statistical tests were used to determine if differences between the two techniques were statistically significant.

5 RESULTS

This chapter will present the results obtained from the trials performed. These include the participant demographics, force measurements obtained from the force plate, results from the biomechanical analysis, ratings of psychosphysical effort, and questionnaire data. All the data were compared to determine if differences between the two handling techniques (Overhead Technique and Side of Body Technique) were evident at the start of the lift and at the end of the lift when in the carry position.

5.1 PARTICIPANTS INVOLVED IN THE STUDY

Eight males participated in the study. Table 5 summarises the anthropometric and demographic characteristics of the group and the number of years participants have worked in the warehouse. The group of study participants represents a wide range of the British 18 – 65 year old male population, from 35.5 % to 99 % for stature, and 35.9 % to 99.4 % for weight. The work done in the warehouse is carried out exclusively by male employees and therefore this group was representative of those who work in the warehouse. Individual measurements are shown in Appendix I.

Table 5. Summary of participant experience, anthropometric, and demographic information.

Variable (units)	Mean	Std.dev	Range
Age (years)	31.3	7.8	20 - 43
Stature (mm)	1821.3	75.1	1730 - 1920
Weight (kg)	89.8	15.7	74.1 - 120.5
Experience (years)	4.4	5.8	1 mth – 17 yrs

Participants did not report any recent occurrences of previous musculoskeletal injury that they felt would affect their ability to perform the handling tasks safely and effectively.

Participants were diverse in experience ranging from 1 month to 17 years. Excluding these extreme ranges, on average, participants had 3 years of warehouse experience in the bed manufacturing industry. All participants were familiar with both techniques investigated excluding one who had used the Overhead Technique infrequently. The study participants on average work 36 hours per week (8 hour shift) with half an hour for lunch and two fifteen minute breaks, mid morning, and in the afternoon and this is representative of the wider warehouse population. Overtime is available to all warehouse employees and this may result in employees working an extra 6 or 12 hours per week. There is little job rotation between tasks in the warehouse environment as all activities involve handling either mattresses or divans.

5.2 FORCE MEASUREMENT

The ground reaction forces (GRF) obtained from the force plate were used to compare the two techniques at the start of the lift and at the end of the lift when the mattress was in the carry position. All results are reported in Newtons (N).

Comparison of Ground Reaction Forces

The mean ground reaction force and standard deviation were calculated for all participants comparing the Overhead Technique and the Side of Body Technique and is shown in Table 6 and Figure 10. The Overhead Technique required a greater force to initially lift the mattress off the conveyor compared with the Side of Body Technique.

Table 6. Mean ground reaction force for all participants at the start of the lift and at the end of the lift, comparing the Overhead Technique and the Side of Body Technique.

	Ground Reaction (N)					
	Start of Lift			End of Lift		
	Mean	**Stdev.**	**Range**	**Mean**	**Stdev.**	**Range**
Overhead Technique	466.86	89.97	386.0 - 634.5	187.39	7.17	175.0 - 195.1
Side of Body Technique	404.07	55.26	341.1 - 490.3	190.74	7.74	181.3 - 204.0

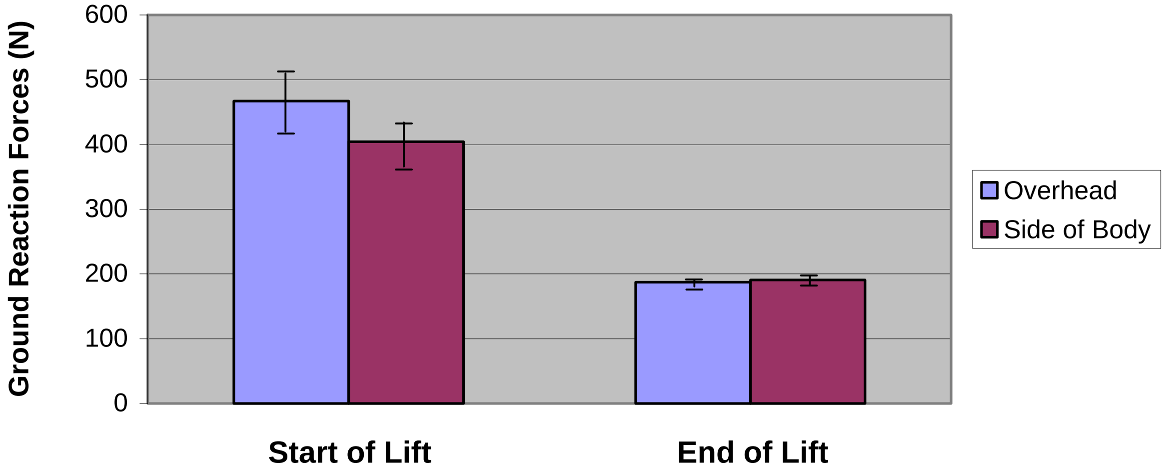


Figure 10. Comparison of the ground reaction forces at the start of the lift and the end of the lift for the Overhead Technique and the Side of Body Technique.

Statistical Analysis

A paired t-test was performed to test the statistical significance of the results and these are presented in Table 7. This analysis indicates that for the start of the lift there is a statistically significant difference between the Overhead Technique and the Side of Body Technique ($p < 0.05$), whereas when in the carry position at the end of the lift there is no statistically significant difference between the two techniques.

Table 7. Statistical significance of ground reaction forces at the start of the lift and at the end of the lift between the two techniques.

	Start of Lift	End of Lift
t-value	2.689	1.372
df	7	7
p-value	0.031	0.212
effect size	0.86	0.45

Comparison of Different Lifting Techniques

A comparison of lifting techniques at the start of the lift was performed for participants who scored the greatest and smallest ground reaction forces for both techniques. The techniques adopted, illustrated in Figure 11, show the three participants at the start of the lift for both techniques. Participant 7 faced the mattress front-on whereas Participant 1 and 6, as did all other study participants, adopted a side-on posture to the mattress and conveyor. The results of the analysis show:

- The side-on posture adopted by Participant 1 produced the greatest ground reaction forces for the Overhead Technique at the start of the lift compared to all other study participants. For the Side of Body Technique, Participant 1 had the third highest ground reaction force at the start of the lift.

- The side-on posture adopted by Participant 6 produced the third greatest ground reaction force for the Overhead Technique and the greatest ground reaction force for the Side of Body Technique when compared to all study participants.

- The front-on posture adopted by Participant 7 produced the lowest ground reaction forces for the Overhead Technique and the second lowest ground reaction force for the Side of Body Technique.

- All participants with the exception of Participant 6 produced a greater ground reaction force for the Overhead Technique compared with the Side of Body Technique at the start of the lift.

Table 8 shows the difference in ground reaction forces between the three participants and the two techniques, it also shows the difference between the highest and lowest ground reaction forces. These data show that using a front-on posture to tip the mattress off the conveyor prior to lifting it produces lower ground reaction forces than lifting the mattress when adopting a side-on posture. The front-on posture results in 88.7 – 248.5 N less force than the side-on posture for the Overhead Technique, and 87.5 – 140.1 N less force for the Side of Body Technique. Data for all study participants are shown in Appendix J.

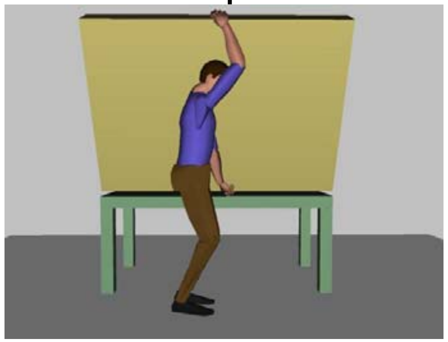
Table 8. Differences in ground reaction forces between the three participants and the front-on or side-on handling techniques adopted at the start of the lift.

	Ground reaction force at the start of the lift (N)		
Participant Number (P)	**Overhead Technique**	**Side of Body Technique**	**Difference between techniques**
P1 (Side-on)	634.49	437.67	196.82
P6 (Side-on)	474.74	490.33	-15.59
P7 (Front-on)	385.99	350.19	35.80
P1 – P7	248.5	87.48	-
P6 – P7	88.75	140.14	-

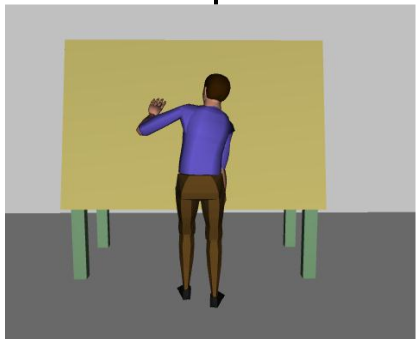
Overhead Technique: Start of the Lift

Side-on posture
Participant 1

Side-on posture
Participant 6

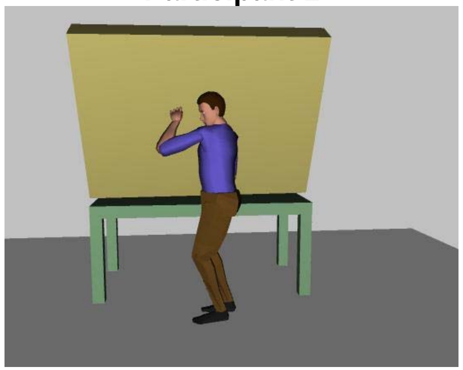


Front-on posture
Participant 7

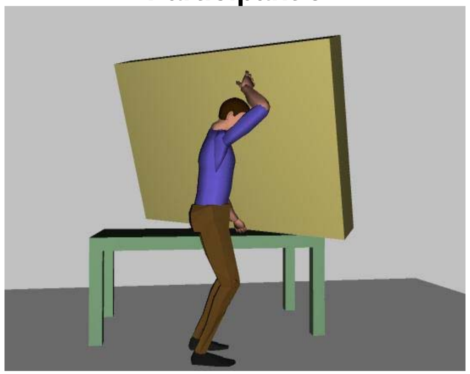


Side of Body Technique: Start of the Lift

Side-on posture
Participant 1



Side-on posture
Participant 6



Front-on posture
Participant 7

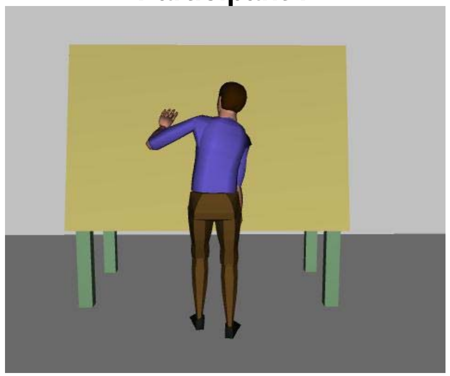


Figure 11. Comparison of side-on and front-on postures adopted at the start of the lift for both the Overhead Technique and the Side of Body Technique.

5.3 BIOMECHANICAL ANALYSIS

Figures 12 and 13 show examples of the postures adopted by study participants when performing the two handling techniques and are representative of handling techniques within the warehouse. Biomechanical analysis was undertaken for 2 components of the handling task:

(1) At the start of the lift: When the mattress was just lifted off the conveyor;

Overhead Technique **Side of Body Technique**

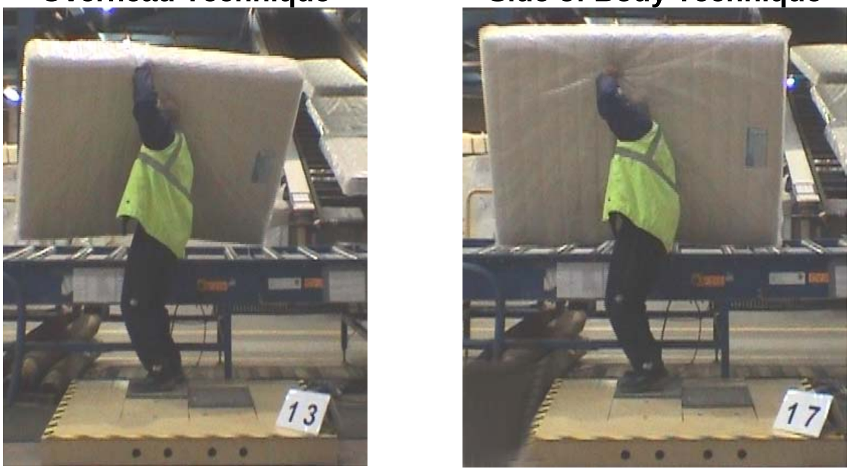


Figure 12. Example of the postures adopted when initiating the lift off the conveyor for both techniques.

(2) At the end of the lift: When the mattress was in the carry position.

Overhead Technique **Side of Body Technique**

Figure 13. Example of the postures adopted at the end of the lift when in the carry position for both techniques.

5.3.1 Low Back Compression Forces

Low back compression forces at the L5 / S1 joint were compared for all participants, for the two parts of the simulated task: 1) at the start of the lift, and 2) at the end of the lift in the carry position. Further details of low back compression force data for individual participants are shown in Appendix K.

Comparison of Low Back Compression Forces

Table 9 and Figure 14 show the mean low back compression forces for all participants comparing the Overhead Technique and the Side of Body Technique at the start of the lift and at the end of the lift. They show that for the Overhead Technique a greater low back compression force is produced at the start of the lift, 149.4 N greater than the Side of Body Technique. At the end of the lift, greater low back compression forces are produced for the Side of Body Technique, 260.2 N greater than the Overhead Technique. Figure 14 also shows the NIOSH (1981) Back Compression Design Limit (DL) of 3400 N.

Table 9. Low back compression forces comparing the Overhead Technique and the Side of Body Technique, at the start of the lift and at the end of the lift.

	Low Back Compression Forces (N)					
	Start of Lift			End of Lift		
	Mean	**Stdev.**	**Range**	**Mean**	**Stdev.**	**Range**
Overhead Technique	3220.3	692.9	2145 - 4103	1135.2	285.6	758 - 1501
Side of Body Technique	3070.9	739.7	2030 - 4520	1395.4	149.9	1214 - 1652

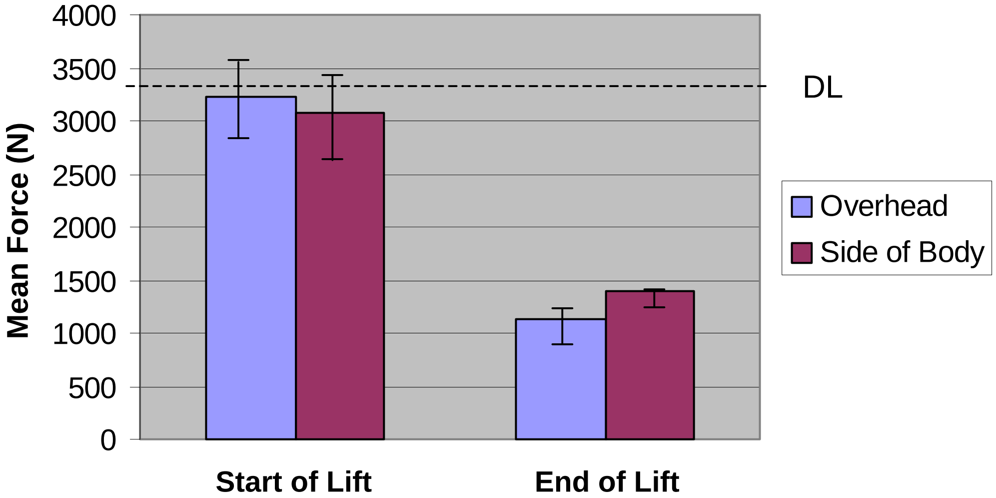


Figure 14. Mean low back compression forces of all participants at the start of the lift and at the end of the lift comparing the Overhead Technique and the Side of Body Technique.

At the start of the lift the mean low back compression force for all study participants did not exceed the NIOSH Back Compression Design Limit (BCDL) of 3400 N for either technique.

This indicates that the activity should represent a nominal risk to employees (Lindbeck, 1995). However, caution is advised interpreting these results as both the Overhead Technique (3220 N) and the Side of Body Technique (3071 N) at the start of the lift produced low back compression forces close to the NIOSH limit. In addition, when comparing the results for individual study participants at the start of the lift (Appendix K), three individuals did exceed the NIOSH BCDL for the Overhead Technique (3589.5 N, 4007.1 N, and 4103.4 N); and two participants exceeded it for the Side of Body Technique (3431.4 N and 4520.7 N).

Statistical Analysis

A paired t-test was used to test the statistical significance of the low back compression forces at the start of the lift and at the end of the lift. The results are presented in Table 10 and show that there is no statistically significant difference between the two techniques at the start of the lift, but a significant difference is observed at the end of the lift when the mattress is held in the carry position ($p < 0.05$).

Table 10. Statistical significance of low back compression forces at the start of the lift and at the end of the lift in the carry position, between the two techniques.

	Start of Lift	End of Lift
t-value	0.622	2.89
df	7	7
p-value	0.554	0.023
effect size	0.209	1.19

Comparison of Different Lifting Techniques

Comparison of the low back compression forces for the different lifting postures adopted at the start of the lift for both the Overhead Technique and the Side of Body Technique (Figure 11) shows that:

- The side-on postures adopted by Participant 1 and Participant 6 generate the second and fifth highest low back compressive forces for the Overhead Technique, and the third and second highest low back compression forces for the Side of Body Technique respectively.

- For both handling techniques the front-on posture adopted by Participant 7 generated the lowest back compression forces.

These data presented in Table 11 show that that adopting a front-on posture results in a lower low back compression force for both techniques (2145.6 N for the Overhead Technique and 2030.8 N for the Side of Body Technique) compared to a side-on posture (4007.1 N for the Overhead Technique, and 3431.4 N for the Side of Body Technique). It can be seen that the low back compression forces generated when adopting a front-on posture are under the 3400 N NIOSH BCDL, compared with side-on postures where the BCDL was either just below, or exceeded the limit. Adopting a front-on posture therefore places less stress on the low back and reduces the likelihood of low back injury.

Table 11. Comparison of low back compression forces when adopting a side-on and front-on posture at the start of the lift for the Overhead Technique and the Side of Body Technique.

	Low back compression forces at the start of the lift (N)		
Participant Number (P)	**Overhead Technique**	**Side of Body Technique**	**Difference between techniques**
P1 (Side-on)	4007.13	3156.19	850.94
P6 (Side-on)	3257.31	3431.41	- 174.1
P7 (Front-on)	2145.61	2030.84	114.77
P1 – P7	1861.52	1125.35	-
P6 – P7	1395.79	2306.06	-

5.3.2 Percent of the Population Capable

The percent of the male population who would have the sufficient strength to generate moments at the major joints during the lifting task, when comparing the Overhead Technique and the Side of Body Technique at the start of the lift and when the mattress is in the carry position are shown in Table 12 and in Figures 15 and 16. (Individual data shown in Appendix L).

Comparison of Strength Capabilities

Similar strength deficiencies are observed at the start of the lift for both techniques that show low estimations for the percentage of the male population who have the capacity to perform the lift. Low strength capabilities were observed at the elbow, shoulder, and trunk at the start of the lift (Figure 15). At the end of the lift, low estimations for the percentage of the male population who are capable were found at the shoulder for the Overhead Technique when the mattress was being carried above the head, whereas elbow capacity is reduced in the Side of Body Technique (Figure 16).

Table 12. Estimated percent (%) of the male population with sufficient strength at the major joints at the start of the lift and at the end of the lift comparing the Overhead Technique and the Side of Body Technique.

		Mean % capable for all participants					
		Elbow	**Shoulder**	**Trunk**	**Hip**	**Knee**	**Ankle**
Start of Lift	**Overhead**	12.13	55.63	42.38	95.00	98.19	93.31
	Side of Body	12.38	56.75	36.25	99.75	98.63	92.88
End of Lift	**Overhead**	95.13	81.00	94.88	100	99.50	98.38
	Side of Body	83.63	97.75	97.88	100	99.13	97.50

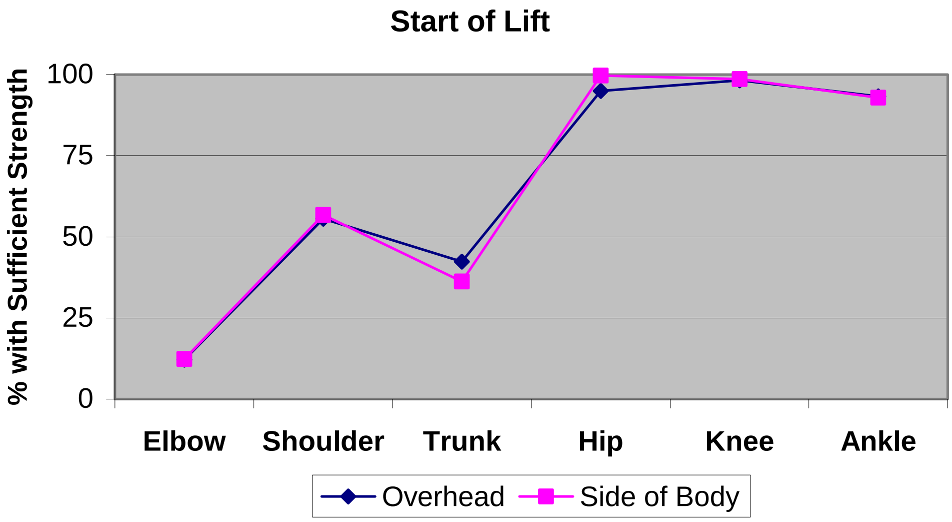


Figure 15. Percentage (%) of the male population with sufficient strength to generate moments about the major joints at the start of the lift, comparing the Overhead Technique and the Side of Body Technique.

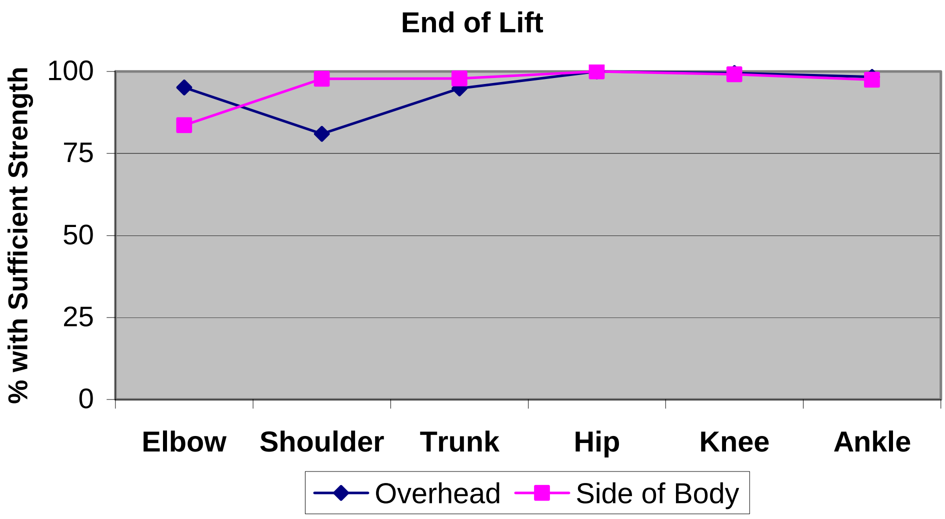


Figure 16. Percentage (%) of the male population with sufficient strength to generate moments about the major joints at the end of lift, comparing the Overhead Technique and the Side of Body Technique.

Comparison of Different Lifting Techniques

Comparisons of the estimated strength capabilities of participants at the start of the lift as in Figure 11 were performed. The front-on posture adopted by Participant 7 who faced the conveyor and tipped the mattress off, prior to lifting it produced much higher percentages of the number of individuals with sufficient estimated strength capabilities at the elbow, shoulder, and trunk, compared with the side-on posture adopted by all other participants. A mean strength estimation for all participants (excluding Participant 7) who adopted a side-on posture was calculated and compared with the strength estimations of the front-on posture adopted by

Participant 7. This data is presented in Table 13 and shows the increased estimated strength capabilities associated with adopting a front-on posture at the start of the lift, compared with a side-on posture.

Table 13. Comparison of percent (%) capable with estimated sufficient strength between the front-on technique adopted by Participant 7 and all other study participants who adopted a side-on posture.

	Overhead Technique % Capable		Side of Body Technique % Capable	
	Front-on posture*	Side-on posture**	Front-on posture*	Side-on posture**
Elbow	97	0	99	0
Shoulder	99	49.4	97	51.0
Trunk	84	36.4	87	29.0
Hip	100	94.3	100	99.7
Knee	100	97.9	100	98.4
Ankle	97	92.8	97	92.3

* Strength capabilities for front-on posture adopted by Participant 7.
** Mean strength capabilities for all other participants (excluding Participant 7).

5.3.3 Conclusions from Force Data and Biomechanical Analysis

Summary of Ground Reaction Force Data

Lower ground reaction forces were observed for the Side of Body Technique at the start of the lift, whereas no difference was observed between the two techniques at the end of the lift. In addition, lower ground reaction forces were observed when adopting a front-on posture and the mattress was tipped off the conveyor prior to lifting it, compared with adopting a side-on posture.

Summary of Low Back Compression Forces

At the start of the lift there was little difference between the techniques when comparing the mean low back compression forces for all study participants. At the end of the lift, a difference was observed showing lower back compression forces for the Overhead Technique compared to the Side of Body Technique. A comparison of the postures adopted at the start of the lift found that a front-on posture generated the lowest back compression forces for both techniques compared with a side-on posture.

Summary of Percent Capable Strength Data

For both techniques at the start of the lift the estimated percentage of the male population capable of performing the lift at the elbow, trunk, and shoulder was reduced. However, adopting a front-on posture at the start of the lift resulted in an increased percentage of the male population capable of performing the lift at these articulation points compared to adopting the side-on posture. At the end of the lift, estimations for the Overhead Technique show that shoulder strength is likely to be the limiting factor, whereas for the Side of Body Technique, elbow strength is likely to be the limiting factor.

5.4 POSTURAL ANALYSIS

Rapid Entire Body Analysis (REBA) was used to compare the two techniques and to determine the level of risk associated with the postures participants adopted during the simulated tasks. This was assessed at the start of the lift and when in the carry position, at the end of the lift. Figure 17 illustrates the variations in handling technique at the end of the lift for both techniques. For example: The Overhead Technique is either held above the head or the mattress is rested on the head and is balanced with the hands. When performing the Side of Body Technique the mattress is held at the side of the body and is supported by the lower arm, or with the arm held above the head supporting the mattress.

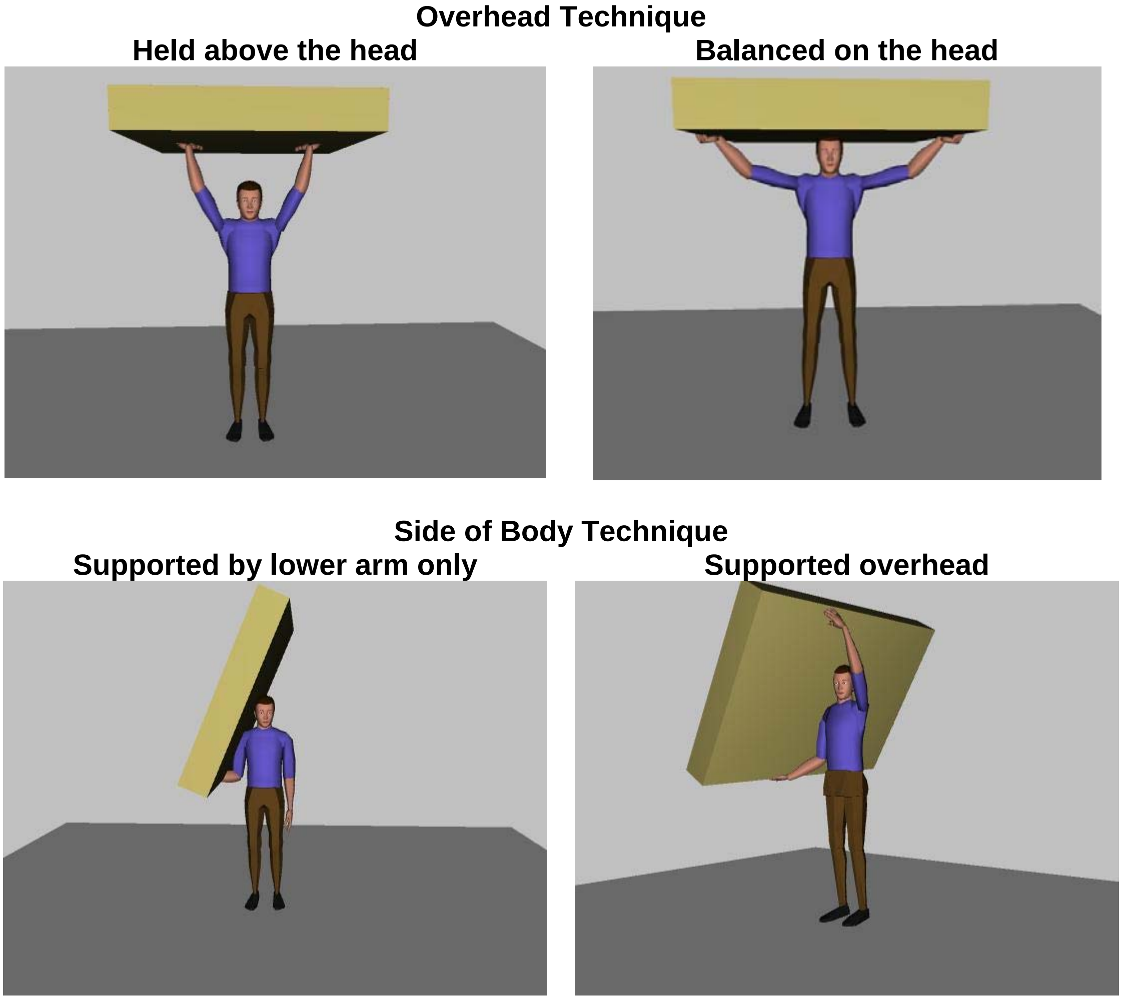


Figure 17. Different methods of mattress handling for the Overhead Technique and the Side of Body Technique.

Comparison of REBA Scores

Table 14 outlines the scores for the individual study participant's and the mean of all the participants' scores to allow for a comparison between both techniques. Little difference can be observed between the two techniques at either the start or end of the lift. At the start of the lift the mean score of all participants when performing the Overhead Technique resulted in a REBA score of 7.5, and 8.1 for the Side of Body Technique. At the end of the lift a REBA score of 8.6 for the Overhead Technique and 7.4 for the Side of Body Technique were observed. All of these results indicate that these tasks represent a high level of risk of musculoskeletal injury.

Table 14. REBA scores and the associated risk level comparing the start of the lift and the end of the lift in the carry position, for the Overhead Technique and the Side of Body Technique.

	REBA Scores			
	Start of Lift		End of Lift	
Participant No.	**Overhead Technique**	**Side of Body Technique**	**Overhead Technique**	**Side of Body Technique**
1	10	10	8	8
2	7	7	7	9
3	8	8	9	9
4	7	7	9	9
5	8	7	9	9
6	8	8	9	5
7	7	7	9	5
8	5	8	9	5
Mean	7.5	8.1	8.6	7.4
Std.dev	1.41	1.25	0.74	2.0
Range	5 - 10	7 - 10	7 - 9	5 – 9
Risk Level	Med - High	High	High	Med - High

Statistical Analysis

A Wilcoxon test was used to determine if a statistical significance existed between the REBA scores at the start of the lift and at the end of the lift. At the start of the lift no difference in scores were observed for 6 out of the 8 study participants. At the end of the lift 4 out of the 8 study participants had equal scores. Therefore for both the start of the lift and at the end of the lift a non-significant result was obtained, as this test requires a minimum number of 5 differences between scores before it can be considered at any significance level.

5.5 BORG PSYCHOPHYSICAL ASSESSMENT OF EFFORT

Table 15 and Figure 18 show a comparison of the mean scores for all study participants for the Overhead Technique and the Side of Body Technique using the Borg CR10 scale. This was done to assess if a difference exists in the study participants perceptions of effort when using the Overhead Technique or the Side of Body Technique. 5 of the 8 participants rated both techniques the same and 3 rated the Overhead Technique as requiring more effort, however the differences, with the exception of one participant were small. Individual ratings data is shown in Appendix N.

Table 15. Comparison of Borg CR10 scores between the Overhead Technique and the Side of Body Technique.

	Borg Scores	
	Overhead Technique	**Side of Body Technique**
Mean	1.8	1.2
Associated verbal rating	Weak	Very weak
Std.dev	1.42	1.01
Range	0.1 – 4	0.1 – 3
Associated verbal rating range	Nothing at all – Somewhat strong	Nothing at all - Moderate

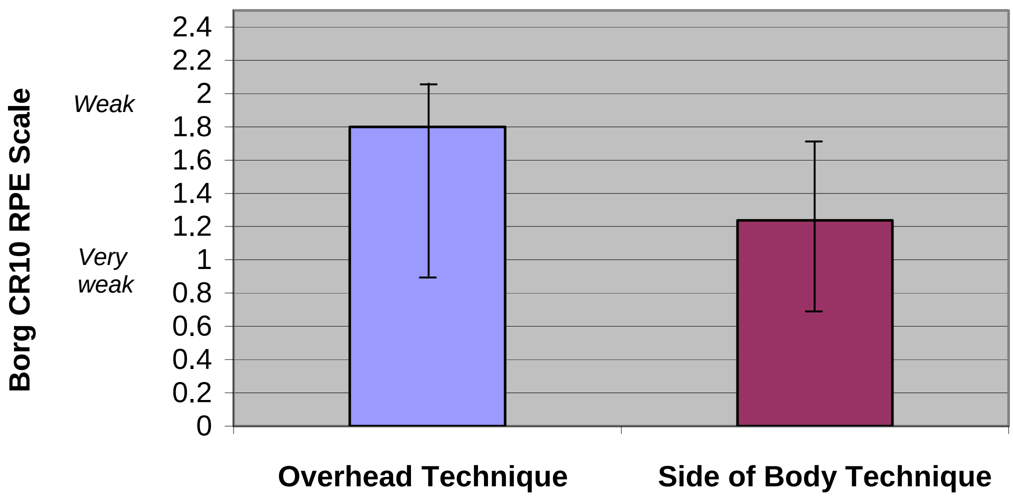


Figure 18. Comparison of mean Borg CR10 ratings of perceived effort comparing the Overhead Technique and the Side of Body Technique.

Statistical Analysis

A Wilcoxon test was used to determine if a statistical significance existed between the ratings of effort when comparing the two techniques. Only 3 out of the 8 participants rated the two techniques differently. Therefore this result is non-significant as this test requires a minimum number of 5 differences between scores to be considered at any significance level.

5.6 QUESTIONNAIRE ANALYSIS

A total of 85 questionnaires were distributed within the warehouse but only 9 completed questionnaires were returned (plus the 8 responses from the study participants). Of these nine, only six provided useful information with regard to technique preference, resulting in an extremely low response rate of 7%. This was despite having management commitment and a follow-up reminder notice displayed within the warehouse. The experience of those who responded ranged from 3 months to 20.5 years.

5.6.1 Technique Preference and Muscular Discomfort

A total of 14 responses were obtained (including those of the 8 study participants) with regard to technique preference. The data is presented in Table 16 and shows that 3 individuals preferred the Overhead Technique, and 9 individuals preferred the Side of Body Technique. In addition, 2 Individuals had no preference.

Table 16. Number of respondents preferring either the Overhead Technique or the Side of Body Technique and the reasons given for their preference.

	Overhead Technique (3)	Side of Body Technique (9)
Reasons for choice	• Easier to perform • More comfortable • Able to keep a neutral spine • Ability to see in most directions when carrying • Less fatiguing on the arms	• Easier to handle • More comfortable / stable • How they have been trained to lift and carry • Feels easier on the body (e.g. neck muscles) • Easier to lift into position

Table 17 presents the circumstances given for selecting one technique over the other. The decisions employees make about which technique to use are made over the course of their workday which enables a combination of both techniques to be used depending on which is the most appropriate.

Table 17. Reasons given for selecting one technique over the other.

Circumstances affecting technique selection
• Weight of the mattress • Space available when carrying in the warehouse (e.g. aisle width) • Level of activity within the warehouse • Fatigue over the shift may result in a change of technique

Table 18 shows the number of respondents and the frequency of muscular discomfort that they experience. 50 % of respondents stated they ‘never’ experience discomfort and 50 % said they ‘often’ or ‘sometimes’ experienced discomfort.

Table 18. Number of respondents and the frequency of muscular discomfort that they experience.

Frequency of muscular discomfort	Number of respondents
Never	7
Sometimes	2
Often	5
Total	**14**

Table 19 identifies the areas of discomfort that were identified by respondents; however, this study was unable to conclusively determine differences in areas of muscular discomfort between the two techniques.

Table 19. Identified areas of muscular discomfort for both techniques.

Identified Areas of Discomfort
• Middle and lower back (sometimes on the opposite side of the back to where the mattress is being held at the side of the body)
• Shoulders
• Neck
• Arms (especially the biceps muscle in the lower arm when holding the mattress at the side of the body)
• Wrists
• Legs / Feet

5.6.2 Psychosocial Factors

Seventeen responses were obtained, including those of the 8 study participants with regard to questions about an individual’s view towards feeling pressured due to time constraints, their ability to cope with job demands, and the support they receive from colleagues. The responses are presented in Table 20 and show that the majority of respondents reported that they ‘never’ feel pressured at work due to the constraints and ‘always’ feel they can cope with the work demands placed on them. The majority of respondents also report to ‘frequently’ or ‘always’ having support from work colleagues.

Table 20. The number of respondents and their responses to questions on psychosocial factors.

	Psychosocial Factors		
	Time pressure	**Work demands**	**Support from colleagues**
Never	8	-	1
Infrequently	3	-	-
Sometimes	6	3	4
Frequently	-	2	6
Always	-	12	6

5.6.3 Summary of Questionnaire Analysis

The questionnaire response rate was extremely low (7 %) and therefore it is impossible to make generalisations from the responses obtained to the entire warehouse population. 3 respondents preferred the Overhead Technique whilst 9 preferred the Side of Body Technique. They also provided useful information as to what circumstances may influence their technique selection over the course of the workday. Wide variations in the responses were observed when questioned about the frequency of muscular discomfort. The responses obtained with regard to the psychosocial risk factors indicate that these warehouse employees are not exposed to the risk factors: time pressure, work demands, and lack of social support; however, due to the low response rate it is not possible to assume that these findings are representative of the wider warehouse population. Therefore it is impossible to rule out if these risk factors contribute to the development of MSDs and LBDs.

6 DISCUSSION

The aim of this section is to:

(1) Discuss the results obtained from the investigation in light of previous relevant research findings; and

(2) Outline the study limitations.

6.1 STUDY FINDINGS: A COMPARISON OF THE TWO HANDLING TECHNIQUES

This study has made a comparison of two different handling techniques that are frequently used in the mattress manufacturing industry. The research findings will be discussed with respect to the start of the lift and at the end of the lift in the carry position.

6.1.1 Start of the Lift

The results indicate that a greater ground reaction force is produced when using the Overhead Technique compared to the Side of Body Technique and this difference was observed to be statistically significant. In addition, both techniques place stress on the elbow, shoulder, and trunk and reduce the estimated percentage of the male population capable of performing the lift at these articulation points.

The mean values for back compression for both techniques did not exceed the NIOSH Design Limit of 3400 N. The observed difference between the two techniques was found to be non-significant. However, some study participants did exceed the 3400 N Design Limit for both techniques and may be exposed to an increased risk of low back injury. Lavender *et al.*, (2000) stated that although biomechanical models are best suited to infrequent and static activities the static postures modelled will provide some indication of the spine compression forces and estimated population strength capabilities. Therefore the results obtained in the current research will provide an estimation of the compression forces and estimated population strength capabilities. However, Lindbeck (1995) argues that an underestimation of the level of risk may occur if dynamic and frequent activities are modelled and may result in 1.2 to 3 times higher peak values of joint moments and compression forces than static analyses. This research attempted to overcome the limitations of using a static biomechanical model by using the ground reaction forces to provide a more accurate estimation of the low back compression forces at the start of the lift. This allowed for the dynamic activity and accelerations involved, as was identified by Lindbeck and Arborelius (1991) who stated that spinal compression forces could be considerably increased during the first acceleratory phase of the lift.

Chaffin (1979) proposed that an increased risk of musculoskeletal injury is predicted where a difference exists between the joint moments and the percentage of the population who are capable of withstanding it. The current research found that when one participant adopted a front-on posture at the start of the lift, whereby the mattress is tipped off the conveyor prior to lifting it, an increase in the estimated percentage of the male population with sufficient strength to perform the lift at the elbow, shoulder, and trunk, compared to adopting a side-on posture was observed. The ground reaction forces, and low back compression forces were also reduced, indicating that this technique places less stress on the low back and the musculoskeletal system, and may have important implications on how mattresses are lifted off the conveyor in the future. However, this technique was only used by one participant and therefore further investigation would be beneficial to confirm these results.

REBA postural analysis showed little difference between the two techniques (the difference between the scores was not statistically significant). In addition, very similar lifting techniques and postures were observed for both the Overhead and Side of Body Techniques at the start of the lift. The REBA scores indicated that both techniques expose the handlers to a high risk of musculoskeletal injury. However, Ferreira (2002) identified that REBA is a sensitive postural analysis method whereby small postural variations can affect the REBA scoring system, and was principally used to compare the postures for both handling techniques.

6.1.2 End of the Lift: Carry Position

Similar ground reaction forces were observed for both techniques at the end of the lift and the differences between the results was not statistically significant. However, greater low back compression forces were found for the Side of Body Technique compared to the Overhead Technique; this difference was statistically significant. Observations from this investigation show that the Overhead Technique allows individuals to maintain a relatively neutral posture, whereas the Side of Body Technique involves asymmetrical handling, with the mattress being supported by the shoulder and head, and involves some degree of spinal rotation and lateral deviation. Ayoub and Mital (1989) identified that when loads are carried asymmetrically the lumbar spine experiences a lateral bending moment. This results in torsional stress being placed on the spine and reduces the maximum acceptable weight of a load to be lifted or carried. The affect of torsional stress on the spine was not considered within this study, whereas Hsiang *et al*., (1997) identified that torsion is more recurrent and more detrimental than compressive forces in many situations. Therefore the affect of torsional stress on the spine when handling mattresses at the side of the body should be the subject of further investigation.

Comparisons between the strength capabilities at the major joints were made between the two handling techniques at the end of the lift. Shoulder strength is likely to be the limiting factor when using the Overhead Technique when the mattress is held above the head, whereas when using the Side of Body Technique, elbow strength is likely to be the limiting factor.

REBA postural analysis showed little difference between the two techniques (the difference between the scores was not statistically significant). REBA scores for both techniques indicated that handlers were exposed to a high risk of musculoskeletal injury. However, the overall results from the biomechanical models indicated a moderate level of risk. REBA can be sensitive to small postural variations such as when using the Side of Body Technique, some participants used the upper arm to balance the mattress at the side of the body and others did not, therefore a higher REBA score was given to those using their upper arm. In this investigation REBA was principally used to identify postural differences between the two handling techniques rather than to provide an overall statement of the injury risk. When using the Overhead Technique the wrists and upper arms produced higher REBA scores, as the arms are held above the head and the wrists are bent backwards. When using the Side of Body Technique the neck produced a higher REBA score as the mattress rests on the side of the head and the neck is tilted to one side (Appendix M).

The results from the analysis of the questionnaire data on postural discomfort indicated that some of the participants experience muscle strain on the opposite side of the body to which they carry the mattress using the Side of Body Technique. This effect was also identified by Zwick *et al*., (1998) when a unilateral and unbalanced use of the trunk muscles on the non-loaded side of the body occurs. In addition, Kumar (2001) identified asymmetric handling as a potential problem and proposed the ‘Differential Fatigue Theory’. He believed that disproportionate demands might be placed on muscles that may become fatigued at different rates. Ultimately this could result in altered muscle kinetics and musculoskeletal injury.

Occupational factors related to shoulder pain and disability during asymmetric handling have been identified by Pope *et al*., (1997) when loads were carried on one shoulder. Their findings identified factors that are of concern with regard to handling the mattress using the Side of Body Technique. Although mattresses are not carried on the shoulder they are being repetitively supported asymmetrically by one arm. McGough *et al*., (1996) investigated the mechanical properties of the long head of the biceps tendon and its implication in shoulder pain. Their findings raise some important issues with regard to this current investigation and the repetitive and asymmetric handling of mattresses held in one arm. Some participants identified on the administered questionnaire, that the biceps muscle may become fatigued when using the Side of Body Technique as the workday progresses. Therefore using this technique may cause overloading of the biceps muscle, which may subsequently increase the risk of shoulder injury over a period of time.

In contrast, carrying loads on the head have been shown to increase the degenerative change in the cervical spine amongst African women (Jager *et al*., 1997). When employees carry a mattress above their head, sometimes they rest it on their head and support it with their hands. This may expose employees to an increased risk of cervical spine damage and degeneration if performed frequently over a number of years.

This study has primarily focused on the compression forces acting on the low back, however, the implications for musculoskeletal injury to other parts of the body should not be overlooked. Previous research such as that performed by Zwick *et al.*, (1998); Pope *et al*., (1997); McGough *et al*., (1996); and Jager *et al*., (1997) have identified a number of risk factors that could be considered in future investigations and may have a greater impact on different parts of the body, such as the trunk, shoulders, elbows, cervical spine, wrists, and biceps muscles. The mattress handling techniques used within the warehouse, if performed repetitively over a number of years, are likely to increase the cumulative damage to these body parts, including the low back, and may expose some individuals to an increased risk of musculoskeletal injury.

6.1.3 Subjective Assessment of the Entire Task

Participant's ratings of effort were compared, and there was no perceived difference in effort between the two techniques. A problem associated with the comparison was that the difference in the ratings of perceived effort were very low. The verbal rating for the Overhead Technique was rated as 'weak' and for the Side of Body Technique was rated as 'very weak'. Therefore participants perceived the Side of Body Technique to require slightly less effort than the Overhead Technique but this difference was not statistically significant.

The qualitative data with regard to technique preference and the reasons given for the preference showed a varied number of reasons why participants preferred one technique to the other. Respondents identified that circumstances could often dictate which technique may be used, such as constraints within the warehouse. Participants identified that the back, shoulders, neck, arms, wrists, legs and feet are the main areas where they experience discomfort.

The questionnaire results concerning psychosocial factors showed that the respondents are not exposed to risk factors associated with time constraints, job demands, and lack of social support in the workplace.

It is difficult to draw conclusions in relation to technique preference, muscular discomfort, and psychosocial risk factors, due to the low response rate. It is therefore not possible to assume that these findings are representative of the wider warehouse population.

6.2 STUDY LIMITATIONS

The aim of this study was to determine if one lifting technique places less stress on the musculoskeletal system, particularly the low back, than the other. In order to draw valid conclusions it is important to acknowledge the study limitations. These will now be outlined and discussed:

(1) **Subject selection:** Some degree of self-selection occurred within this study. The 'Call for Volunteer' posters that were distributed in the warehouse would have encouraged those who were interested in the study to take part. Furthermore, the selection criteria stated on the poster could have excluded some employees from volunteering to participate. For example if they had experienced a recent back injury.

(2) **Subject experience:** All but one of the study participants had a lot of experience performing both handling techniques. One participant had only been employed with the company for 1 month and therefore had mostly been using the side of body technique. It was apparent that he was not as confident as the other participants at performing the Overhead Technique and this may have influenced his results.

(3) **Alteration of the task:**

a. The force plates were set up and surrounded by a wooden safety platform alongside the conveyor at a quiet end of the warehouse. The force plates and wooden platform raised the height of the floor by 10 cm. The conveyor height could not be raised by the equivalent amount and therefore participants were reaching 10 cm lower than if they were normally performing the task standing on the warehouse floor. During questioning none of the participants stated that this factor altered their handling technique.

b. Upon lifting the mattress off the conveyor, participants would normally carry the mattress to a storage area. It was thought that getting participants to hold the mattress in the carry position would provide an estimation of the forces acting on the body. It is acknowledged that the affect that the two handling techniques have on gait would make for an interesting future investigation.

(4) **Observation:** The fact that this was a simulated task and the participants were being watched by a researcher and assistant, another participant (2 participants completed the trials together, alternating lifts), and video recorded, may have influenced how the participants performed during the lifting trials and the techniques they adopted. In addition, the task occurred in an operational warehouse and occasionally other employees would walk by to observe what was happening and may have made some participants self conscious, thereby affecting their performance.

(5) **Participant attitudes:** An exclusively male population and 'macho' attitude existed within the warehouse environment. This may have influenced the questionnaire results as some of the participants were reluctant to express if either of the two techniques caused any muscular discomfort, or required high levels of effort.

(6) **Questionnaire response rate:** An extremely low response rate was observed from the questionnaire that was distributed to the wider warehouse population. This could be due to a lack of awareness of the project, (despite posters in the workplace), or that employees simply did not want to participate. In an attempt to improve the initial response rate follow up posters were displayed in the warehouse and line managers were asked to remind their employees to complete the questionnaire. However, this effort yielded no further responses and the response rate was not improved. Therefore, the responses obtained cannot be considered to be representative of the wider warehouse population who did not respond.

(7) **Video analysis:** The limitations of using video footage and attaching body markers was also evident. Lindbeck (1995) suggested that it might be difficult to collect accurate posture data particularly for large asymmetric tasks. This was apparent in this research project as the mattress obscured the view of various body segments, particularly the shoulder, elbow and wrist at the start of the lift and at the end of the lift when in the carry position using the Side of Body Technique. In order to minimise the area obstructed from view, video cameras were positioned to the side of, and behind the participant as this provided the least obscured view.

(8) **Hand force measurement:** At the end of the lift when using the Side of Body Technique, it was important to determine the proportion of the load held in the lower arm. This was done using a hand held dynamometer and performed twice to ensure a level of consistency. The proportion of the weight of the mattress was then determined and used to input the weights in the biomechanical model. This was not an extremely accurate method compared to if a hand force transducer had been used, but it was considered to be a sufficiently good estimation of the proportion of the load held in the lower arm. Consistent measurements were achieved and therefore an acceptable level of confidence in this method was generated.

(9) **Biomechanical modelling:** Marklin and Wilzbacher (1999) identified that the development of LBDs are cumulative in nature and recognised that the 3DSSPP software does not account for the frequency of lifting. They concluded that 3DSSPP should be used to assess acute injury risk for non-frequent tasks and not for cumulative trauma. Additional problems that were identified within this research project include:

a. The Jack computer program incorporates the software used in the 3DSSPP, Michigan Model and requires the inputting of hand loads to determine the low back compression forces. Difficulty was experienced at the start of the lift as it was unclear what proportion of the load during the lift was in each of the hands. After watching preliminary video footage of the lifting activity it was realised that the lower arm was bearing the majority of the load, whilst the top arm held onto the plastic covering of the mattress to provide balance and support. It was apparent that lifting the mattress involved significantly more than 50 % of the load being lifted in the lower arm, but was less than 100 %. Therefore, a split of 80 % held in the lower arm and 20 % in the upper arm was made as an approximate division of the load between the two arms. This was based on an entirely subjective assessment and may vary between individuals. This division was based on a ‘best guess’ to allow for an estimation of the back compression forces and the percentage of the population capable to perform the lifts to be obtained.

b. The ground reaction forces when using the Overhead Technique at the end of the lift were equally divided between the hands. This division was made when the mattress was balanced on the head as it was concluded that force would still be transmitted through the body and would help to keep the method consistent.

c. At the end of the lift when using the Side of Body Technique the shoulder and head was used to support the mattress, with one arm holding it underneath. Some participants also used their other arm to support the mattress above the head. For this technique it was particularly difficult to determine the hand loads to input into the biomechanical model. The hand force measurements obtained using the hand held dynamometer for the Side of Body Technique were input into the model. The Jack computer system allows for loads to be added to other body parts instead of just the hands, therefore the difference in the proportion of the load being held in the lower arm was entered as a load on the shoulder where the mattress was being supported. This provided more realistic results and is not available in the standard 3DSSPP software. A review of the literature was performed to determine if other studies had identified similar problems when performing asymmetric lifts and in determining the proportion of loads in different arms, however nothing specific was found that would help to identify a better method that could be used in the Jack biomechanical model.

d. The results obtained in relation to the NIOSH BCDL of 3400 N may underestimate the overall level of risk to the lower back, as the model is better suited to infrequent tasks. The mattress handling task is repetitive and therefore the risk of injury may be increased, as the model does not take duration of exposure and fatigue into account.

(10) Psychophysical assessment of effort: Kilbom (1998) outlined that RPE scales have been used to a limited extent in industry and may provide useful information. During this study, the ratings obtained were quite low and showed little difference in the perceived level of effort required to use the two techniques. Due to the exclusion of individuals with a history of back pain in the last six months this study could not determine how participants with reduced physical capability may perceive the exertion of the task.

(11) Previous research: Limited research literature with regard to mattress handling could be found and it was therefore difficult to compare this research to other similar studies. In addition, no research articles could be found with regard to the use of the Jack 3-dimensional computer-modelling program. Therefore there was no guidance on how to overcome the difficulties that were faced, particularly with determining the proportion of the hand loads during the asymmetric lifts, and whether it is valid to enter these loads to other parts of the body, for example, the shoulder.

6.3 SUMMARY

The aim of this study was to determine if one lifting technique placed less stress on the musculoskeletal system than the other, particularly with regard to the low back. In order to achieve the study aim a variety of different methods that the author was familiar with were selected as suggested by many authors (David (2005); Tracy (1998); Op De Beeck and Hermans (2000)). In addition, Monnington (1997) identified this to be particularly important when investigating asymmetric handling tasks.

The results of this study have identified that both techniques place the low back and musculoskeletal system under a moderate level of stress. However, the Overhead Technique allows the spine to be kept in a more neutral posture compared to the Side of Body Technique resulting in lower back compression forces. Circumstances may determine what technique is used and when, and therefore alternating between the two techniques over the duration of the workday should not be discouraged.

This research makes a valuable contribution to the prevention of manual handling injuries in the bed manufacturing industry as it has compared the two handling techniques currently used within the industry, and identified the affects of lifting and holding a mattress on the body. Currently, the bed manufacturing industry instructs their employees to adopt the Side of Body Technique identified by Stanley (2005), however, this study has shown that the Overhead Technique places less stress on the low back and therefore alternating between the two techniques over the course of the workday may allow the different muscle groups used in the two techniques to rest and recover. This study has also identified an alternative lifting technique when initiating the lift from the conveyor. Using a front-on posture was shown to result in lower back compression forces and increased estimations of the percentage of the male population capable of performing the lift with sufficient strength at the elbows, shoulders, and trunk compared to a side-on posture. This technique should therefore be adopted to reduce the risk of injury to warehouse employees. This research supports the findings of Stanley (2005), in that the frequent handling of mattresses within the warehouse increases the risk of low back and musculoskeletal injury. Therefore the industry should continue to investigate alternative methods of handling mattresses in order to reduce the risk of injury.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

With respect to the study aim of determining if one mattress handling technique places less stress on the musculoskeletal system, particularly with regard to the low back, compared to the other, the following conclusions can be drawn:

(1) More effort is required to lift the mattress into the overhead position compared with holding the mattress at the side of the body. This was observed by the greater ground reaction forces for the Overhead Technique as a greater acceleration of the load is required to reach the overhead position.

(2) Mean low back compression forces at the start of the lift for both techniques were close to the 3400 N (NIOSH, 1981) limit. However, some study participants exceeded this limit. Therefore, some individuals with greater low back compression forces will be exposed to an increased risk of low back injury. Furthermore, given the limitations of using biomechanical analysis that are based on static postures and infrequent activities, the overall level of injury risk to the low back may be underestimated as the biomechanical model does not consider the affects of exposure duration and fatigue.

(3) Holding the mattress above the head or balancing it on the head at the end of the lift, as when using the Overhead Technique keeps the spine in a more neutral posture. This resulted in lower back compression but may place additional stress on the cervical spine, shoulders, and wrists compared to the Side of Body Technique.

(4) Greater low back compression forces were observed when holding the mattress at the side of the body. This is due to the load being carried asymmetrically and any associated twisting and lateral bending of the spine that occurs as a result. Fatigue in the lower carrying arm may place additional stress on the biceps muscle, which could cause cumulative damage to the shoulder resulting in pain or disability if performed frequently over a number of years.

(5) At the end of the lift when in the carry position the estimated percentage of the population with sufficient strength to perform the two handling techniques differ. Strength in the shoulder is likely to be the limiting factor in the Overhead Technique, whereas, elbow strength is likely to be the limiting factor in the Side of Body Technique.

(6) At the start of the lift for both techniques adopting a front-on posture facing the mattress and tipping it off the conveyor prior to lifting, resulted in lower ground reaction forces and lower back compression compared with the side-on posture. This posture will reduce the exposure of mattress manual handlers to the risk of low back injury.

Table 21 provides a comparison of the two handling techniques at the start of the lift; the end of the lift; and an overall comparison that these conclusions are based on.

Table 21. Comparisons of the two handling techniques.

<table>
<tr><th></th><th>Overhead Technique</th><th>Side of Body Technique</th></tr>
<tr><td rowspan="3">Start of the lift</td><td>• Greater effort and acceleration of the load is required to the lift the mattress into the carry position.</td><td>• Requires less effort, shown by the lower ground reaction forces to lift the mattress into the carry position.</td></tr>
<tr><td colspan="2">• Both techniques placed similar compression forces on the spine at the start of the lift. The NIOSH BCDL of 3400 N was exceeded by some participants for both techniques exposing them to an increased level of risk.</td></tr>
<tr><td colspan="2">• Adopting a front-on posture at the start of the lift resulted in lower ground reaction forces and low back compression forces for both techniques. An increase in the strength capabilities at the shoulder, elbow and trunk were also observed.</td></tr>
<tr><td rowspan="3">End of the lift</td><td colspan="2">• Both techniques produced similar ground reaction forces.</td></tr>
<tr><td>• Lower back compression forces were observed when holding the mattress above the head.</td><td>• Greater back compression forces were observed when handling the mattress at the side of the body.</td></tr>
<tr><td>• Participants were observed to keep a more neutral posture, but additional stress may be placed on the cervical spine, shoulders, and wrists.</td><td>• Lateral bending of the trunk is observed placing additional stress on the spine. Fatigue may also occur in the lower carrying arm, placing additional stress on the biceps muscle and elbow.</td></tr>
<tr><td>Overall</td><td>• This technique requires more effort to get the mattress into the overhead position, but once there, the spine is kept in a more neutral posture resulting in lower back compression forces. This technique may increase the risk of injury at the cervical spine, shoulders, and wrists.</td><td>• This technique requires less effort to lift the mattress into position at the side of the body, but greater back compression forces are observed when held in this position, due to the lateral bending of the trunk. The biceps muscle and elbow may be at an increased risk of injury.</td></tr>
</table>

In conclusion, both techniques place moderate levels of stress on the low back, and other parts of the musculoskeletal system, primarily the elbows, shoulders, and trunk. Some individuals may be exposed to an increased risk of musculoskeletal injury, particularly when initiating the lift depending on the technique adopted, (front-on or side-on). The low back compression forces when using the Overhead Technique are slightly lower than those obtained for the Side of Body Technique, however, the majority of the results showed very little difference between the two techniques. A probable reason for the observation of lower back compression forces when using the Overhead Technique is that it allowed the participant to adopt a more neutral posture compared to the lateral bending of the trunk observed in the Side of Body Technique. In addition, the results indicate that circumstances may dictate what technique is used and when, and employees may alternate between the techniques over the course of their workday, which should not be discouraged. Therefore, there does not appear to be any advantage in instructing employees to solely adopt one technique over the other.

7.2 RECOMMENDATIONS

Based on the findings of this research the following recommendations are made which the bed manufacturing industry should consider:

(1) Adopting a front-on posture and tipping the mattress prior to lifting it off a conveyor has been shown to lower the back compression forces acting on the spine when performed by one participant and increase the percentage of the population capable of performing the lift at the elbow, shoulder, and trunk. Therefore this technique should be adopted by warehouse employees with immediate effect, to reduce the load placed on the lower back, shoulders, trunk, and elbows to reduce the level of musculoskeletal risk employees are exposed to. However, adopting this technique may also benefit from further analysis in order to quantify the results from this study. This would help establish if similar results are found when assessing a larger study group.

(2) Alternating between the two handling techniques is recommended as it will provide the opportunity for different muscle groups to rest and recover over the course of the workday, and reduce the risk of low back and musculoskeletal injury.

(3) The results of this study show both handling techniques place the low back and musculoskeletal system under a moderate level of stress. Therefore alternative methods of handling mattresses within the warehouse should be sought and evaluated by the industry to try and minimise the risk of injury to their employees.

(4) This research has identified where future investigation should be directed and to provide additional evidence to confirm if one technique is preferable to the other, whist also highlighting other manual handling issues. The following questions should be the subject of further investigation:

   a. What affect the two techniques have on gait, when the mattresses are carried, particularly carrying mattresses of different sizes and weights?

   b. What is the affect on other body parts when performing this handling activity?

   c. How lifting and carrying larger and heavier mattresses affects the musculoskeletal system?

   d. What affect holding the mattress at the side of the body has on torsional stress of the spine and the associated level of risk to the lower back?

   e. Examine the handling techniques adopted when loading vehicles, and how the different sizes of mattresses affect body postures?

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APPENDICES

1. APPENDIX A. CALL FOR VOLUNTEERS POSTER

HEALTH & SAFETY LABORATORY

Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

CALL FOR VOLUNTEERS

Your company has chosen to participate in a study run by the Health and Safety Laboratory.

Study Title:

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

Background to the Study

Handling within the warehouse environment is common practice in the mattress manufacturing industry. Two common techniques have been identified, the Overhead Technique and the Side of Body Technique. The majority of employers now train their employees to use the Side of Body Technique rather than the more traditional Overhead Technique. This study will make a comparison of these two handling techniques regularly performed within warehouse areas.

Study Requirements

As part of this study I want to collect information on the forces acting on the body when you are lifting a mattress off the conveyor into one of the two lifting / carrying positions (e.g. above the head or at the side of the body as shown below). I will measure the forces by asking you to stand on a force plate to perform the lifts, which act like measuring scales. You will be asked to hold the mattress in the 'carry position' for 5 seconds before lowering back onto the conveyor. There will be two video cameras recording each of the six trials that you will be asked to perform. Some body measurements (e.g. height, weight, etc) will also be collected. At the end of the trials you will be asked about how tiring you found the lifts and to indicate the lifting method that you prefer. The total time anticipated to perform these trials is 1.5 hours.

Before the trials, you will be asked to read and sign a 'Participant Information and Instruction Sheet', and read the 'Safety Instructions for Volunteers' sheet. Once you have done this you will be asked to complete the 'Volunteer Consent Form'. Should you have any questions when reading or completing these forms please ask the researcher who will help you.

This study is supported by the Health and Safety Laboratory (HSL), part of the Health and Safety Executive (HSE), and by the University of Surrey as part of the MSc Ergonomics programme that I am enrolled in. A report of the study findings will be produced for HSL / HSE and as part of my Masters thesis (MSc) for the University of Surrey.

All information you give me during this study is anonymous and will be kept in confidence, seen only by me, and used only in relation to this study. No information relating to an individual will be passed on or shared with any other individual or organisation. Participation in this study is entirely voluntary. If for any reason you wish to no longer participate, please inform the researcher; you are free to withdraw at any stage.

Volunteer Criteria:

I am asking for experienced volunteers with at least six months experience and who are used to performing both techniques and who fit the following criteria:

- You are not currently on 'light' or 'special' duties;
- You have not suffered from a back complaint in the last six months;
- You have not suffered any other muscle or joint problems that affect how they work, within the last six months; and
- You are currently of general good health.

This study has been carefully designed to minimise any risks to your health and safety. Participants should note that HSL / HSE and The University of Surrey have 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 HSL / HSE / University of Surrey.

If you would like to participate in this study please contact your line manager for further information.

Leanne Stanley

Overhead Technique

Side of Body Technique

2. APPENDIX B. FORCE PLATE CALIBRATION PROCEDURE AND OPERATING PROCEDURE DURING THE TRIAL

Force Plate Set-Up Information

To determine the ground reaction forces that warehouse personnel exert during the handling task a Kistler force plate (type 9281B) was used.

The force plate was connected to a 9865B charge amplifier. A 12-bit A/D card data output device was fitted to a Pentium Pro PC with 64MB of RAM operating version 3.11 of the Bioware force plate software (Kistler Instrumente AG, Winterthur, Switzerland). The charge amplifier range was set to 10000 pC/10V. Data was collected at a sampling frequency of 100 HZ for a period of 30 seconds.

Two force plates were taken during the study trials and calibrated, however, one was not working properly on the first day of the trials, therefore the participants were asked if using one force plate would be sufficient and not constrain their posture too much from how they normally perform the lifting task. The participants agreed that one force plate was sufficient and only one force plate was used in the second series of trials to ensure consistency.

Calibration Procedure

Prior to data collection incremental 25 kg loads were applied to the force plate to check the factory calibrations of the vertical force measuring components, up to a maximum of 100 kg. The data for both trial periods is shown in Table 22 and Figure 18.

The use of the force plate in a 'real-world' environment meant the force plate could not be used in a fixed installation surface. However, a high linearity of 1.06 % was observed following calibration.

Table 22. Measurements taken during the two site visits in December and March compared with the calibrated weights.

Measured Weight (kg)	Actual Weight (Dec) (kg)	Actual Weight (Mar) (kg)
25	25.37	25.84
50	50.72	50.68
75	75.99	75.4
100	101.07	100.61

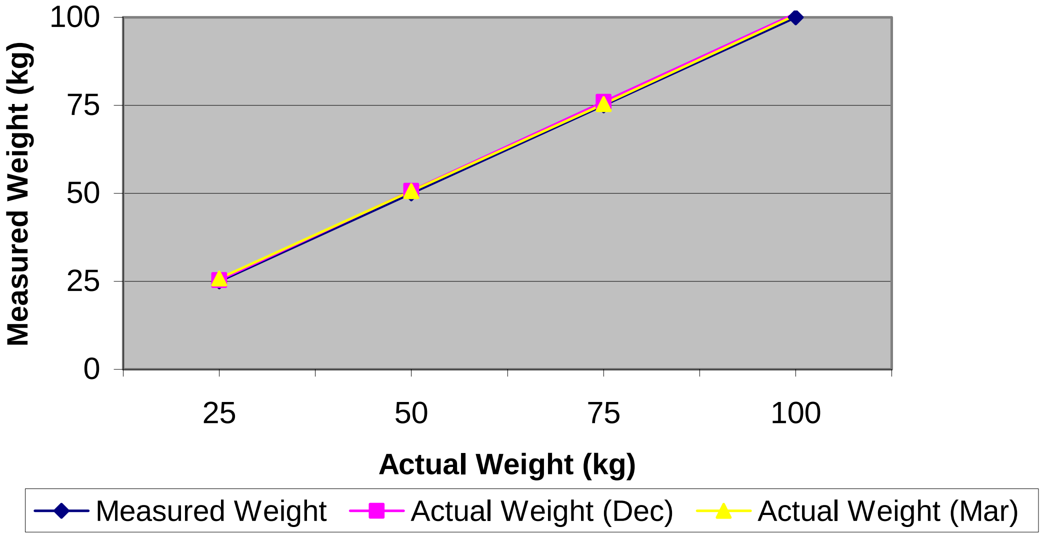

Figure 19. Graph showing difference in the calibrated weights and the actual weights measured by the force plates in December and March data collection periods.

Operating Procedure / Participant Instructions

Prior to testing:

(1) The participants were asked to stand on the force plate whilst their body weight was recorded manually.

(2) The participant was then asked to step off the force plate.

(3) This information was then entered into the computer prior to an individuals trial.

When testing:

(1) The participant was asked if they were ready to continue testing prior to each trial.

(2) When ready the record button was activated and the participant was advised to perform the trial. For example:

- Stand on the force plate;
- Lift the mattress off the conveyor into one of the two 'carry positions;
- Hold the mattress in the carry position for 5 seconds;
- Lower the mattress back onto the conveyor;
- Step off the force plate.

3. APPENDIX C. PARTICIPANT INFORMATION SHEETS / HEALTH SCREENING QUESTIONNAIRE

3.1 VERBAL INFORMATION AND INSTRUCTION SHEET

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

This study will make a comparison of the two handling techniques regularly performed within warehouse areas. Previous research in the mattress manufacturing industry has found that many employers are teaching their employees to lift and carry mattress to the side of their body rather than the more traditional technique of lifting the mattress directly above the head.

As part of this study I want to collect information on the forces acting on the body when you are lifting a mattress off the conveyor into one of the two lifting / carrying positions (e.g. above the head or at the side of the body). I will measure the forces by asking you to stand on a force plate to perform the lifts. You will be asked to hold the mattress in the 'carry position' for 5 seconds before lowering back onto the conveyor. There will be two video cameras recording each of the six trials that you will be asked to perform. Some body measurements (e.g. height, weight, etc) will also be collected. At the end of the trials you will be asked about how tiring you found the lifts and to indicate the lifting method that you prefer. The total time anticipated to perform these trials is 1.5 hours.

Before the trials, you will be asked to read and sign a 'Participant Information and Instruction Sheet', complete a 'Health Screening Questionnaire', and read the 'Safety Instructions for Volunteers' sheet. Once you have done this you will be asked to complete the 'Volunteer Consent Form'. Should you have any questions when reading or completing these forms please ask the researcher who will help you.

This study is supported by the Health and Safety Laboratory (HSL), part of the Health and Safety Executive (HSE), and by the University of Surrey as part of the MSc Ergonomics programme that I am enrolled in. A report of the study findings will be produced for HSL / HSE and as part of my Masters thesis (MSc) for the University of Surrey.

All information you give me during this study is anonymous and will be kept in confidence, seen only by me, and used only in relation to this study. No information relating to an individual will be passed on or shared with any other individual or organisation.

Participation in this study is entirely voluntary. If for any reason you no longer wish to participate please inform me; you are free to withdraw at any stage.

This study has been carefully designed to minimise any risks to your health and safety. Participants should note that HSL / HSE and The University of Surrey have 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 HSL / HSE / University of Surrey.

Leanne Stanley
Researcher

3.2 WRITTEN PARTICIPANT INFORMATION AND INSTRUCTION SHEET

HEALTH & SAFETY LABORATORY
Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

Study Title:

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

INSTRUCTIONS FOR PARTICIPANTS

The following tasks you are going to be asked to perform, and the results that are obtained, will be strictly confidential and your identity will be protected. If you feel you wish to withdraw from the study you are entitled to do so at any time. This study is asking you to do no more than your usual daily work tasks involving handling mattresses. At the end of this form you will be asked to complete a brief health screening questionnaire to ensure that you are able to participate in this study.

The Task: You will be asked to perform 6 trials lifting a double mattress off a conveyor. 3 of the trials you will be asked to lift the mattress off a conveyor above your head (Overhead Technique) hold it in this position for 5 seconds and then lower it back down. The other 3 trials you will be asked to lift the mattress off the conveyor and hold it to the side of your body (Side of Body Technique) before lowering it. You will be given plenty of time to familiarise yourself with this task.

Safety Precautions: If during the course of these trials you experience any difficulties you must immediately tell the researcher who will be on hand to provide assistance. Please listen carefully to the verbal instructions you receive and please ask questions if you need further information. If you feel you need time to warm-up before participating in the trials please let the researcher know.

Risks: The physical nature of this activity may expose some people to a risk of muscle strain or sprain, pulled tendons, back pain or sprain, or hernia. Muscle soreness may also be experienced by some people. As you currently perform these tasks as part of your daily work routine the risk of any of the above occurring during these tests is small. It is important to follow the safety procedures described.

Measuring Procedures: Whilst performing each of the trials you will be asked to stand on a force plate that determines the forces you exert during each lifting and lowering task.

Video recordings will be made for each of the trials you perform and reflective markers will be attached to your skin or clothing using adhesive tape. The use of the markers and the information collected from the video footage will be used to track the movement of your limbs during each task.

At the end of each lifting task you will be shown a rating scale and asked to give a score on how physically hard you found it. (i.e. rate once for Overhead Technique and rate once for Side of Body Technique).

At the end of all the trials you will be asked to complete a brief questionnaire about your job. All answers you give will be anonymised.

Leanne Stanley
Researcher

3.3 HEALTH SCREENING QUESTIONNAIRE

HEALTH & SAFETY LABORATORY

Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

All information disclosed on this form will be kept in confidence and seen only by the researcher. No information relating to an individual, other than an opinion on their suitability for the proposed study, will be released without their consent.

PARTICIPANT DETAILS

Name:		Date of Birth:	
Address:		Gender:	Male / Female
		Telephone:	

HEALTH SCREENING QUESTIONS — PLEASE CIRCLE

1.	Are you on light or special duties at the moment?	Yes / No
2.	Have you suffered from back pain within the last 6 months?	Yes / No
3.	Have you suffered from any other muscle or joint problems within the last 6 months?	Yes / No
4.	Do you currently feel that you are in good health?	Yes / No

EMPLOYMENT HISTORY

Current Occupation:		Experience: (Yrs / Months)	
Previous Occupation:		Experience: (Yrs / Months)	

<u>Acknowledgement of what is required:</u> 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: ……………………………..

3.4 SAFETY INSTRUCTIONS

HEALTH & SAFETY LABORATORY

Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

BEFORE EACH TRIAL

1. Familiarisation

- If you feel that you need more time to familiarise yourself with the task or practice the technique, please do not hesitate to ask.

2. Perform Task in a Controlled Manner

- Perform the task in a smooth controlled manner.

3. Overexertion

- At no time are you expected to significantly overexert yourself.
- If at any time you feel the task is beyond your capabilities then you must immediately tell the researcher and the task can be reassessed.
- If you experience any significant levels of discomfort you must immediately tell the researcher.

4. Assistance

- If at any time you experience any difficulties then you must immediately tell the researcher who will quickly be on hand to provide assistance.

5. Opportunities for Rest

- Rest breaks are built into the design of the experiment, but please let us know if you feel physically fatigued and require additional time to rest.

6. Opportunities for Questions

- At any time if you have any queries or concerns please do not hesitate to ask.

4. APPENDIX D. HSE ETHICS APPROVAL / VOLUNTEER CONSENT FORM

HEALTH & SAFETY LABORATORY
Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

VOLUNTEER CONSENT FORM

Title of Project:

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

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

Please initial as appropriate:

Have you read the information sheet? (Instructions for Participants)	**YES ....**	**NO ....**
Have you completed the Health Screening Questionnaire?	**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 University of Surrey / HSL /HSE 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 University of Surrey / HSL / HSE reports / Journal Articles.	**YES ....**	**NO ....**
I understand that the University of Surrey / HSL / HSE 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 HSL / HSE and the University of Surrey have 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 HSL / HSE / University of Surrey.

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 20.01.06

(Dr D Snashall, Chair to the Research Ethics Committee)

5. APPENDIX E. ANTHROPOMETRIC DATA COLLECTION SHEET

A Comparison of Two Manual Handling Techniques Performed within Warehouse Area in the Mattress Manufacturing Industry.

Participant ID No:		Group ID No:		Date:	

DEMOGRAPHICS

Age:		Gender:	

ANTHROPOMETRIC MEASURES

Stature:	mm
Weight:	kg

Shoulder Ht:	mm	Illiac Crest Ht:	mm
Elbow Ht:	mm	Hip Height:	mm
Knuckle Ht:	mm	Knee Height:	mm
Biacromial Breadth:	mm	Ankle Height:	mm

Dominant Hand:	

6. APPENDIX F. TRIAL ORDER SHEET

Table 23. Randomised trial order used in the study.

Participant Number	Trial Number					
	1	**2**	**3**	**4**	**5***	**6***
1	Tech 2	Tech 1	Tech 1	Tech 2	Tech 2	Tech 1
2	Tech 1	Tech 2	Tech 1	Tech 2	Tech 2	Tech 1
3	Tech 1	Tech 2	Tech 2	Tech 1	Tech 1	Tech 2
4	Tech 2	Tech 1	Tech 2	Tech 1	Tech 1	Tech 2
5	Tech 1	Tech 1	Tech 2	Tech 2	Tech 2	Tech 1
6	Tech 2	Tech 2	Tech 1	Tech 1	Tech 1	Tech 2
7	Tech 1	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2
8	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2	Tech 1

* Borg CR10 Scale administered after these trials.

7. APPENDIX G. BORG CR10 SCALE INFORMATION AND DATA COLLECTION SHEET

BORG CR10 SCALE INFORMATION SHEET

Instructions for scaling perceived exertion.

We want you to rate your perceived (P) exertion, that is, how heavy and strenuous the two tasks performed feel to you. This is mainly dependant on the strain and fatigue in your muscles and on your feeling of breathlessness or aches in the chest. You must only consider your subjective feelings and not any physiological cues or what the actual physical load is.

1 Is "very light" like walking slowly at your own pace for several minutes.

3 Is not especially hard; it feels fine, and it is no problem to continue.

5 You are tired, but you don't have any great difficulties.

7 You can still go on but have to push yourself very much. You are very tired.

10 This is as hard as most people have ever experienced before in their lives.

- This is "Absolute maximum," for example, 11 or 12 or higher.

Scaling your perceived exertion:

Start with a **verbal expression** and then choose a **number**. (E.g. if your perception is "very weak" then say 1; if "moderate", say 3 etc).

You can also use half values or decimals (E.g. 1.5, 4.5 or 0.3, 0.8).

It is important that you answer what **you** perceive, not what you think you should answer.

Be as honest as possible and try not to overestimate or underestimate the intensities.

THE BORG CR10 SCALE

Considering **the verbal expression** first, please point to the number on the scale that matches how physically demanding you feel the task is.

It is important that you answer what **you perceive**, not what you think you should answer.

0	**Nothing at all (no perception)**
0.3	
0.5	**Extremely weak (just noticeable)**
1	**Very weak**
1.5	
2	**Weak (light)**
2.5	
3	**Moderate**
4	**Somewhat strong**
5	**Strong (heavy)**
6	
7	**Very strong**
8	
9	
10	**Extremely strong (almost maximal)**
11	
•	**Absolute maximum (highest possible)**

RATINGS OF PERCEIVED EXERTION AND TECHNIQUE PREFERENCE DATA COLLECTION SHEET

RATINGS OF PERCEIVED EXERTION (Using the CR10 Scale)

Participant ID No.	OVERHEAD TECHNIQUE	SIDE OF BODY TECHNIQUE

TECHNIQUE PREFERENCE: Which technique do you prefer?

OVERHEAD TECHNIQUE	SIDE OF BODY TECHNIQUE	NO PREFERENCE

What are your reasons for choosing this technique?

Are there certain circumstances where you would choose one technique over the other? When?

Do you find one technique easier than the other? How?

Do you experience any muscular discomfort / pain when performing either of these techniques? Yes / No

If any, which technique causes most discomfort / pain?

Overhead Technique / Side of Body Technique

Where do you feel the discomfort / pain?

ADDITIONAL COMMENTS:

8. APPENDIX H. ADMINISTERED QUESTIONNAIRE

HEALTH & SAFETY LABORATORY
Harpur Hill, Buxton, SK17 9JN
Telephone: 01298218000

UniS
EIHMS, University of Surrey,
Guildford, Surrey, GU2 7TE, UK

A Comparison of Two Manual Handling Techniques Performed within the Warehouse Area in the Mattress Manufacturing Industry.

All information disclosed in this questionnaire is anonymous and will be kept in confidence and seen only by the researcher and used in relation to the above named study. No information relating to an individual will be passed on or shared with any other individual or organisation.

INFORMATION ABOUT YOUR JOB.

1. How many years and months have you been doing your **present type of work** with this company?

2. Have you worked for other bed manufacturers?

3. **If yes,** what is the total length of time you have worked in the warehouse area with your previous employer?

4. Do you perform any other physical activities outside of this employment? (Please outline type of activities)

5. On average, how many hours a week do you work in this warehouse? (including overtime but excluding the main meal break)

6. How many of these hours are spent handling mattresses?

7. Do you rotate or change your duties regularly during the day?
8.

YES / NO

7.a If **yes**, outline what other tasks you perform.

7.b. **If yes,** how often:

Changing once every hour ____
Changing once about every 2 hours ____
Changing once about every 2-4 hours ____
Other ____

If you have ticked *Other* please say how often

____

8. On average how many breaks do you have each working day?

____

9. Ignoring your lunch-break, how long is each of your breaks on average?

____

10. Do you experience any difficulty in performing your job? (E.g. back pain or other muscular pain).

Never Infrequently Sometimes Frequently Always

Please explain ____

____

____

11. Are there times when you are constantly handling mattresses and feel pressured due to time constraints? (Please circle the most appropriate)

Never Infrequently Sometimes Frequently Always

Please explain____

____

12. Do you feel you are able to cope with the job demands during busy periods? (Please circle the most appropriate)

Never Infrequently Sometimes Frequently Always

Please explain____

____

13. Do you feel you have adequate support from work colleagues and management? (Please circle the most appropriate)

Never Infrequently Sometimes Frequently Always

Please explain____

____

9. APPENDIX I. ANTHROPOMETRIC RESULTS

Table 24. Stature and weight of participants in the study showing the percent of the 18 – 65 British male population that they relate to.

Participant	Stature (mm)	Stature as a % of pop.	Weight (kg)	Weight as a % of pop.
1	1740	41.1	93.6	85.4
2	1880	96.2	99.1	91.9
3	1780	63.4	78.7	52.6
4	1910	98.5	78.0	49.1
5	1780	63.4	120.5	99.4
6	1920	99.0	95.8	89.1
7	1730	35.5	74.1	35.9
8	1830	85.6	78.2	49.1

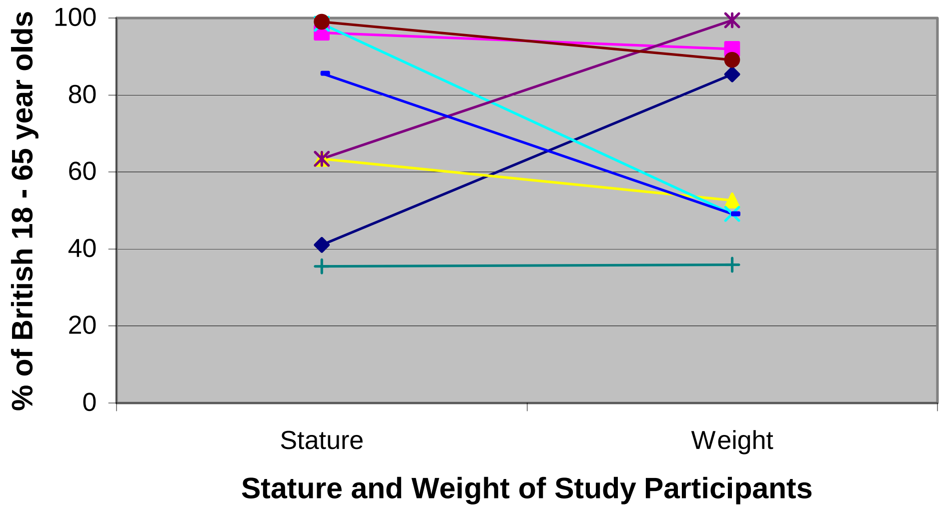

Figure 20. Graph showing study participant stature and weight as a percentage of British male 18 – 65 year olds.

PeopleSize 2000 Professional, Version 2.05 (Open Ergonomics Ltd, 1993 – 2001) was used to determine the percent of the British 18 – 65 year old male population that this study group includes.

PeopleSize 2000 Professional, used the HUMAG dataset which is based on stature and weight data sampled from health surveys in 1994 and 1995. The sample size was between 13,678 and 16,443. The mean stature for the British male, 18 – 65 years is 1756 mm and the mean weight is 79.5 kg.

10. APPENDIX J. GROUND REACTION FORCE DATA

Table 25. Mean ground reaction force (GRF) data for individual participants for both techniques at the start and end of the lift.

	GRF at Start of Lift (N)		GRF at End of Lift (N)	
Participant No.	**Overhead Technique**	**Side of Body Technique**	**Overhead Technique**	**Side of Body Technique**
1	634.49	437.67	185.34	203.98
2	561.92	469.25	174.95	183.09
3	394.42	341.17	184.17	183.58
4	395.50	378.83	181.42	181.32
5	471.50	374.22	194.76	195.93
6	474.74	490.33	195.15	194.86
7	385.99	350.19	190.35	192.11
8	416.29	390.89	192.99	191.03
Mean	**466.86**	**404.07**	**187.39**	**190.74**
Std.dev	**89.97**	**55.26**	**7.17**	**7.74**
Range	**386.0 – 634.5**	**341.1 – 490.3**	**175.0 – 195.3**	**181.3 – 204.0**

11. APPENDIX K. LOW BACK COMPRESSION DATA

Table 26. Low back compression force data at the start and at the end of the lift.

	Low Back Compression Forces (N)			
	Start of Lift		End of Lift	
Participant No.	**Overhead Technique**	**Side of Body Technique**	**Overhead Technique**	**Side of Body Technique**
1	4007.13	3156.19	1352.01	1501.63
2	3589.47	3145.00	1315.62	1652.32
3	2743.62	2468.59	1043.65	1294.71
4	3347.93	4520.67	1501.60	1412.05
5	4103.38	3117.46	1380.88	1371.26
6	3257.31	3431.41	758.37	1488.35
7	2145.61	2030.84	872.56	1228.70
8	2567.63	2697.42	857.15	1214.44
Mean	**3220.26**	**3070.95**	**1135.23**	**1395.43**
Std.dev	**692.93**	**739.76**	**285.57**	**149.98**
Range	**2145 - 4103**	**2030 - 4520**	**758 - 1501**	**1214 - 1652**

12. APPENDIX L. PERCENT OF POPULATION WITH SUFFICIENT STRENGTH DATA

Table 27. Data for individual study participants and the estimated percent of the population with sufficient strength to generate moments at the major joints during the lifting task.

		Start of Lift % Capable		End of Lift % Capable	
Participant No.	**Body Part**	**Overhead Technique**	**Side of Body**	**Overhead Technique**	**Side of Body**
1	**Elbow**	0	0	100	72
	Shoulder	0	5	91	96
	Trunk	0	19	91	99
	Hip	100	100	100	100
	Knee	98.5	99	99	99
	Ankle	98.5	97	98	99
2	**Elbow**	0	0	100	23
	Shoulder	83	92	71	96
	Trunk	5	19	95	91
	Hip	99	99	100	100
	Knee	99	98	99	98
	Ankle	75	81	98	91
3	**Elbow**	0	0	100	99
	Shoulder	82	88	96	98
	Trunk	66	76	99	99
	Hip	100	100	100	100
	Knee	99	99	100	99
	Ankle	96	97	99	99
4	**Elbow**	0	0	61	81
	Shoulder	30	5	51	96
	Trunk	53	10	79	98
	Hip	100	99	100	100
	Knee	89	97	99	99
	Ankle	99	98	98	98
5	**Elbow**	0	0	100	100
	Shoulder	78	69	56	99
	Trunk	15	7	96	98
	Hip	99	100	100	100
	Knee	100	96	99	99
	Ankle	97	89	97	97

		Start of Lift % Capable		End of Lift % Capable	
Participant No.	**Body Part**	**Overhead Technique**	**Side of Body**	**Overhead Technique**	**Side of Body**
6	**Elbow**	0	0	100	95
	Shoulder	32	35	88	99
	Trunk	47	34	100	99
	Hip	62	100	100	100
	Knee	100	100	100	99
	Ankle	89	89	99	98
7	**Elbow**	97	99	100	99
	Shoulder	99	97	98	99
	Trunk	84	87	99	99
	Hip	100	100	100	100
	Knee	100	100	100	100
	Ankle	97	97	99	99
8	**Elbow**	0	0	100	100
	Shoulder	41	63	97	99
	Trunk	69	38	100	100
	Hip	100	100	100	100
	Knee	100	100	100	100
	Ankle	95	95	99	99
Mean % capable for all joints	**Elbow**	12.1	12.4	95.1	83.6
	Shoulder	55.6	56.8	81.0	97.8
	Trunk	42.4	36.3	94.9	97.9
	Hip	95.0	99.8	100.0	100.0
	Knee	98.2	98.6	99.5	99.1
	Ankle	93.3	92.9	98.4	97.5

13. APPENDIX M. REBA POSTURAL ANALYSIS RAW DATA

Table 28. REBA postural analysis showing the raw data for individual participants at the start of the lift and at the end of the lift comparing the Overhead Technique and Side of Body Technique.

	REBA Scores			
	Start of Lift		End of Lift	
Body Part and Participant No.	**Overhead Technique**	**Side of Body Technique**	**Overhead Technique**	**Side of Body Technique**
Trunk				
1	2	2	1	3
2	2	3	2	3
3	2	2	2	3
4	3	3	2	3
5	3	3	2	3
6	2	2	2	2
7	2	3	2	2
8	2	2	2	2
Neck				
1	2	2	1	2
2	2	3	1	2
3	2	2	1	2
4	1	1	1	2
5	2	2	1	2
6	3	3	1	2
7	2	1	1	2
8	2	2	1	2
Legs				
1	2	2	1	1
2	2	2	1	1
3	2	2	1	1
4	2	2	1	1
5	2	1	1	1
6	2	2	1	1
7	2	2	1	1
8	1	1	1	1

	REBA Scores			
	Start of Lift		End of Lift	
Body Part and Participant No.	**Overhead Technique**	**Side of Body Technique**	**Overhead Technique**	**Side of Body Technique**
Upper Arms				
1	3	3	5	2
2	2	2	4	4
3	2	2	5	4
4	2	2	5	4
5	2	2	5	4
6	2	2	5	2
7	1	1	5	2
8	2	3	5	2
Lower Arms				
1	2	2	1	2
2	1	2	1	1
3	2	2	1	1
4	1	1	1	1
5	1	1	2	1
6	1	1	1	1
7	2	2	1	1
8	1	2	1	1
Wrists				
1	2	2	3	2
2	1	1	2	2
3	1	1	3	2
4	1	1	3	2
5	1	1	2	2
6	1	1	3	2
7	1	1	3	2
8	1	1	3	2

14. APPENDIX N. BORG CR10 SCORES FOR INDIVIDUAL PARTICIPANTS

Table 29. Individual ratings of perceived effort, comparing the Overhead Technique and the Side of Body Technique.

Participant Number	Overhead Technique	Side of Body Technique
1	1	1
2	3	3
3	0.1	0.1
4	3	2
5	1	0.5
6	0.3	0.3
7	2	2
8	4	1
Mean	1.8	1.2
Std. dev	1.42	1.01
Range	0.1 - 4	0.1 - 3