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The measurement and assessment of lumbar stress during bedmaking

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THE MEASUREMENT AND ASSESSMENT OF LUMBAR STRESS DURING BEDMAKING

A thesis submitted in partial fulfilment of the
requirements for the award of the degree of

HONOURS MASTER OF SCIENCE

from

THE UNIVERSITY OF WOLLONGONG

by

RODNEY S. BARRETT, B.Ed.

DEPARTMENT OF HUMAN MOVEMENT SCIENCE

1992

ABSTRACT

The hospitality industry is a growth area that plays an important role in our tourist-dependent economy. However, working conditions disadvantage some staff. Hotel linen-maids, responsible for early morning room cleaning, tend to comprise poorly paid ethnic females from low socio-economic groups that perform difficult manual work under demanding time contraints. The bedmaking task has been identified by many of these workers as a major factor contributing toward the causation of musculoskeletal injury, particularly to the low-back region. This is not surprising given the magnitude of the loads encountered in bedmaking and the "extreme" postures necessitated by the location and nature of these loads. Furthermore, it was feared that the trend toward the introduction of larger, heavier beds which are lower to the floor may have exacerbated this risk. The purpose of this study was to assess the level of lumbar stress associated with standard bed size and bed height combinations in order to determine guidelines for safer work practices in the hospitality industry.

To facilitate analysis, the bedmaking task was reduced to a series of five discrete tasks intended to represent components of bedmaking associated with the greatest potential for injury to the worker. These were defined as "bedding-on", "bedding-off", "lifting the mattress" and "pushing" and "pulling the bed sideways". Twelve subjects performed each task for three trials on each of six bed conditions (single, double and queen size beds at two standard bed heights - with and without bed legs).

Stresses on the lumbar spine were assessed using a static biomechanical model with quasidynamic input, electromyography of selected arm and trunk muscles and force platform data indicating the peak vertical and horizontal ground reaction forces exerted beneath the feet for each trial. A three factor analysis of variance (ANOVA) was used to test the effect of task, bed size, and bed height on these dependent variables. Post-hoc two sample t-tests were conducted to determine specific difference between groups.

Results indicated that increased bed size and reduced bed height increased the physical stress on the employee in bedmaking. In some cases this stress was above the potentially hazardous Action Limit published by the National Institute for Occupational Safety and Health. It is therefore recommended that the trend toward the use of larger and heavier beds be reversed and that all beds be fitted with legs and casters to produce a safer working height.

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CHAPTER I

INTRODUCTION

(A) Context of the problem

Back injuries occur more frequently in the "heavy" industries such as construction, mining and engineering, where heavy loads are still commonplace (ACTU-VTHC, 1983). However, back injuries also occur in workplaces that are not normally considered "heavy" such as patient handling by nursing staff and bedmaking.

The initiative to investigate the stresses associated with occupational bedmaking arose as a result of an approach by a hotel linen maid concerned by the number of her co-workers leaving the industry. It was proposed that the introduction of larger and heavier beds which were lower to the floor increased the physical stress on the employee to a potentially hazardous level. Approaches to management failed to resolve the issue and resulted in harrassment from both the Executive Housekeeper and Management. The conflict was culminated by the resignation of the employee who originally raised the issue.

The Hospitality and Tourism Industry is one of the growth areas of employment. It has a high proportion of semi-skilled, casual and non-unionised labour. In addition to this, hotel housemaids largely comprise of poorly paid ethnic females from low socio-economic groups with limited resources for gaining improved working conditions or rehabilitation. Employment is often of a seasonal or transitory nature with a high turnover of frontline staff. Hence proper access to information, training and education is often limited.

For the March Quarter (1989) there were 402,662 bed spaces available in Hotels, Motels and Guest Houses throughout Australia. For this period the bed occupancy rate was 35.2% and takings from accommodation alone amounted to $506,234,000 (Australian Bureau of Statistics, 1989). In view of our economic dependence on the tourist trade and the apparent disadvantaged nature of this work situation, further investigation was warranted.

The stresses imposed on the musculoskeletal system, particularly the lower back, during the bedmaking task have not previously been assessed. Further initiative to investigate these stresses arises as a cumulative result of several potentially hazardous components of the work situation.

Preliminary investigation of the bedmaking task revealed that, for a double bed, the mattress must be lifted on 14 occasions. The complete task requires at least 20 forward flexion movements. This routine is performed between 15 and 20 times per day, usually within the space of several hours. Space restrictions often limit accessibility to the bed and in some cases beds need to be moved to gain necessary access. Potential injury to the low back may be associated with this action as the total bed weight can be as high as 151kg (king size bed). It is also likely that the non-rigid loads encountered in bedmaking are associated with a greater risk of unbalanced and hence unexpected loading.

As the excessive stress resulting from modern, heavy beds still remains and is growing with the increased number of hotel beds to cater for the burgeoning tourist market, an intervention procedure based on empirical evidence was considered necessary.

(B) Statement of the problem

The purpose of this study was to compare the effect of two bed heights and three bed sizes on lumbosacral forces, ground reaction forces and electromyographic activity of implicated muscles during simulated bedmaking tasks. The dimensions of beds selected for use in this study were consistent with those sold for both domestic and hotel use.

(C) Significance of the study

The problem of back pain arising from occupational bedmaking in the hospitality industry has not previously been investigated. This study attempts to establish a possible link between working conditions for linen maids and the apparent high incidence of low back injury.

The significance of the study was to identify the potentially hazardous components of the bedmaking task in view of recent trends toward the introduction of larger and heavier beds that are lower to the ground.

(D) Statement of the research hypothesis

The null hypotheses proposed were that:

1. Increased bed size will not significantly affect the lumbosacral compressive and shear forces during bedmaking.

2. Decreased bed height will not significantly affect the lumbosacral compressive and shear forces during bedmaking.

3. Increased bed size will not significantly affect the peak vertical and horizontal ground reaction forces exerted beneath the feet during bedmaking.

4. Decreased bed height will not significantly affect the peak vertical and horizontal ground reaction forces exerted beneath the feet during bedmaking.

5. Increased bed size will not significantly affect the electromyographic activity of selected muscles during

bedmaking.

6. Decreased bed height will not significantly affect the electromyographic activity of selected muscles during bedmaking.

7. Different components of the bedmaking task will not significantly affect the stresses imposed on the human musculoskeletal system during bedmaking.

(E) Limitations and delimitations

The following limitations were applied to this study:

1. All trials were conducted in the Biomechanics Laboratory at the University of Wollongong under simulated conditions.

2. Each subject was required to perform all tasks while standing within the confines of a force platform (600 x 400 mm) with surface electrodes placed on the trunk and shoulder region.

3. The effect of bedmaking experience on task performance was assumed negligible.

4. Standard cinematographic analysis procedures were used to determine accelerations. Errors inherent in the use of such procedures necessitated the use of data smoothing techniques.

The following delimitations were applied to this study:

1. Only tasks performed by female students in the Department of Human Movement Science at the University of Wollongong were analysed as part of this study.

2. The tasks of "bedding-on", "bedding-off", "lifting the mattress", and "pushing" and "pulling the bed sideways" were assumed to be representative of the bedmaking task as performed in the hospitality industry by experienced linen maids.

3. Three trials of each task were considered representative of the performance characteristics of each subject.

4. The lumbosacral compressive and shear forces, peak vertical and horizontal ground reaction forces and electromyographical activity of selected muscles were the parameters chosen to represent the stresses on the human musculoskeletal system during bedmaking.

5. The bed caster and leg combinations used to produce the high and low bed conditions in the study were assumed to differ in height only.

(F) Definitions

The following definitions relate to the intended meaning of terms as used within the context of this study.

Ankle joint

Most lateral projection of lateral malleolus.

"Bedding-off" (Bed-off)

The motion used to remove a sheet (equally with both hands) from a bed when standing alongside the bed at its midline. The sheet was "tucked in" under the mattress on all four sides. Hand placement was self selective.

"Bedding-on" (Bed-on)

The motion used to apply a blanket (equally with both hands) to a bed when standing alongside the bed at its midline (flicking motion). The blanket was placed on the near side of the bed (unfolded and gathered along its long axis) prior to each trial.

Cervical spine

Vertebrae prominens (7th cervical vertebrae).

Double size bed

Royale Collection Orthofirm Luxury spring bed (138 x 192 cm) with a mass of 59 kg manufactured by Hurstville Bedding Company.

Elbow joint

Centre of circular band through olecranon and transverse anterior fold.

Electromyography (EMG)

The study of muscle function through the enquiry of the electrical signal emanating from the muscles.

High bed condition

Refers to a bed surface height of 56 cm comprising 15 cm (caster and leg), 20 cm (base) and 21 cm (mattress).

Hip joint

Most lateral projection of greater trochanter.

Integrated Electromyographical activity of the Anterior Deltoid muscle (IEMG(AD))

Refers to the area under the curve of the mean rectified electromyographical signal eminating from the detection area of the electrode placed over the anterior deltoid (measured in Volts.milliseconds). This was then expressed as a percentage of electromyographical activity associated with a maximal voluntary isometric contraction of the same muscle.

Integrated Electromyographical activity of the Erector Spinae muscle (IEMG(ES))

Refers to the area under the curve of the mean rectified electromyographical signal eminating from the detection area of the electrode placed over the erector spinae muscle (measured in Volts.milliseconds). This was then expressed as a percentage of electromyographical activity associated with a maximal voluntary isometric contraction of the same muscle.

Knee joint

Lateral femoral epicondyle.

"Lifting the mattress" (Lift-mattress)

Gripping left hand back corner of the mattress (from beneath) with the right hand and lifting it to a height of approximately 200 mm while simultaneously tucking a sheet in with the left hand using a horizontal sweeping motion.

Linen maid

The individual responsible for the making of beds in the hospitality industry.

Low bed condition

Refers to a bed surface height of 46 cm comprising 5 cm (caster), 20 cm (base) and 21 cm (mattress).

Lower arm link

The straight line between the elbow and wrist joint.

Lumbosacral compressive force (L5/S1 Comp)

The load applied normal to the surface of the joint between the fifth lumbar vertebra and the sacrum causing shortening and widening of the structure (expressed in Newtons).

Lumbosacral shear force (L5/S1 Shear)

The load applied parallel to the surface of the joint between the fifth lumbar vertebra and the sacrum causing internal angular deformation or slip (expressed in Newtons).

Peak Vertical Ground Reaction Force (PVGRF)

Refers to the largest ground reaction force exerted against a force platform (situated beneath the feet) along the vertical axis (expressed in Newtons).

Peak Horizontal Ground Reaction Force (PHGRF)

Refers to the largest ground reaction force exerted against a force platform (situated beneath the feet) along the anterio-posterior axis (expressed in Newtons).

Percentage of Maximal Voluntary Isometric Contraction (%MVIC)

This technique provides a basis for comparison between tasks and individuals performing the same tasks and involves expressing the electromyographical activity during task performance as a percentage of the electromyographic activity associated with a maximum voluntary isometric contraction.

"Pulling the bed sideways" (Pull-bed)

Hands grip underneath the long side of the bed base adjacent to its corner. Bed is pulled approximately 400 mm with the subject's feet remaining on the force platform.

"Pushing the bed sideways" (Push-bed)

Hands are placed against the long side of the bed base (palms facing down) adjacent to the corner. Bed is pushed equally with both hands a distance of approximately 400 mm with subject's feet remaining on force platform.

Queen size bed

Royale Collection Orthofirm Luxury spring bed (153 x 204 cm) with a mass of 76 kg manufactured by Husrtville Bedding Company.

Segment angle

The anticlockwise angle formed between the given segment and the right hand horizontal.

Shank link

The straight line between the knee and ankle joint.

Shoulder joint

Lateral aspect of acromion process.

Single size bed

Royale Collection Orthofirm Luxury spring bed (93 x 192 cm) with a mass of 45 kg manufactured by Hurstville Bedding Company.

Thigh link

The straight line between the hip and knee joint.

Torso link

The straight line between the cervical spine and the hip joint.

Upper arm link

The straight line between the shoulder and elbow joint.

Wrist

Centre of circular band joining the radial and ulnar styloid processes.

CHAPTER II

REVIEW OF THE LITERATURE

In an attempt to gain an insight into the scope of the available knowledge pertaining to the musculoskeletal stress involved in the bedmaking task, this literature review has been divided into four sections: (A) the problem of low back pain as it relates to its costs, causes, control guidelines and preventative strategies, (B) the measurement of loads on the human spine in relation to current methodologies, (C) the nature of the bedmaking task with respect to physical requirements and work conditions in the hospitality industry, and (D) the measurement of spinal loads specifically in bedmaking.

(A) The problem of low back pain

Impairment of the low back is the most frequent cause of activity limitation in persons under 45 years (Andersson, 1981; Kelsey and White, 1980) and is of considerable cost to the community. As many as 80% of adults in industrialised countries such as Australia will suffer from low back pain at some stage in their lives, with more than half of this group suffering pain more than once (Hultman, 1987). In fact, it is claimed that back pain is the greatest single cause of time loss attributed to work in Australian industry (National Health and Medical Research Council, 1982).

While national statistics on back injuries in Australia do not exist, the returns of the Workers Compensation Commission of New South Wales (1987) indicate that back pain accounted for 26% of all injuries reported. Furthermore, conservative calculations indicate that low back pain could be costing Australia more than $615 million per year in lost production, workers' compensation and hospital payouts (Department of Arts, Sport, the Environment, Tourism, and Territories, 1987). Additional to the huge losses associated with compensation claims, work absence and reduced productivity are less obvious costs such as increased staff turnover, poor industrial relations, low corporate morale and devalued corporate image (Worksafe, 1989b). These hidden costs lead to a substantial drain on economic and labour resources. However, the social consequences borne by individuals and organisations should not be underestimated (Gore, 1986). Due to the number, severity and cost of compensation claims for back injuries in Australia, this problem has been given high priority by federal and state governments, their statutory bodies, and numerous industrial organisations.

The factors underlying the occurrence of work-related back injuries are not well understood although the type of work done seems to be related (Gagnon, Sicard and Sirois, 1986). Of the various factors proposed as the main protagonists for low back pain, manual handling has been most commonly implicated (Andersson, 1981). According to the Draft National Standard and Draft Code of Practice for Manual

Handling (Worksafe, 1989a), manual handling is defined as any activity requiring the use of force exerted by a person to lift, push, pull, carry or otherwise move or restrain any animate or inanimate object. It has been estimated that one-third of all compensable injuries are attributable to manual handling (Australian Bureau of Statistics, 1986). These figures reveal that in the six states there was a total of 32,987 manual handling-related accidents in a twelve month period, resulting in a time loss due to injury of 412,661 working weeks at a cost of $166,169,900. Injuries to the back arising from manual handling are reported by authorities in Great Britain, the United States and the Netherlands to be the most frequent and costly of all musculoskeletal disorders (Dul and Hilderbrandt, 1987; Edwards, 1987; Nelson, 1987).

Chaffin and Park (1973) demonstrated an almost three-fold increase in low back injury rates in the overstressed populations. These injuries range from short term aches and strains to protracted disorders that can lead to permanent disability. Edgar (1979) categorised these as pathologies of the extensor system (musculotendinous strains) and pathologies of the spine (intervertebral disc lesions, bone pathology, lumbosacral strain, spondylolysis, spondylolisthesis, lower lumbar instability and abdominal hernia). However, regardless of the pathology, prevention is clearly better than treatment and methods of bending and lifting need to be taught.

Factors associated with injury risk include the magnitude of the load, frequency and duration of lift (Ljungberg, Kilbom and Hagg, 1989), lifting posture (Jorgensen and Nicolaisen, 1987), the nature of the load (Khalil, Asfour, Moty, Steele and Rossomoff, 1987a), environmental conditions and the functional capacity of the worker (Aghazadeh and Dharwadkar, 1985; Mital, 1987). To illustrate the complexity of the situation, a study by Parnianpour, Bejjani and Pavlidis (1987) found that there was no simple, safe or proper lifting technique and that each lifting task warranted an individual evaluation. Furthermore, work by Hebert and Miller (1987) questioned the success of traditional lifting techniques in safeguarding against low back injury.

The relationship between low back pain and human muscular strength (Chaffin, 1974; Thorstensson and Arvidson, 1982) and trunk extensor endurance (Jorgensen and Nicolaisen, 1987) have been investigated in an attempt to determine the limiting factor in manual handling exertions. Jorgensen (1970) and Poulsen (1981) have also assessed back muscle strength as a limiting factor in manual handling exertions. The rationale for these studies and others (Jorgensen, 1970; Poulsen, 1981) was that fatigue of the spinal extensors during manual handling results in greater loads being borne by the passive posterior ligamentous structures of the lumbar spine resulting in cumulative trauma. These studies, although limited in technique for measuring strength (at different speeds through the full range of motion at given joints), did report that muscular factors were important but were less conclusive about the extent of this relationship.

Simply stated, the risk of injury is increased when the job demands are beyond the safe working capacity of the individual. As approximately one-third of all industrial jobs involve some form of manual materials handling (Cook and Neumann, 1987), the rationale for appropriate guidelines to ensure safety whilst engaged in lifting seems clear.

The development of manual handling criteria arises from four types of evidence or study from which data about the effects of lifting can be derived. These are: (i) epidemiological; (ii) physiological; (iii) psychophysical; and (iv) biomechanical.

Epidemiology is the science concerned with identification of the incidence, distribution and causes of illness and injuries in a group of people. Studies in this domain (Andersson, 1981; Chaffin and Park, 1973; Frymoyer, et al., 1980; Frymoyer, et al., 1983; and Kelsey and White, 1980) have established a positive relationship between the incidence of injury and weight lifted, location and size of load, and the frequency, duration and pace of lifting.

Physiological studies measure the body's ability to perform repetitive lifting tasks without excessive fatigue by monitoring oxygen consumption, metabolic energy expenditure and heart rate. For example, Garg and Saxena (1979) studied the effects of lifting frequency and technique on physical fatigue according to physiological criteria and Garg, Chaffin and Herrin (1978) have developed prediction procedures for determining metabolic rate for manual materials handling jobs.

Psychophysical studies are designed to quantify the subjective tolerance of people to the stresses of manual materials handling. Snook (1978) and Ayoub, Dryden, McDaniel, Knipfer and Dixon (1979) have addressed this approach and published maximum acceptable weights for lifting based on dynamic strength for males and females (National Institute for Occupational Safety and Health (NIOSH), 1981). Gamberale, Ljunberg, Annwall and Kilbom (1987) tested the reliability and validity of psychophysically determined maximum acceptable workloads and discovered (i) selected loads were satisfactorily reproducible but varied with instructions given; and (ii) there were no consistent relations between acceptable workload and the physical characteristics or performance capacity of the worker. According to Snook (1978), a proper use of psychophysical estimates can reduce the occurrence of injuries more effectively than selecting the worker for the job or training the worker to lift properly.

Biomechanical studies aim to quantify the forces and torques acting on the human musculoskeletal structure during manual handling. According to Chaffin (1987b), there are six methodological areas of occupational biomechanics research. These include biomechanical modelling, anthropometry, mechanical work capacity evaluation, bioinstrumentation, classification and time prediction methods and other kinesiological methods. All have the purpose of improved worker performance and reduced risk of mechanical trauma through the development of worker selection and training criteria, tool and workplace design guidelines and material handling limits.

A comparison of biomechanical, psychophysical and physiological criteria by Garg and Ayoub (1980) showed that (i) the recommendations based on a given criteria were not in agreement, (ii) the maximum permissable weights of the load based on psychophysical studies were lower than those based on biomechanical criteria, and (iii) the psychophysical criteria, as compared to the physiological fatigue criteria, will result in greater workloads at higher frequencies of lifting. This was probably due to differences in subject populations used in terms of age, size and nationality, experimental conditions, and the methodologies employed to determine the safe maximum working load. Furthermore, Garg (1987) showed that the maximum permissable limits were conservatively based on psychophysical, physiological and biomechanical criteria. To facilitate a meaningful comparison it was recommended that a comprehensive study be undertaken to measure these criteria simultaneously.

Current occupational health and safety legislation in New South Wales covering all workplaces under state jurisdiction maintains that a general duty of care be placed on all persons. More specific guidelines are provided by the Factories and Shops Act (New South Wales State Government, 1962) which imposes maximum load limits on the basis of age and gender. This approach has tended to perpetuate a simplistic approach to hazard management as reliance on weight alone neglects the contribution of other risk factors such as the nature of the load, the posture adopted and the frequency and duration of lift. As a result, many workers have been obliged to perform potentially hazardous manual tasks.

Guidelines for manual handling have also been established by other authorities (Australian Council of Trade Unions-Victorian Trades Hall Council (ACTU-VTHC) Occupational Health and Safety Unit, 1983; Committee on Occupational Safety and Health in Commonwealth Government Employment, 1982; National Swedish Board of Occupational Safety and Health, 1983; NIOSH, 1981; Standards Association of Australia (SAA), 1974; Trade Union Congress (TUC) of the United Kingdom, 1983; United Kingdom Health and Safety Commission (HSC)).

The Australian Standard 1339-1974 (Manual Handling of

Materials) is an advisory code which does not favour the specification of maximum weights. Rather it makes suggestions in relation to assessment of manual handling tasks, education and training, environmental factors, work organisation, medical examinations and accident investigation. The ACTU-VTHC, HSC, TUC and Swedish guidelines identify job re-design as the priority for minimising injuries due to manual handling and provide information to facilitate this process. Conversely, the NIOSH Work Practices Guide for Manual Lifting (1981) outlines load limit recommendations based on task variables and refer to specific load limits (for lifting tasks only) based on epidemiological, biomechanical, physiological, and psychophysical criteria. Work performed beyond the Maximum Permissable Limit (MPL) has been shown to significantly increase the risk and severity of injury to the musculoskeletal system. Biomechanical compression forces on the L5/S1 disc of 650kg (6377N) would exceed this condition. Conversely, the Action Limit (AL) of 350kg (3430N) L5/S1 disc compression corresponds to a moderate increase in the incidence and severity of musculoskeletal injury. Only 25% of men and 1% of women have the muscular strength to perform work above the MPL while over 75% of women and 99% of men could lift loads described by the AL. Loads below the AL are considered acceptable as they theoretically represent nominal risk to the majority of workers. The guide also makes mention of worker selection, training, engineering and administrative controls in order to identify and eliminate unacceptable work practices.

In an attempt to confront the problem of low back pain, Worksafe Australia has recently published a Draft National Standard and Draft Code of Practice for Manual Handling (1989a). It is hoped that this document will form the basis of an effective means for preventing, identifying, assessing, and controlling the risks arising from manual handling activities in the workplace. The principal feature of this draft was the provision for a method of risk assessment to be applied to manual handling tasks rather than the exclusive use of weight limited action levels. This gives recognition to the complexity of factors implicated in musculoskeletal injury, particularly to the low back, resulting from manual handling. A multifaceted approach to injury prevention in manual handling considers the actions and movements involved, workplace layout, lifting posture, duration and frequency of activity, distance and time handled, force applied, weight and nature of the load, workplace conditions, work organisation, and age, skill and experience of the worker in terms of their potential to cause injury during manual handling.

While epidemiologists have long identified the association between manual handling and the occurrence of low back pain, the solution to the issue of prevention has been less clear. The prevention of low back pain at the workplace has traditionally been attempted by three approaches: (i) education and training in work methods such as lifting techniques; (ii) selection of workers with sufficient physical capacity and guidance of workers with (temporary) reduced capacity; and (iii) ergonomic design of the task or workplace (Dul, et al., 1987).

The degree to which training has been successful is in question (Ayoub, 1982; St-Vincent, Tellier and Lortie, 1989). Despite efforts directed at legislation and worker training, the problem of manual materials-handling remains severe (Drury, Law and Pawenski, 1982). Even back care specialists and educators have been found to suffer low back pain to the same extent as the general population (Scholey and Hair, 1989). Further to this, pre-placement selection programs are only aimed at newly hired employees and are limited by human rights requirements and the size of the available worker pool. Re-designing the job to better match the capabilities of the typical workforce is probably the most effective prevention strategy (Chaffin, 1987a). However, the ergonomic approach of designing the workplace to fit the worker is considered only partially effective (Snook, Campanelli and Hart, 1978). Alternatives to changing the design of equipment or the workplace are often impractical, prohibitively expensive, or unavailable (Aird, Nyran and Roberts, 1988). Troup and Edwards (1985) argued that although the ergonomic approach was recognised as the most logical, selection and training were important and should be used where appropriate or where further ergonomic improvement was not feasible. An extensive review of the literature by Snook (1988) concluded that no single approach by itself will control the problem. Ayoub (1982) provided useful guidelines for specific training in safe handling and jod redesign for the control of manual lifting hazards.

(B) Measuring loads on the human spine

The mechanism of the lumbar spine and trunk has been investigated by numerous authors (Ashton-Miller and Schultz, 1988; Bogduk, 1980; Farfan, 1975; Floyd and Silver, 1955; Gracovetsky, Farfan and Lamy, 1981; Lindahl, 1966; Morris, Lucas and Bresler, 1961; Ortengren and Andersson, 1977; Panjabi, 1985; and Soderberg and Barr, 1983). The anatomical structure and functional capacities of this region must be understood before loads can be meaningfully quantified.

To institute preventative measures based upon the assumption that loads on the spine should be kept low, we must be able to measure, or at least estimate, the loads imposed on the spine by physical activity (Andersson, 1985). The quantification of these loads has involved a variety of biomechanical approaches.

There are no direct methods to measure all forces in the component structures of the spine in vivo. Disc pressure measurements can be used as semi-direct indicators of loads on the discs and vertebrae while electromyography (EMG) and intra-abdominal pressure (IAP) measurements can be used as indirect measures. Further to this, biomechanical modelling of human task performance enables the estimation of load moments at the main articulations (produced by external forces) and the forces on the various musculoskeletal tissues (internal forces). Special low back biomechanical models attempt to predict the load moment about the lubosacral disc. Subsequent estimates of compression and shear forces can then be compared with pre-established safe load limits.

Disc pressure measurements were first obtained by insertion of a fluid filled membrane-covered needle connected to a transducer into the lumbar disc (Nachemson and Morris, 1964). Subsequent investigations have refined measurement techniques using a transducer needle (Nachemson and Elfstrom, 1970). These authors used this procedure to study different postures, common movements, and physical activities and have provided the basis for numerous studies into work postures and activities. Nachemson (1981) showed that forward flexion and rotation increased disc pressure by 400% in comparison to the upright standing position. Andersson, Ortengren, and Nachemson (1976a, 1977), in studying pressure reponses to changes in trunk moment (both as a function of posture and hand-held weight) in pulling and lifting tasks, identified a linear relationship between trunk moment and observed pressure in static trunk postures. From this it was concluded that pressure measurements can be used to estimate loads on the lumbar spine for static postures.

The disadvantage of intra-discal pressure measurement is that it is an invasive procedure and carries the potential for injury to the subject, especially under movement conditions. This often precludes the use of disc pressure measurements in occupational field studies. Furthermore, disc pressure is only a partial indicator of spinal load in certain postures as it does not reflect the load borne by the lumbar facets (Marras, King and Joynt, 1984).

Measurements of muscle activity and IAP, on the other hand, have been used extensively in studies in the field of ergonomics to indicate loads on the lumbar spine. This has been successfully accomplished even during heavy industrial work (Davis, 1981; Ortengren, Andersson, Broman, Magnusson and Petersen, 1975). However, the validity of IAP measurements as an indication of loads on the lumbar spine has been severely criticised (Gracovetsky, 1988).

Electromyography (EMG) is the study of muscle function through the inquiry of the electrical signal (action potentials) emmitted from contracting muscles (Basmajian and DeLuca, 1985). EMG recordings of human muscle represent one of the few direct means to quantitatively assess the status of the musculoskeletal system in vivo. The source of the EMG signal is the depolarisation of the muscle tissue during contraction. The signal can be processed to determine the force or fatigue characteristics within a given muscle (Marras, 1987). EMG studies of trunk muscles have provided valuable insight into the functional anatomy of the lumbar spine (Carlsoo, 1964; Floyd and Silver, 1955; Ortengren and Andersson, 1977) and has enabled the contribution of specific muscles to be quantified under different loading conditions (Eckholm, Arborelius, and Nemeth, 1982; Kippers and Parker, 1983; Jonsson, Brundin, Hagner, Coggman and Sondell, 1985; Pope, Andersson, Broman, Svensson and Zetterberg, 1987).

One of the primary reasons for the recording and processing of myoelectric signals in occupational biomechanics is to predict muscle contraction forces required for, and the compression produced by, the execution of weight lifting tasks. However, the relationship of electromyographic activity to muscle force is dependent on many factors (including the type of contraction and the type of fibre and its distribution within the muscle). The relationships between voluntary isometric tension or torque and myoelectric activity are entirely empirical and depend upon the subject, the quantitative measure of the electromyogram used, the electrode separation and the postures and joints over which the the muscles act. Posture in particular is said to shift the spatial arrangement of tissue deep to the electrode site affecting the quality of the measurable waveform features (Grieve and Pheasant, 1976). Care is therefore necessary in predicting muscle contraction levels from EMG data. This is particularly true for dynamic conditions (Chaffin and Andersson, 1984).

Electromyographic investigations of lumbar stress during lifting are based upon the monotonic (linear or curvilinear) relationship between the mechanical and electrical output of a muscle. This has been observed by numerous investigators (Andersson, Ortengren and Herberts, 1976a; Andersson, Ortengren and Nachemson, 1977). An increase in signal amplitude is always an indication of increased muscular output provided that muscular fatigue is not taking place (Jonsson, 1985), thereby faithfully reflecting the overall stress on the back (Kumar and Turner, 1983).

There are several methods for estimating the contraction level of a particular muscle. One such method is to relate the myoelectric activity during work to a static test contraction. The contraction most commonly used in ergonomic studies is a maximum voluntary isometric contraction. This allows EMG activity during work to be expressed as a percentage of maximum voluntary isometric contraction (%MVIC) and results in a normalisation of myoelectric data such that the results from one subject or experiment can be compared with those from another subject or from another experiment within the same subject. For example Takala, Leskinen and Stalhammar (1987) used isometric test contractions to determine the highest root mean square (rms)

EMG values for 0.5 second periods recorded over 5 seconds to reference the data collected from hip extensor and trunk muscles during stooping and lifting. Results indicated that the erector spinae muscle switches on earlier in loaded versus unloaded back lifts and that the peak activity of the erector spinae was significantly lower in the 10 kg leg lift compared with the back lift for males only. It was postulated that differences due to gender may have been a result of the muscular capacity of some female subjects being reached.

Conversely, given the availability of a force transducer, it is possible to express the myoelectric results in relative force of contraction. Bjorksten, Itani, Jonsson and Yoshizawa (1987) used this method to evaluate the muscular load in shoulder and forearm muscles during typing, knitting, crocheting and cleaning activities. A "ramp test" was conducted in which the subjects were asked to perform an isometric contraction against a resistance while EMG and force data were collected simultaneously. Activity during each task was then expressed as a percentage of the maximal voluntary force of contraction (%MVC).

In a study by Andersson, Ortengren, and Schultz (1980), a mathematical model to determine the loads imposed on the trunk muscles during sagittally symmetric work at a table was validated using electromyography. The model predictions of the muscle tensions were highly correlated with myoelectric signal levels. Similar findings were established in studies conducted by Schultz, Andersson, Ortengren, Bjork and Nordin (1982a) and Schultz, Andersson, Ortengren, Haderspeck, and Nachemson (1982b). As an addendum to the work by Andersson, et al. (1980), Schultz, Anderson, Haderspeck, Ortengren, Nordin, and Bjork (1982c) attempted to test the validity of this model in more complex circumstances such as when performing bending and twisting movements. Correlations were moderate yet provided a basis for useful insight into lumbar loads associated with these movements. However, with the development of portable instrumentation to study human motions and muscle reactions, it is now possible to make on-site studies, thus providing the means to improve and further validate existing models (Chaffin, 1985).

Myoelectric back muscle activity has also been used to successfully predict disc pressure under static conditions (Ortengren, Andersson and Nachemson, 1978, 1981). Again, use of this technique in dynamic situations where the acceleration forces are significant requires further investigation.

Ortengren and Andersson (1977) and Andersson (1982, 1985) have summarised many of the studies concerned with myoelectric activity of the trunk muscles during lifting. A general discussion of this approach to work place evaluation is provided by Kadefors (1978) with particular reference to the problem of estimating muscle force or even tension in absolute terms using rectified and filtered EMG.

Though the technique of electromyography has its limitations, it is still a valuable tool in ergonomics. While absolute quantification of dynamic activity stress is not possible, relative assessment of load permits comparison of tasks, tools and work design or redesign, optimisation and effective management of work place parameters to ensure workers health and safety in addition to ensuring optimum productivity (Kumar, 1987).

Intra-abdominal pressure is believed to assist in the load relieving capability of the trunk (Marras, et al., 1984). Hemborg and Moritz (1987) attributed the IAP rise during lifting to a co-ordinated contraction of muscles surrounding the abdominal cavity. Of these, the diaphragm seemed to be of greatest importance in conjunction with transverse abdominus and the muscles comprising the pelvic floor. The oblique muscles, and in particular, the anterior abdominal muscles, appeared to be of less importance. However, oblique abdominal activity peaks tended to coincide with IAP peaks (Stalhammar, Leskinen and Takala, 1987). Cresswell and Thorstensson (1989) agreed that IAP can be increased without the development of a large counter-moment produced by the dual action of the trunk flexors suggesting that other abdominal musculature was responsible for control over IAP during controlled lifting tasks. However, the IAP during lifting did not appear to be affected by strength training of the abdominal musculature (Hemborg, Moritz, Hamberg, Lowing and Akesson, 1983). Improved IAP response during lifting was probably related to better co-ordination of trunk musculature indicating it was a practiced response facilitated by training in lifting technique (Hemborg and Moritz, 1987).

It was postulated that the pressure increase during strenuous lifting tasks produced a trunk extension moment reducing the muscular contraction necessary for moment equilibrium (Bartelink, 1957). This phenomenon was observed by Davis (1956) and helped to explain the discrepency that existed between the calculated lumbar loads during lifting and the tissue tolerance of the vertebral units under experimental stress conditions (Perey, 1957). Davis found that IAP increased when trunk moment increased. This was later confirmed by several other investigators (Andersson, 1982; Andersson, et al., 1977). Andersson, et al. (1977) also determined that a linear relationship existed for IAP and the trunk load and angle during lifting. However, asymmetries in load and posture appeared to influence the relationship as did dynamic forces and postural changes. Clearly, the nature of the task under investigation determines the validity of IAP measurements.

The two most common IAP measurement systems are the pressure-sensitive radio pill and the catheter-mounted pressure transducer. The radio pill has the advantage of being less invasive and easy to swallow but is presently too expensive to be disposable and very sensitive to pressure changes. Conversely, the catheter transducers give excellent readings but are somewhat uncomfortable for use in occupational settings (Chaffin and Andersson, 1984). This makes their use inappropriate for all but highly funded and well controlled laboratory research.

Biomechanical models of the musculoskeletal system are non-invasive and relatively simple to use. These models are concerned with accurately predicting the risk and task performance capability of a worker performing a manual task (Chaffin, 1988) and as such have implications for new and existing work situations as part of the engineering design process. More specifically, the development of computerised biomechanical models of the musculoskeletal system has meant that alternative manual work methods, equipment design, and personnel selection and training methods now can be evaluated to assure compliance with tissue failure criteria (Chaffin, 1985).

Biomechanical models have the advantage of being practical. Often it is not possible to measure the effects of manual handling in industry, particularly when a new work situation is being developed. Under these circumstances it is possible to simulate the task and predict safety and performance outcomes. Similarly, by modelling potentially hazardous tasks where injury is likely, the worker is spared from experimental risk.

The contribution of biomechanical models to our understanding of the mechanisms of injury related to manual handling will be enhanced as research developments begin to account more accurately for the anatomical complexity of the human musculoskeletal system in motion. However, even the earliest and most simplistic of models have facilitated important discoveries.

The first comprehensive attempt at spine modelling was a simple static sagittal plane model by Morris, Lucas and Bresler (1961). This model assumed that two types of internal forces acted to resist the external load moment. One was the extensor erector spinae muscles that exerted force approximately 5cm posterior to the centres of rotation in the spinal discs. The second stabilising force was assumed to be caused by the abdominal pressure acting in front of the spinal column, pushing the upper torso into extension, thus resisting the load moment acting on the lumbar spine. What resulted from the application of this model was the realisation that large compression forces developed in the spinal column acting to compress the disc during load lifting (Chaffin, 1987b). This model was later refined by Chaffin (1975a) to predict the forces at the "L5/S1 joint" in static coplanar lifting analyses which assumed a single back muscle force based on average anthropometric data (Dempster, 1955). Computation of "L5/S1" compression using this model include better lumbar-pelvic postures, abdominal pressure responses and anthropometric scaling factors and further provided a basis for understanding how loads held in various postures can create potentially harmful compressive disc forces. The magnitude of these compressive forces were confirmed by Nachemson and Elfstrom (1970) using intra-discal pressure measurement techniques.

While static biomechanical models are useful for numerous ergonomic applications, they neglect the effect of inertial forces on a movement. A study by Garg, Chaffin, and Freivalds (1982) indicated that the inertial forces during the first acceleration phase of a lift can add considerably to the maximum L5/S1 compression. In this study six subjects were asked to repeatedly lift the maximum load they believed they could safely lift from the floor to carrying height. A static analysis showed that the compressive forces in these lifts were below the NIOSH AL. However, the dynamic analysis indicated that the peak forces actually exceeded the MPL. In fact, the dynamic biomechanical simulation of lifting psychophysically determined maximum loads showed that the compressive force at the low back and peak task moments at various body joints were approximately two to three times greater than those based on static biomechanical simulation. Bush-Joseph, Schipplein, Andersson and Andriacchi (1988), Leskinen, Stalhammar, Kourinka and Troup, (1983), and McGill and Norman (1985), all published similar findings indicating that the inertial factors increase the spinal load considerably for common lifting techniques.

Dynamic considerations are important only when motion involves significant linear or angular accelerations. The product of a mass and its linear acceleration is called an inertial force; the product of a moment of inertia and its angular acceleration is called an inertial moment. In a biomechanical analysis, body dynamics need to be considered only when the inertial forces and the inertial moments produced are of magnitudes that are significant when compared with the forces and moments needed for equilibrium (Schultz and Andersson, 1981). If the inertial forces and moments are large compared with the forces and moments that would be required for equilibrium, an activity involving body motion should be analysed as a dynamic activity.

Both static and dynamic biomechanical models are reported in the literature for the analysis of the stresses arising from manual handling. However, static models have been applied more widely because they are simpler to use and usually compare calculated stresses with predetermined capacities of static strength (percentage of population capable) and injury limits (AL and MPL). Until systematic data on dynamic muscle strengths and acceptable limits for compressive force under dynamic conditions becomes available, the use of static biomechanical analysis has a somewhat greater practical utility.

Unfortunately for the analyst, it is rare that a manual handling task is performed entirely within confines of the sagittal (two dimensional) plane. It was therefore necessary to develop a three dimensional model that enables the investigation of axial torque development in manual handling. A three-dimensional static back model was proposed by Schultz and Andersson (1981) that presented procedures to calculate loads on the lumbar spine and the contraction forces in the trunk muscles that are likely to be produced by given physical activities. This was extensively validated through disc pressure measurements (Schultz, Andersson, Ortengren, Haderspeck and Nachemson, 1982b) and recordings of myoelectric trunk muscle activity (Andersson, Ortengren and Schultz, 1980; Schultz, Andersson, Ortengren, Bjork and Nordin, 1982a; Schultz, et al., 1982b). Model predictions of the muscle tensions of several trunk muscles were highly correlated to the measured myoelectric activities in symmetrical work postures. For assymmetric movements in the sagittal plane, the biomechanical model used in these studies predicted loads imposed on the lumbar trunk structures moderately well, but not as well as for tasks that tend only to flex at the trunk. For measured intradiscal pressures and predicted compressions good agreements were found throughout (Andersson, 1985). These three-dimensional whole body spinal motion segment models, however, are presently restricted to static analysis over a limited range of motion, and do not include passive tissue stiffness responses that have recently been shown to be important when modelling the motion segments throughout their ranges of motion (Miller, Schultz, Warwick and Spencer, 1986). Two of the greatest problems in this more advanced form of model are to present spatial data describing the position of each body segment in both time and three-dimensional space, and to intuitively understand the complex vector representations of forces and torques that result from this type of analysis (Chaffin, 1969).

Developments in biomechanical modelling have also incorporated more complex internal load estimations such as strain in the ligaments posterior to the lumbo-sacral joint centre of rotation and strain in the posterior aspect of the outermost layer of the annulus to complement estimations of the moment generation requirement of the trunk erector musculature and compression on the sacral endplate (Anderson, Chaffin, Herrin and Matthews, 1985). Previous models by Andersson, et al. (1980), Cappozzo and Gazzini (1982) and Schultz and Andersson (1981) have included estimates of contraction forces of trunk musculature in relation to the centroid of the vertebrae.

Although plagued by assumptions, the continued development of these models to new levels of sophistication will enhance our understanding of the causation and prevention of injury, particularly in manual materials handling tasks. This is reflected in the increasing diversity of approaches and applications of biomechanical modelling in ergonomics as indicated in current literature by Bloswick and Chaffin, 1987 (ladder climbing), Magnusson, Ortengren and Andersson, 1987 (meat cutting) and Tonnes, Behm and Kilbom, 1987 (load carrying by firefighters). Other approaches such as optimisation of mechanical efficiency (Dutta and Taboun, 1989) and complicated dynamic analysis of symmetrical (Leskinen, Stalhammar, Kourinka and Troup, 1983) and asymmetrical (Mital and Kromodihardjo, 1985) tasks are also becoming more prevelant in the literature.

(C) Bedmaking as an occupational task

Many injuries to the back occur, not because the loads are particularly heavy, but because workers are forced to repetitively adopt postures that are biomechanically unsound. The bedmaking task characteristically involves a series of lifting, pushing, and pulling tasks usually performed in the forward flexed posture. The forward flexed posture is necessitated by the bed position and renders recommended lifting techniques largely impracticable. Workers tend to assume a straight legged and trunk flexed position identified as accounting for higher levels of spinal compression than in leg lifting techniques (Anderson and Chaffin, 1986; Bradbeer, 1984; Leskinen, et al., 1983a). An example of this "awkward" posture is given in Appendix C (based on data form Wiktorin and Nordin, 1986). By comparing the lumbar loads associated with an upright posture and a flexed posture in a hypothetical bedmaking situation, an indication of the potential for injury is gained.

Upright posture

Flexion moment = arm moment + head and trunk moment

where
arm weight= 60 N,
arm moment arm = 0.18 m,
head and trunk weight = 340 N, and
head and trunk moment arm = 0.17 m.

$$= 60(0.18) + 340(0.17)$$

$$= 68.6 \text{ Nm}$$

Extension moment = erector spinae muscle force x erector spinae force arm

where erector spinae force arm = 0.05 m

$$= F \times 0.05$$

In static equilibrium,

$$\text{Flexion moment} = \text{Extension moment}$$

$$68.6 = F(0.05)$$

$$F = 1372 \text{ N}$$

L5/S1 compression = F + force of body weight above L5/S1(cosϕ)

where ϕ = angle formed between the vertical and the inclination of the trunk.

= 1372 + (60 + 340)cos 30

= 1372 + 346

= 1718 N

L5/S1 shear = force of body weight above L5/S1(sinϕ)

= (60 + 340)sin 30

= 200 N

Flexed posture

Flexion moment = arm moment + head and trunk moment

where arm moment arm = 0.67 m, and

head and trunk moment arm = 0.31 m.

= 60(0.67) + 340(0.31)

= 145.6 Nm

Extension moment = erector spinae muscle force x erector spinae force arm

= F x 0.05

In static equilibrium,

Flexion moment = Extension moment

$$145.6 = F \times 0.05$$

$$F = 2912 \text{ N}$$

L5/S1 compression = F + force of body weight above L5/S1($\cos\phi$)

$$= 2912 + (60 + 340)\cos 70$$

$$= 3049 \text{ N}$$

L5/S1 shear = force of body weight above L5/S1($\sin\phi$)

$$= (60 + 340)\sin 70$$

$$= 376 \text{ N}$$

These figures do not include the contribution of a hand load and reveal how the extreme postures inherent in bedmaking result in musculoskeletal stresses far beyond those found in the recommended upright lifting postures. Of particular interest are the lumbosacral compression and shear forces associated with the two conditions. Compression was increased from 1718 N to 3409 N and shear forces from 200 N to 376 N simply by varying body position. It is important to note that the compression associated with the flexed condition is comparable with the NIOSH Action Limit of 3430 N beyond which the likelihood of injury is increased. By adding a load to the hand, an acceleration, or even a twisting motion, it is not difficult to recognise the potential for injury in the performance of this work task.

Recent literature published in bedmaking or allied areas of manual handling has concentrated on the handling of patients by nursing aides. Nursing aides are a group of workers that provide basic and non-medical patient care who are particularly liable to lower back injury. The risk factors for this type of injury appear to be associated with the handling of patients and, more specifically, in lifting patients with the trunk flexed forward (Delhin, Hedenrud and Horal, 1976). An ergonomic study by Lortie (1985) indicated that activities involving a horizontal effort such as turning patients in bed were more likely to increase the risk of injury especially in view of the flexible nature of the load. This may have implications for the work performed by linenmaids as the work posture, position of the load relative to the body, nature of the load and direction of effort involved in patient handling closely resemble those in bedmaking.

Numerous studies have been conducted that attempt to quantify the lumbar stress inherent in the common work tasks performed by nursing aides (Gagnon, Akre, Chehade, Kemp and Lortie, 1987a; Gagnon, Chehade, Kemp and Lortie, 1987b; Gagnon and Lortie, 1987; Gagnon, Sicard and Drouin, 1985; Gagnon, et al., 1986; Khalil, Asfour, Marchette and Omachonu, 1987b). Other studies have taken the form of accident analysis (Jensen, 1987; Skovron, Nordin, Torma-Krajewski, 1987; Sterling and Mulvihill, 1987; Venning, 1987), work analysis (Takala and Kukkonen, 1987; Wachs and Parker, 1987) or the assessment of training programs (Prezant, Demers and Strand, 1987; St-Vincent, et al., 1987). This research, summarised and appraised by Lortie, et al. (1987), has confirmed the existence of risk factors in certain aspects of patient handling and provided recommendations for modification of current work practices. For example, Owen (1987) suggests that attention should be given to the confined work space and to the work surface as the load cannot be held close to the body because of the width of the bed; the knees cannot be flexed due to the position of the side rail; the best height for lifting cannot be achieved because some beds are not adjustable; and the feet cannot be placed shoulder width apart because of the confined workspace. As beds have been designed for the comfort and safety of the patient with little regard for the nursing staff, it was suggested that nurses and engineers work together to apply ergonomic principles to job design, workplace design and the environmental factors associated with nursing tasks.

Little specific information is available on the occupational health problems of the lumbar spine associated with working in the forward flexed position. This is surprising because of the large number of tasks that utilise this position and the attendant costs to employee, employer, and insurance organisations of any injury resulting from poor working conditions. The recently published discussion paper and Draft Code of Practice for Manual Handling (Worksafe Australia, 1987) concentrated primarily on lifting, lowering, and carrying and paid little attention to working in the forward flexed posture. In addition, it focused on fixed, rigid loads (containers) and provided little guidance for the handling of flexible loads as in bedmaking.

The Worksafe document (1987) does however make reference to "abated action levels" for load lifting. Preliminary investigations of the bedmaking task based on still photographs resulted in stresses at or in excess of these guidelines. The most recent Draft National Standard and Draft Code of Practice for Manual Handling (Worksafe Australia, 1989a) reports evidence to suggest that in working postures other than when seated the risk of back injury increases significantly where objects above the range 16-20 kg (156.8-196.0 N) are being handled. Also, variation from the ideal lifting method, low working heights, lift frequency, lift duration, prolonged bending, and the physical capacity, skill and experience of the worker, are mentioned as possible risk factors that may be pertinent to the bedmaking task. It is possible an accumulation of these factors may combine to increase the risk of injury, particularly to the low back during bedmaking. Similarly, Action Limits based on the National Institute for Occupational Safety and Health's Work Practices Guide to Manual Lifting (1981) indicate that spinal loads in the lower and larger bed conditions may be exceeded.

While there is no statistical or epidemiological data available to support a recent increase in the incidence of injury, these factors provide an intuitive justification for the investigation of this disadvantaged work situation. Furthermore, as an insight into the forward flexed manipulation of a non-rigid load may have implications for the understanding of stresses imposed on the lumbar spine in a number of similar work situations (such as patient handling by nursing aides), further investigation is warranted.

(D) Measurement of spinal loads in bedmaking

Biomechanical models of varying complexity have been used in the assessment of lumbar stress (Gracovetsky, Farfan and Lamy, 1977; Schultz and Andersson, 1981). These models have been largely restricted to the analysis of static postures incorporating the lifting of free loads such as in bedmaking. However, to facilitate an understanding of the potential dynamic aspects of bedmaking, it was necessary to develop an experimental design that would combine a static biomechanical model of the whole body to estimate loads particularly at the L5/S1 level with a variety of kinesiological motion analysis techniques.

In order to measure the spinal loads during bedmaking using contemporary methodologies, it was necessary to reduce the task to a series of more readily quantifiable components. For the purpose of this study these comprised the tasks of "bedding-on", "bedding-off", "lifting the mattress", and "pushing" and "pulling the bed sideways" (for three different bed size and two bed height conditions). The heavy loads and relatively long time periods involved in accomplishing these movements provided the basis for the assumption that inertial forces acting were negligible. For a biomechanical analysis, body dynamics need only be considered when the inertial forces assume significant magnitudes when compared with the forces and moments needed for equilibrium (Chaffin and Andersson, 1984). It was believed that the particular body motions that were the focus of this study could safely be considered quasi-static activities as only small changes delineated successive body positions. Further to this, three-dimensional biomechanical models of human task performance are complex and limited in defining and describing the motion of a model's components. As a consequence, the biomechanical model chosen was planar (sagittal) and static. Rotation or lateral deviation could not be accounted for using this modelling approach.

The Two Dimensional Static Strength Prediction Program (Version 4.0) developed by the Center for Ergonomics at the University of Michigan (1989) was selected for use on the basis of its extensive applications in studying the effect of load and posture on lumbosacral disc compression and its capability for computing strength moment limits at each joint. It was based on 22 years of research concerning the biomechanical and static strength capabilities of the employee in relation to the physical demands of the work environment. The model took account of such factors as (i) instantaneous body segment positions, (ii) curvature changes in the spine, and (iii) the force due to intra-abdominal pressure. Internal forces (compression and shear at L5/S1) were determined from free-body diagrams using static Newtonian equations.

The biomechanical model treated the body as a series of five rigid links from which the reactive forces and torques were computed for each articulation (ankle, knee, hip, shoulder, and elbow) based on input describing the external forces (due to body weight and hand held load). According to Chaffin (1975a), up to 95% of all serious back injuries occur at L4/L5 and L5/S1. Since the L5/S1 disc incurs the greatest moment in lifting, compressive and shear forces at this level were investigated.

Three sets of input data were required to describe the bedmaking task. These included the external force at the hand, instantaneous body segment positions and the anthropometric characteristics of each subject.

It is customary for the weight of the hand held load (ie. the product of its mass and the acceleration due to gravity) to comprise the input into a static biomechanical model when describing the external force exerted against the hand. This would be entered into the program as a vector acting at the distal end of the link representing the forearm-hand aggregate in a direction opposing the motion. However, this approach is known to severely underestimate the demands of certain dynamic lifts. As dynamic modelling is often prohibitively expensive and very time consuming, McGill and Norman (1985) proposed a method whereby the inertial forces of the load and the load weight were incorporated into an otherwise static model. This quasi-dynamic approach produced peak lumbar moments in excess of the full dynamic model by approximately 25%. While accepting that if the accelerations of the load dominate the system, the dynamic interactions of the body segments may be neglected in the low back moment calculation, the authors concluded that a conservative assessment of injury risk was indicated with this method.

Instantaneous body segment positions were described as angles subtended by the relevant segment and the horizontal and were empirically determined using photographic records. Recent developments in video and computer technology allow instantaneous segment endpoint locations to be scanned and transferred directly to a static or dynamic biomechanical model for analysis (DeGreve, 1987).

The body measurements needed as model input data were body stature and body weight. From these, the link lengths (i.e.

the straight line distances between articulations) were estimated based on the empirical relationships developed by Dempster, Sherr and Priest (1964). Each of the links in the model was considered to have a mass estimated from proportionality constants (Drillis and Contini, 1966) with distribution of the mass within each link based on the data of Dempster (1955).

To perform an analysis of lumbar spinal stress, the geometry of the erect spinal column and the contribution of intra-abdominal pressure were considered. The geometry of the average erect spinal column and pelvis were developed from the dimensions of Fick (1904), Lanier (1939) and Chaffin, Schultz and Snyder (1972). Proportional scaling of the hip-to-shoulder distances enabled the study of smaller or larger individuals. From this a hip joint-to-L5/S1 link length comprising 20% of the hip-to-shoulder distance was established. The superior surface of the sacrum was estimated to be at an angle of 40 degrees from the horizontal when standing erect (Theime, 1950). The curvature change for the column during sagittal rotation of the hips was assumed from the data of Dempster (1955) which disclosed that for the first 27 degrees of trunk flexion the pelvis does not rotate (i.e. rotation is from lumbar spine) and that for each additional degree of trunk rotation the pelvis contributes about two-thirds of a degree. Also, it was assumed that 22-29 per cent of lumbar rotation occurs at the L5/S1 and L4/L5 discs respectively (Allbrock and Uganda, 1957; Davis, Troup and Burnhard, 1965; Lindahl, 1966; Rolander, 1966). Regretably, Leskinen, Takala and Stalhammar (1987) reported that there was no universal rule that could be used to predict the co-ordination between lumbar and pelvic movements for both lifting and lowering, and such a rule would be misleading when different individuals were considered. However, Kippers and Parker (1989) found that modelling the thoracolumbar vertebral column as a single segment allowed better estimation of lumbar intervertebral angular change than a three segment model. This simplified approach enhanced the user-friendliness of the current model.

The contribution of intra-abdominal pressure in relieving compression on the lumbar spine was estimated from the data of Morris, et al. (1961). This estimation comprised a least squared error expression that considered IAP to be a function of hip angle and torque. Additional compressive forces on the lumbar spine due to the abdominal muscles were assumed negligible. Abdominal pressure was thereby attributed to the oblique and transverse muscles which were not well positioned to contribute toward sagittal flexion or extension of the trunk. Fisher (1967) reported a correlation coefficient of 0.73 for this expression and attributed the error to uncertainty regarding the exact position of the trunk and an inability to assess the time rate of force application. Peak pressures for rapid lifts have been recorded that exceed the pressures in sustained lifting by up to 20% (Asmussen and Poulsen, 1968). A limit of 150 mmHg was consistent with pressures measured in those who regularly lift weights.

The amount of force created by IAP was estimated by assuming the following three conditions which were similar to those proposed by Morris, et. al. (1961): (i) a diaphragm area of 465 cm^2 and a pelvic area of 517 cm^2 upon which the abdominal pressure can act, (ii) the line of action of the force acts parallel to the line of action of the normal compressing forces on the lower lumbar spine, and (iii) the forces act through finite moment arm distances from the centres of the discs. The moment arms have been assumed to vary as the sine of the angle at the hips, with the erect position having moment arms of 6.2 cm at the pelvis and 6.7 cm at the diaphragm level, and the 90 degree hip angle position having 13.7 cm at the pelvis and 14.9 cm at the diaphragm (Chaffin, 1969).

The average moment arm of the erector spinae muscles was assumed to be 5cm (Bartelink, 1957; Munchinger, 1962; Perey, 1957; and Theime, 1950) with its line of action parallel to the normal compressive force on the vertebral disc interface. This estimation is contentious in view of recent findings by Nemeth and Ohlsen (1987) suggesting 61 mm was a better estimation based on Computed Tomography (CT) techniques. However, in the context of a comparative study, this disagreement was incidental as a relative assessment of spinal stress was still valid. The estimate of the magnitude of the muscle force required to maintain a particular trunk position against the gravitational forces that act on the body masses and any mass being held in the hands was accomplished by dividing the estimated torque at the centre of the two discs (L4/L5 and L5/S1) by the 5 cm moment arm assumed for the back muscles (Chaffin, 1969).

Analysis of loads that the lumbo-sacral joint might be subjected to in the course of bedmaking cannot be considered complete without a concurrent study of other joints. It is possible that performance of a given task may reduce loads on the spine but increase loads on other joints such as at the shoulders (Gagnon, et al., 1987b). This was achieved in the present study by way of dynamography and electromyography.

A force platform mounted level with the floor permitted the measurement of the three orthogonal forces and moments exerted on the platform during the execution of a given task. The forces exerted by the feet against the ground were of major interest in bedmaking as they indicated the dynamic effects of loading. Of particular interest in this study were the vertical and horizontal ground reaction forces exerted against the platform. In the manner of Leskinen, Stalhammar, Kourinka and Troup (1983a), it was believed that an increase in these forces was indicative of increased stress upon the musculoskeletal system.

Electromyography was used to assess the level of activity and activation patterning of selected muscles implicated in the bedmaking task. Due to the potential for injury to the upper arms during the bedmaking task, this particular problem was partially explored in this investigation using EMG recordings of the anterior deltoid muscle (active in shoulder joint flexion), supplementing the EMG data on the erector spinae, rectus abdominus, and oblique externus muscles.

Although not the focus of this particular study, an additional model output indicated the percentage of the population capable of sustaining moment eqilibrium at each joint according to specific external loading conditions.

Muscular strength appeared to be the primary limiting factor in many common exertions (Andersson and Schultz, 1979). Consequently, static strength prediction was based on the assumption that the moments created at each joint due to the application of the load on the hands and body during manual materials handling must have been less than or equal to the muscular moment strengths at each joint.

The moments at each joint were determined for equilibrium conditions for given postures, anthropometry, and external loads. The muscle produced moment strengths were obtained by refering to population values that have been developed for most major muscle functions (Stobbe, 1982). These values are known to vary according to joint angle. Furthermore, for muscles that span two joints, the angle at adjacent joints must also be considered. Clarke (1966), Schanne (1972), and Burggraaf (1972) have developed prediction equations for mean joint moment strength as a function of joint angle for males and females in the sagittal plane.

By setting the predicted mean strength equation equal to the load moment at a particular joint, the average lifting capacity in that posture could be predicted. An example of this process is given by Chaffin and Andersson (1984). The computer prediction model used in this study included the strength capabilities of over 3000 industrial workers (Anderson and Chaffin, 1986) measured for a large number of muscle groups. From this the predicted muscle moment requirement for bedmaking could be interpreted in relation to the distribution of muscle moment production capabilities for male and female working populations. The comparison is presented in terms of the percent of each population capable of the required moment for each muscle group and in relation to the AL and MPL defined by NIOSH (1981). The model results correlate with average population static strength at r = 0.8.

(E) Summary

In view of the concerns held by a representative group of linen-maids working in the Hospitality industry over the safety of current work practices, it would seem important to assess the nature of these claims before additional changes are implemented on a wider scale, particularly since they involve the introduction of larger and heavier loads positioned lower to the ground. A standardised biomechanical methodology aimed at quantifying loads on the human musculoskeletal system during manual materials handling has been well documented in the literature. It was foreseen that the evaluation of these loads would have important implications for the development of preventive measures and the institution of safer work practices in the hospitality industry.

CHAPTER III

METHODS AND EXPERIMENTAL PROCEDURES

In order to estimate the forces on the musculoskeletal system and to examine the extent of muscular involvement of selected muscles implicated in bedmaking, a mathematical model was selected and used in conjunction with motion analysis techniques. The experimental procedures were as follows:-

(A) Subjects

Twelve female undergraduate students enrolled in Human Movement Science at The University of Wollongong volunteered as subjects for this study. Each subject was required to provide a written informed consent (Appendix G) prior to participating in the proposed project. Subject ages ranged from 18 to 34, with a mean age of 21.7 ± 4.9. All subjects were in good health at the time of the experiment and had no previous history of low back pain or other physical impairment.

(B) Experimental conditions

The experimental phase of this study was conducted in the Biomechanics Laboratory at The University of Wollongong. The act of bedmaking was reduced to five discrete tasks assumed to represent components of bedmaking associated with the greatest potential for excessive lumbar stress. These tasks were defined in consultation with an experienced linen maid and comprised:-

"Bedding-on":

The motion used to apply a blanket (equally with both hands) to a bed when standing with both feet on a force platform alongside the bed at its midline. The blanket was placed on the near side of the bed (unfolded and gathered along its long axis) prior to each trial, gathered by the subject and then applied using a symmetrical upward and outward flicking action that allowed the blanket to settle over and covering the mattress.

Figure 1. Subject performing the task of "bedding-on"

"Bedding-off":

The motion used to completely remove a sheet (equally with both hands) from a bed when standing with both feet on a force platform alongside the bed at its midline. The sheet was "tucked in" on all four sides and removed using a self-selected hand placement using a symmetrical lifting action.

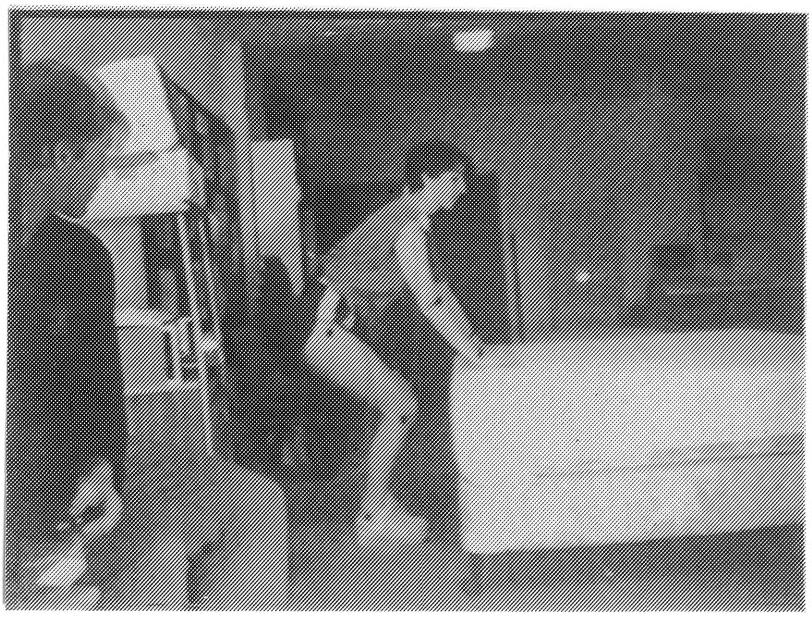


Figure 2. Subject performing the task of "bedding-off"

<u>"Lifting the mattress"</u>:

Gripping the corner of the mattress (from beneath) with the right hand and lifting it to a height of approximately 200 mm while simultaneously tucking a sheet in with the left hand using a horizontal sweeping motion while standing on a force platform.

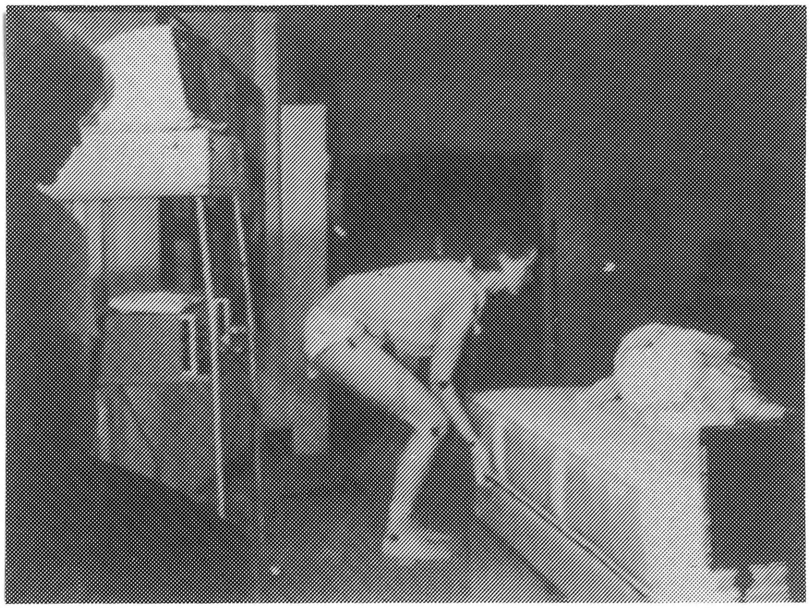


Figure 3. Subject performing the task of "lifting the mattress"

"Pulling the bed sideways":

Hands grip underneath the long side of the bed base adjacent to its corner. Bed is pulled approximately 400 mm with the subject's feet remaining on the force platform.

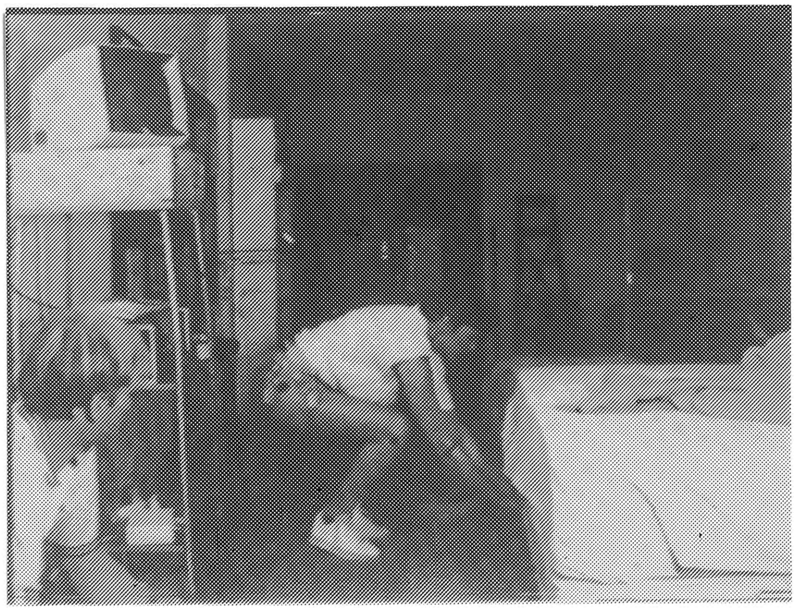


Figure 4. Subject performing the task of "pulling the bed sideways"

"Pushing the bed sideways":

Hands are placed against the long side of the bed base (palms facing down) adjacent to the corner. Bed is pushed equally with both hands a distance of approximately 400 mm with subject's feet remaining on the force platform.

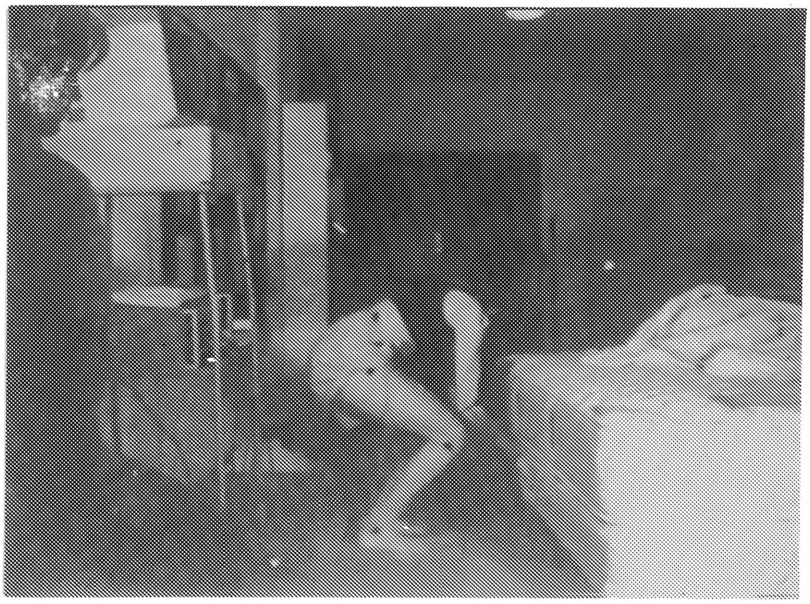


Figure 5. Subject performing the task of "pushing the bed sideways"

These tasks were administered for three bed sizes (single, double, and queen) and two bed heights (560mm and 460mm). The mass characteristics of beds for domestic use are described below.

Table 1: Mass characteristics of beds used in the study (kg)

Bed size	Bed	Bedding	Total
Single	44.8	6.0	50.8
Double	58.7	10.0	68.7
Queen	75.8	15.0	90.8

The beds used in this study were maufactured for domestic use and were provided with legs and casters to produce a working height of 560 mm. Beds for the hospitality industry tend to be heavier (due to a requirement that fire-proofing material must be incorporated into the mattress) and lower (460 mm). The bed height differential used in this study arose as casters only were provided for beds used in the hospitality industry, mainly because bed legs tend to increase the liklihood of damage.

The order of testing was randomised to offset the possible effects of learning and fatigue. This was achieved by assigning random numbers between one and six to each bed condition and random numbers between one and five to each task for each subject. If, for example, the random number "1" was assigned to the double low-bed condition, this would be the first bed condition for analysis for that subject. The order of tasks performed for this condition was then determined from the random numbers allocated to the five bedmaking tasks under investigation.

For the tasks of "bedding-on", "bedding-off", and "lifting the corner of the mattress", the side of the bed was aligned with the side of the force platform. This enabled the subject to assume a comfortable position while remaining on the force platform for the duration of the task. When "pulling the bed sideways", the starting position for the bed was 400 mm away from the side of the force platform. The task was completed by pulling the bed so the near corner was aligned with the side of the platform (positions indicated by adhesive tape on floor). This process was reversed for the bed pushing task. Task familiarisation was achieved by providing each subject with written definitions of each task (as above). The subject was asked to demonstrate each task to the investigator prior to recording. This allowed the subjects to become familiar with the instrumentation, ask any questions regarding the procedure, and reduce anxiety. No time criterion were set which allowed the subjects to perform each task at their chosen speed. Inconsistent movements were screened such that data from incomplete or non-planar trials were discarded. Verbal feedback was given to the subjects after each trial regarding task performance criteria.

(C) Data collection and analysis procedures

Three seperate methodologies were used to quantify the musculoskeletal stress associated with bedmaking. These were (i) biomechanical modelling of lumbosacral compression and shear forces; (ii) measurement of vertical and horizontal ground reaction forces; and (iii) measurement of myoelectric activity of selected muscles implicated in each task. The following section introduces these methods, data synchronisation techniques and the statistical procedures employed.

(i) Biomechanical modelling

The Static Strength Prediction Program developed at the University of Michigan (1989) was used for analysis of the bedmaking task. The model is two-dimensional (sagittal) and quasistatic (inertial forces assumed zero). For each point in the lift the model required input describing the load vector at the hands and the posture and anthropometry of the subject. These were determined as follows:-

Load vector at the hands

A motor-driven 16 mm LOCAM Model 5001 intermittent pin registered camera with an Angenieux (f = 2.2) 12-120 mm lens was used to record the motion of the load during the initiation phase of each trial for a single subject.

The camera was positioned three metres from the subject so the optical axis of the lens was perpendicular to the motion being filmed and was operated at 50 frames per second with a shutter opening of 120 degrees (3 factor shutter), producing an exposure time of 1/150th second. A camera height of one metre minimised perspective error and ensured that landmarks were clearly visible. Kodak ASA 100 film (400 ft per roll) was used in conjunction with three halogen artificial light sources positioned adjacent to the camera. The camera was started approximately one second prior to each task performance to ensure that it had reached the desired film speed prior to filming the motion.

The film image of each trial was projected onto a PCD Digitiser analysis screen using a Vanguard (Model M-16CW) projection head. The x and y coordinates of the landmark representing the point of application of the hand held load were digitised frame by frame. This landmark was indicated by black landmark paint on the medial and lateral metacarpal heads of the right hand and ensured that the landmark was visible in pronated and supinated forearm positions. To ensure that the coordinates were accurately determined, a stationary reference point in the field of view of the camera was digitised for each frame analysed.

Approximately 25 frames were analysed per trial starting several frames before any discernable movement of the load could be detected. Data were recorded, stored and analysed on a President AT personal computer with 20 Megabyte hard disk using a custom-built DIGIPLOT digitising software. Displacement data were plotted and smoothed using a second order Butterworth recursive digital filter with a cut-off frequency set arbitarily at 10 Hz. Linear accelerations were determined from the change in velocity data over a 0.02 second time interval.

This enabled the linear accelerations of the load during the initiation phase of each task to be determined and were assumed to be representative data. Maximum horizontal accelerations were determined for "bedding-on" and "pushing" and "pulling" tasks. Maximum vertical accelerations were used to describe the motion of the load for the tasks of "bedding-off" and "lifting the mattress".

The mass of each load was directly measured for "bedding-on" (mass of blanket) and for "pushing" and "pulling" tasks (mass of bed plus bedding). A spring balance was used to determine the force necessary to lift the corner of the mattress to a height of 200 mm and to dislodge a sheet that was firmly "tucked in" using a vertical lifting motion ("bedding-off").

The external forces at the hands due to manipulation of loads were determined as the product of the mass being manipulated and the accelerations of the load during the initiation phase of the movement. This constituted a quasi-dynamic approach to biomechanical modelling and offset the limitations of a static model to some extent.

Postural data

The instantaneous positions of the trunk and extremities for each subject during each trial were recorded using a National Panasonic (NVM7) high shutter speed video camera. The location of the equipment remained fixed throughout the experiment.

Segment endpoints were located and highlighted with 3 cm black painted squares according to the following definitions:-

Cervical spine:	Vertebrae prominens (7th cervical vertebrae).
Shoulder:	Lateral aspect of acromium process.
Elbow:	Centre of circular band through olecranon and transverse anterior fold.
Wrist:	Centre of circular band joining radial and ulnar styloid processes.
Hip:	Most lateral projection of greater trochanter.
Knee:	Lateral femoral condyle.

Ankle: Most lateral projection of lateral malleolus.

For the duration of the testing, the subjects wore minimal clothing (a sleeveless midriff top, fitted training brief and sports shoes without socks) to facilitate landmark identification.

The video image for each trial was displayed on a Sony 60 cm flat screen playback unit using a National VHS video system. The still frame advance facility was used to identify the posture with the greatest degree of trunk and spinal flexion during the execution of each task that coincided with the initiation of the movement. This position was chosen for analysis as a result of its proposed association with peak loads on the lumbar spine. Landmarks representing the endpoints of the trunk and limb segments were manually transcribed onto transparencies using a felt tip pen.
A stick figure representation of the subject was constructed according to the following link system definitions:-

Shank link: The straight line between the knee and ankle.

Thigh link: The straight line between the hip and knee.

Torso link: The straight line between the seventh cervical vertebrae and the hip.

Upper arm link: The straight line between the shoulder and the midpoint of the circular band surrounding the elbow.

Lower arm link: The straight line between the elbow and the midpoint of the circular band surrounding the wrist.

Vertical and horizontal reference axes were constructed on the screen and the surface used for angular measurements to ensure all trials were processed in the same fashion. The transparencies (which were perfectly rectangular) were positioned squarely against both axes when transcribing the segment endpoints and measuring segment angles. Horizontal reference lines were placed beneath the tranparencies to facilitate the measurement process. Each angle was measured three times and a representative mean value determined.

The following kinematic variables were manually determined for each trial using a protractor.

1. Lower arm angle
2. Upper arm angle
3. Torso angle
4. Upper leg angle

5. Lower leg angle

These angles constituted input for the biomechanical model and refer to the angle subtended by the relevant body segment and the horizontal (see Appendix H for error estimates).

Anthropometric characteristics

The anthropometric characteristics required as input to the model were the height and weight of each subject. Height was determined using a stadiometer and weight using electronic scales (accurate to 0.01 kg). All measurements were taken with subjects in footwear and light clothing to represent actual working conditions.

The outputs analysed as part of this study were L5/S1 compressive and shear forces. The model estimates these as follows:-

The moment at the hip (M_H) was expressed as a function of the moment due to body weight above the level of the hip (M_{BW}) and the moment arising from the hand-held load (M_L). A diagrammatic representation is given in Appendix F.

$$\begin{aligned} M_H &= M_{BW} + M_L \\ &= b'mg_{BW} + h'mg_L \end{aligned}$$

where b' is the horizontal distance from hip to centre of

gravity of body weight above hip; and
h' is the horizontal distance from hip to centre of gravity of hand-held load.

The hip moment was then used to predict the intra-abdominal pressure (IAP) created when the diaphragm and muscles of the abdominal wall contract. The empirical prediction equation is:-

$$IAP = 10^{-4} [43-0.36(\phi'H + \phi'T)][M_H^{1.8}]$$

where IAP refers to intra-abdominal pressure (mm of Hg),
ϕ'H and ϕ'T respectively describe the position of the hip and thigh relative to the vertical axis (degrees), and
MH is the load moment at the hip (Nm).

The amount of force (F_A) created by the IAP was estimated according to (i) an average diaphragm area of 465 cm^2 upon which the pressure can act, and (ii) a line of action of the force that acts parallel to the line of action of the compression forces on the lower lumbar spine. The moment arm of the force F_A was assumed to vary as the sine of the angle at the hips ϕ'H. The moment arm varied from 7 cm when standing erect to 15 cm when stooped at 90 degrees from the vertical (See Appendix E for a diagrammatic representation). Therefore,

$$F_A = IAP \times Area$$

where F_A is the force created by IAP (N);
IAP is the intra-abdominal pressure created in the abdominal cavity (Ncm^{-2}); and
Area refers to the average diaphragm area on which the IAP can act ($465\ cm^2$).

In order to estimate the compressive and shear forces on the lumbar spine it was necessary to make several assumptions. Although the rectus abdominus muscle could produce a spinal compressive force, its contribution was assumed negligible due to its relative inactivity during lifting (Stalhammar, Leskinen and Takala, 1987). Secondly, the line of action of the erector spinae muscles were assumed to act parallel to the compression on the L5/S1 disc with a moment arm of 5.0 cm.

The moment equation for equilibrium at L5/S1 is:

$$\Sigma M_{L5/S1} = 0$$

$$b(mg_{BW}) + h(mg_{LOAD}) - D(F_A) - E(F_M) = 0$$

To solve for the unknown muscle force F_M, the equation can be rearranged as follows:

$$F_M = \frac{b(mg_{BW}) + h(mg_{LOAD}) - D(F_A)}{E}$$

where F_M is the erector spinae muscle force necessary to stabilise the spine (N),

b, h, D, and E are the moment arms of the respective forces (cm),

mg_{BW} is the weight of the body above the L5/S1 level (N),

mg_{LOAD} is the weight of the load in the hands (N), and

F_A is the force due to abdominal pressure acting at the centre of the diaphragm (N).

The forces acting parallel to the disc compression force can be expressed by:

$$\Sigma F_{COMP} = 0$$

The reactive force of compression (FC) is therefore given by:

$$\sin\delta mg_{BW} + \sin\delta mg_{LOAD} - F_A + F_M - F_C = 0$$

This can be rearranged to give:

$$F_C = \sin\delta mg_{BW} + \sin\delta mg_{LOAD} + F_M - F_A$$

The reactive shear force (F_S) across the L5/S1 disc can be solved using:

$$\Sigma F_{SHEAR} = 0$$

ie., $\cos\delta mg_{BW} + \cos\delta mg_{LOAD} - F_S = 0$

Therefore,

$$F_S = \cos\delta mg_{BW} + \cos\delta mg_{LOAD}$$

Though highly simplistic, the preceding model of the low back is of assistance in predicting the relative forces on the low back when lifting various loads in front of the body (Chaffin and Andersson 1984).

(ii) Forces beneath the feet

A Kistler (Type 9281) force platform (600 x 400 mm) was used to measure the horizontal and vertical components of the external forces under both feet for all tasks. The platform was bolted to the concrete floor with its surface flush with four square metres of customboard false flooring. The surface (including the platform) was covered by synthetic carpet squares on which the beds were placed. Data from four channels were recorded and stored on a President XT personal computer. The four channels represented the three orthogonal components of ground reaction force and the trigger generated pulse used to synchronise force, film and EMG data.

Data were collected at a frequency of 100 Hz for a period of 5 seconds using the custom-built DATALOG (Version 1.1) force platform data logging program. This enabled output to be expressed as force-time histories and calculated peak force values for each channel (expressed in Newtons). Of particular interest were the Peak Vertical Ground Reaction Forces (PVGRF) and the Peak Horizontal Ground Reaction Forces (PHGRF). It was assumed that larger PVGRF of PHGRF values were indicative of higher levels of musculoskeletal stress when comparing within and between tasks.

PVGRF's are descriptive of tasks involving a vertical effort as in lifting. The PHGRF refers to forces in the anterio-posterior direction and were especially pertinent in pushing and pulling tasks. Horizontal ground reaction forces in the medio-lateral direction were not considered as part of this study.

(iii) Myoelectric activity

Myoelectric activity (EMG) from four muscle sites was recorded using bi-polar surface electrodes (Meditrace Ag/AgCl pellet electrodes) with an inter-electrode distance of 12 mm (in anatomical position). The skin was prepared by way of shaving the electrode placement site, cleansing with alcohol and light abrasion. Electrodes were placed bilaterally over the following muscles:-

erector spinae (ES):	3 cm lateral from the mid-line at the L3 level;
rectus abdominus (RA):	3 cm lateral to the umbilicus;

obliquus externus (OE): 5 cm anterior and 3 cm lateral to the anterior superior iliac spine (ASIS); and

anterior deltoid (AD): on the anterior head midway between acromion process and deltoid tuberosity.

Electrode placement was on the subject's right hand side and parallel with the direction of fibres for each muscle.

Earth electrodes for the trunk muscles were placed on the contralateral anterior superior iliac spine. The earth electrode from the deltoid was located over the ipsilateral clavicle. Preamplifiers were taped to the skin adjacent to each set of electrodes.

Mean rectified EMG signals were amplified and filtered with a 15-1000 Hz band pass filter using a HUMTEC 100 isolated differential amplifier. Data were sampled at a frequency of 200 Hz for a period of 3000 milliseconds using a WASP interface card and stored on a President XT personal computer with a 20 Megabyte Hard Disk Drive.

The myoelectric potential for Maximum Voluntary Isometric Contraction (MVIC) was determined as follows:-

The anterior deltoid was activated in 45 degrees of shoulder joint flexion against maximum manual resistance applied against the wrist. The erector spinae was activated in 45 degrees of forward fexion using a back strength dynamometer adjusted so that the lower limbs could not actively contribute to torque development. It was believed that these angles closely resembled those assumed in bedmaking.

The determination of MVIC for rectus abdominus and obliquus externus followed procedures proposed by Ekholm, Arborelius, Fahlcrantz, Larsson and Mattsson (1979). To activate rectus abdominus, the subject assumed a symmetrically supine position with knees flexed to 110 degrees, feet fixed, trunk raised (curled-up) from the floor to 30 degrees and the arms elevated forward. Maximum manual resistance was applied to the shoulders in the sagittal plane during the contraction. The test position for obliquus externus combined the position for rectus abdominus with lateral rotation to the right and left sides with the upper limbs directed toward the hip and maximum manual resistance applied diagonally to the shoulder.

There was no training of these movements prior to the test, but all subjects received standardised information before the experiment. Specifically, the subject was asked to apply a maximal force against the set resistance for a period of 3 seconds. One investigator was responsible for all instruction and provided the manual resistance for all recordings.

Mean rectified EMG data files for each task were converted to integrated waveforms (IEMG) over 10 millisecond intervals using the Waveform Analysis Package (WASP) Version 2.0 (University of Queensland, 1986). The maximum IEMG interval (V.ms) was the parameter chosen to quantify the muscular contribution in bedmaking as it was believed by the investigator to best represent possible peak load situations. Because the signal offset cannot be removed from an intergrated waveform by the WASP program, this was achieved by sampling the baseline IEMG activity prior to the commencement of each task and removing it from the maximum IEMG bin. This baseline value was determined by averaging values obtained from approximately 15 randomly selected trials.

In order to compare EMG activity between different muscles and different individuals, myoelectric potential recorded during the experiment was then expressed as a percentage of previously recorded activity for a Maximum Voluntatry Isometric Contraction (%MVIC).

(iv) Synchronisation of data

Synchronisation of force and EMG data was accomplished using a manual trigger that initiated the WASP data collection program and transmitted an electrical pulse that was recorded on a specific channel on the DATALOG force platform data logging program. This coincided with a flashgun placed in the foreground of the film area emmitting a flash that provided synchronisation with film data.

(E) Statistical procedures

A three factor analysis of variance (ANOVA) was used to test the effect of the independent variables (task, bed size and bed height) on the dependent variables (L5/S1 compression and shear forces, peak vertical and horizontal ground reaction forces and EMG activity of selected muscles) using the Genstat 5 Statistical Package (1987). HGRF's were considered in a seperate ANOVA as they were pertinent to pushing and pulling tasks only. The subject factor was blocked and histograms of the residuals were checked for normality prior to proceeding with the analysis. Additional descriptive statistics were determined using the StatView 512+ statistical package (Brainpower, 1986).

Post-hoc two sample t-tests were conducted manually to determine specific differences between groups.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter contains results and discussion based on statistical analysis of the data collected in the study. It is presented in four sections comprising: (A) characteristics of the sample, (B) kinematics and kinetics of the hand-held loads in bedmaking, (C) the effect of bed size on the dependent variables, and (D) the effect of bed height on the dependent variables.

Electrocardiographic (EKG) contamination of torso electromyographic signal prevented the quantification of EMG activity arising from rectus abdominus and obliquus externus. Redfern (1987) proposed a method for removing the EKG component from the processed EMG signal in order to give a better representation of the electrical activity of the muscle. However, this technology was not available at the time this research was conducted. In studying patient handling by nursing aides, Gagnon, et al. (1980) demonstrated that the EMG activity for obliquus externus and rectus abdominus was generally low and used this as a justification for the decision to omit these muscles from their static planar biomechanical model. Given the similarity of tasks analysed with those in the current study it is reasonable to assume that these findings would have been replicated. Although qualitative observations of EMG for rectus abdominus and obliquus externus indicated increased activity in pushing tasks, quantitative analysis of EMG activity during bedmaking was restricted to the erector spinae and anterior deltoid muscles.

(A) Characteristics of the sample

The age, height and weight characteristics of the subjects participating in the study are presented in Table 2.

When compared to the values for the "reference women" defined by Behnke and Wilmore (1974), these subjects were on average 4.0 cm taller and 5.2 kg heavier.

(B) Kinematics and kinetics of hand held loads

The accelerations presented in Table 3 were determined from averaging three trials at each bed condition for one subject and were assumed representative for all subjects.

Results indicated that acceleration of the load was independent of bed size and bed height.

The mass of the hand-held load for each task and bed condition combination is given in Table 4. These were determined by direct weighing of the load using electronic scales or by using a spring balance for lifting tasks.

Table 2: Age, height and weight of subjects.

SUBJECT	AGE (YEARS)	HEIGHT (CM)	WEIGHT (KG)
MW	24	163.5	64.48
WG	34	163.0	60.18
AM	21	175.2	73.74
RH	18	157.9	71.06
AW	18	156.4	51.20
PA	20	167.7	53.90
AK	19	159.2	60.60
JH	28	159.8	65.70
PM	18	171.4	55.14
KL	20	178.3	61.22
JS	22	172.9	66.42
JG	18	179.9	57.12
MEAN	22.7	167.0	61.73
SD	4.91	8.1	6.86
RANGE	18-34	156.4-179.9	51.20-73.74

Table 3: Acceleration of load for each task at each bed condition (ms^{-2}).

TASK	SINGLE	DOUBLE	QUEEN
BED ON	25	25	25
BED OFF	12	12	12
LIFT MATTRESS	5	5	5
PUSH BED	2	2	2
PULL BED	2	2	2

Table 4: Load mass for each task in each bed condition (kilograms).

TASK	SINGLE	DOUBLE	QUEEN
BED ON	1.4	2.7	3.1
BED OFF	3.8	9.4	12.2
LIFT MATTRESS	8.0	8.0	8.0
PUSH BED	48.5	66.0	84.5
PULL BED	48.5	66.0	84.5

The force at the hand for each task and bed condition combination is given in Table 5. This force represented the product of mass and acceleration indicated in Tables 3 and 4 and incorporated the acceleration of the load due to gravity.

Table 5: Force at hand for each task at each bed condition (Newtons).

TASK	DIRECTION	SINGLE	DOUBLE	QUEEN
BED ON	PUSH	36	67	105
BED OFF	LIFT	83	205	266
LIFT MATTRESS	LIFT	118	118	118
PUSH BED	PUSH	97	132	169
PULL BED	PULL	97	132	169

For "push bed" and "pull bed" tasks the external force acting at the hands was assumed to be equal in magnitude but opposite in direction.

(C) The effect of bed size on the dependent variables

Results indicated that bed size had either a significant main or interaction effect on all six dependent variables (L5/S1 Comp, L5/S1 Shear, PVGRF, PHGRF, IEMG(ES), and IEMG(AD)). These results will be considered in turn as follows:-

1. The effect of bed size on lumbosacral compression (L5/S1 Comp) and lumbosacral shear (L5/S1 Shear) forces

Previous research (Gagnon, et al., 1985) has suggested that mathematical models can be readily used to discriminate the relative demands imposed on the spine by different tasks. However, the absolute values of the loads contain a large degree of uncertainty and should be interpreted with caution. This should be considered in relation to the following results. However, model validations (Andersson, et al., 1985) clearly indicated the existance of excessive disc compressive forces in typical lifting tasks.

A significant difference was determined for the effect of bed size on the Task x Size interaction for L5/S1 Comp (Table 6). The tasks of "bedding-off" (Figure 6, p 93) and "pushing the bed" (Figure 8, p 95) were associated with significantly greater L5/S1 Comp values as bed size was systematically increased. A concomitant decrease in L5/S1 Comp was observed for the task of "pulling the bed sideways".

Table 6: ANOVA summary table for bed size on lumbosacral compression (L5/S1 Comp)

Source	df	SS	MS	F
Task x Size	8	83680000	10460000	24.76*
Residual	319	134800000	422500	

* p< 0.01

For "bedding-off", the NIOSH Action Limit (AL = 3450N) was exceeded by five out of twelve subjects in the double bed conditions (Average L5/S1 Comp = 3464N) and seven out of twelve for the queen size beds (Average L5/S1 Comp = 4125N). Conclusions by Andersson, et al. (1980) based on biomechanical modelling of muscular contraction forces during work at a table concluded that loads on the spine can be kept low by keeping the magnitude of the external loads low and by keeping the loads and the upper body segments as close horizontally to the lumbar spine as possible. These precautions are particularly relevant to "bedding-off" as they confirm that bed size should not only be minimised (to minimise the external forces acting), but also suggest that the worker should minimise forward bending of the trunk to keep the load as close to the body as possible. This could be achieved by gripping the load much closer to the edge of the bed at which the worker is positioned. These precautions would keep the major determinants of lumbar stress (moments due to body weight and the external load) to a minimum.

Additional to these suggestions, the magnitude of the external load could be reduced considerably if the worker were to free the corners of the bedding from the corners of the mattress prior to "bedding-off". This action would be facilitated by the use of fitted sheets that could not be removed unless this practice were strictly adhered to. Working in pairs would simplify this process as each worker could remove the bedding from corners adjacent to them and would also negate the temptation for individual workers to perform tasks clearly above their own safe working limits.

"Pushing the bed" resulted in one subject exceeding the AL for the queen size low bed condition (L5/S1 = 3510N). The position of the load relative to the worker for this task once again necessitated the adoption of a forward flexed posture. Increased external loading due to increased bed size produced greater predicted L5/S1 Comp forces in contradiction of findings by Lee, et al. (1987) who used 100, 200, 300 and 400 N hand forces (produced by a cart on a high traction floor) and found no significant difference in L5/S1 Comp. According to the model used in this study, the horizontal hand force created when "pushing the bed" produces a flexion moment at L5/S1 that requires strength in extension (produced by erector spinae muscle force) to achieve static equilibrium. As larger external loads produce a greater contribution to the flexion moment, the erector spinae muscle force, which acts in compression to balance the moments due to body weight above L5/S1 and the external load, is considerably greater for the larger bed conditions. The reason for the disagreement of these results with the findings of Lee, et al. (1987) appear to relate to the position of the external load relative to the worker. In the current study the horizontal loads were well below the level of the L5/S1. Lee, et al. used working heights above the L5/S1 level as part of a dynamic biomechanical analysis. It is likely that loads above L5/S1 would have contributed toward L5/S1 moments that directionally oppose those acting below this level.

The need for administrative and/or ergonomic intervention is thus clearly indicated for both "bedding-off" and "pushing the bed sideways". In the case of "bedding-off", task modification and reduction in bed size would circumvent this problem. Training in safe manual handling practices specific to the bedmaking task is recommended. Training should stress the risk associated with lifting from the forward flexed posture and provide alternative courses of action as previously detailed.

As bed size was increased during the "pull bed" task, L5/S1 Comp was significantly reduced (Figure 7). This decrease occurred as a result of the increased horizontal load component for larger beds. According to the model, this increased horizontal load produced an extension moment at

L5/S1 (as opposed to the vertical load component due to body weight which produced a flexion moment) that decreased the erector spinae muscle force necessary for moment equilibrium. As the erector spinae muscle force acts in compression, its reduced tension decreased the resultant L5/S1 Comp. In fact, as the horizontal pulling force is systematically increased, a point is reached where the external force produces an extension moment which negates contraction of the extensors of the L5/S1 joint and necessitates strength in flexion for static equilibrium. Once again, this result contradicts findings of Lee, et al. (1987) who used a two-dimensional sagittal linkage model as the basis for a dynamic biomechanical analysis and found that the compressive force at L5/S1 increased proportionally as pulling force increased. The position of the load relative to the worker is the likely reason for this descrepency. However, in agreement with Lee and his co-workers was the finding that L5/S1 Comp forces in pulling tasks tended to be less than those associated with pushing.

A significant Task x Size interaction effect was also determined for the effect of bed size on L5/S1 Shear (Table 7). The tasks of "bedding-off" (Figure 6) and "pulling the bed" (Figure 7) incurred a significant increase in L5/S1 Shear as bed size increased while "pushing the bed" (Figure 8) and "bedding-on" (Figure 9) resulted in a significant decrease in L5/S1 Shear with increased bed size.

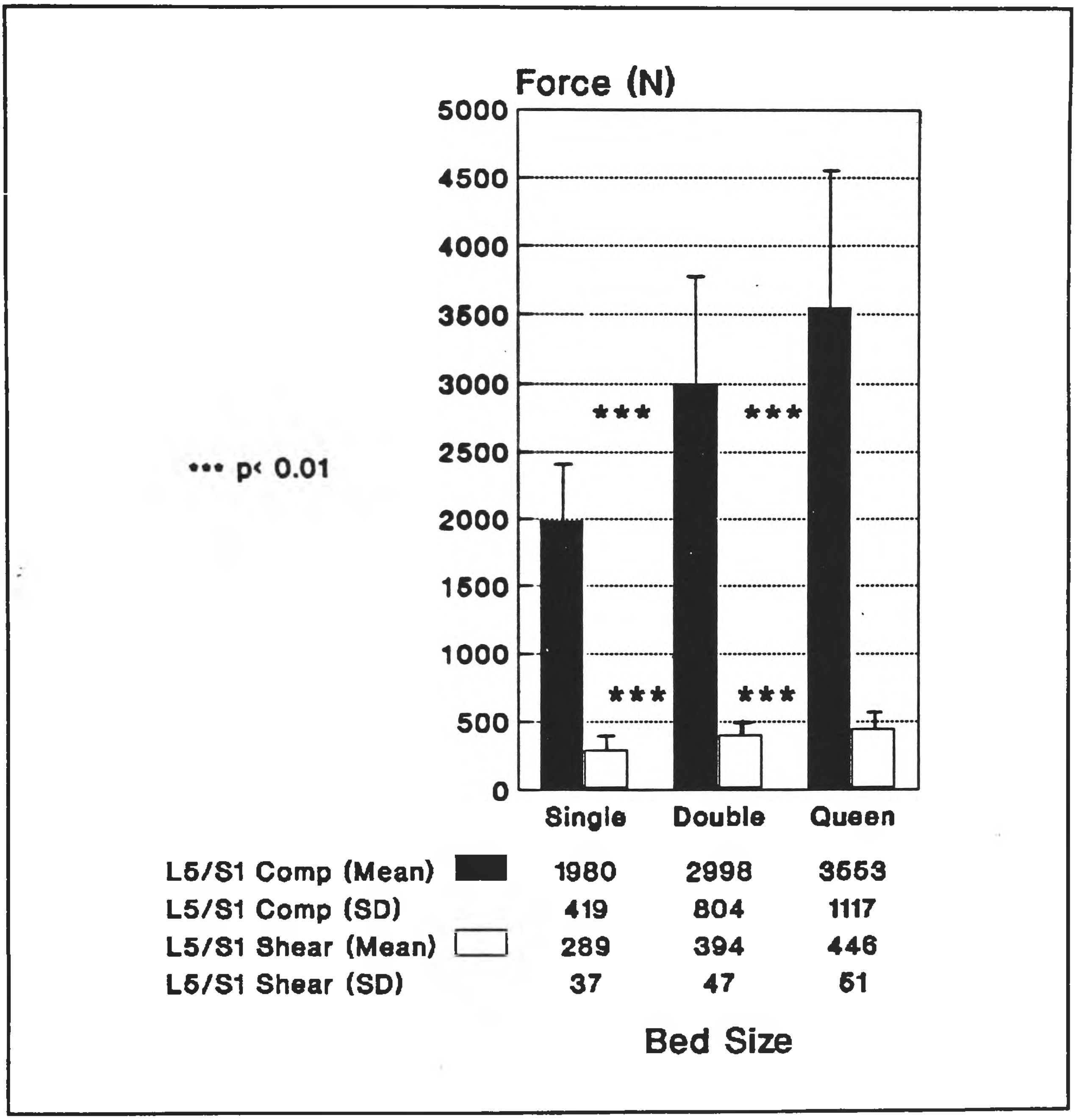
Table 7: ANOVA summary table for bed size on lumbosacral shear (L5/S1 Shear)

Source	df	SS	MS	F
Task x Size	8	1013000	126600	51.31*
Residual	319	787000	2467	

* p< 0.01

The forward flexed posture associated with "bedding-off" ensured that the body weight above L5/S1 and the weight of the external load contributed to the magnitude of lumbosacral shear forces during task performance. These tended to increase proportionally with increased external loading which suggested L5/S1 Shear forces associted with "bedding-off" were directly related to the magnitude of the external load (given that postural factors were relatively independent of bed size). Figure 6 illustrates the effect of bed size on L5/S1 Comp and L5/S1 Shear values in "bedding-off". The significant increase in these variables with increased bed size was indicative of increased stress on the human musculoskeletal system.

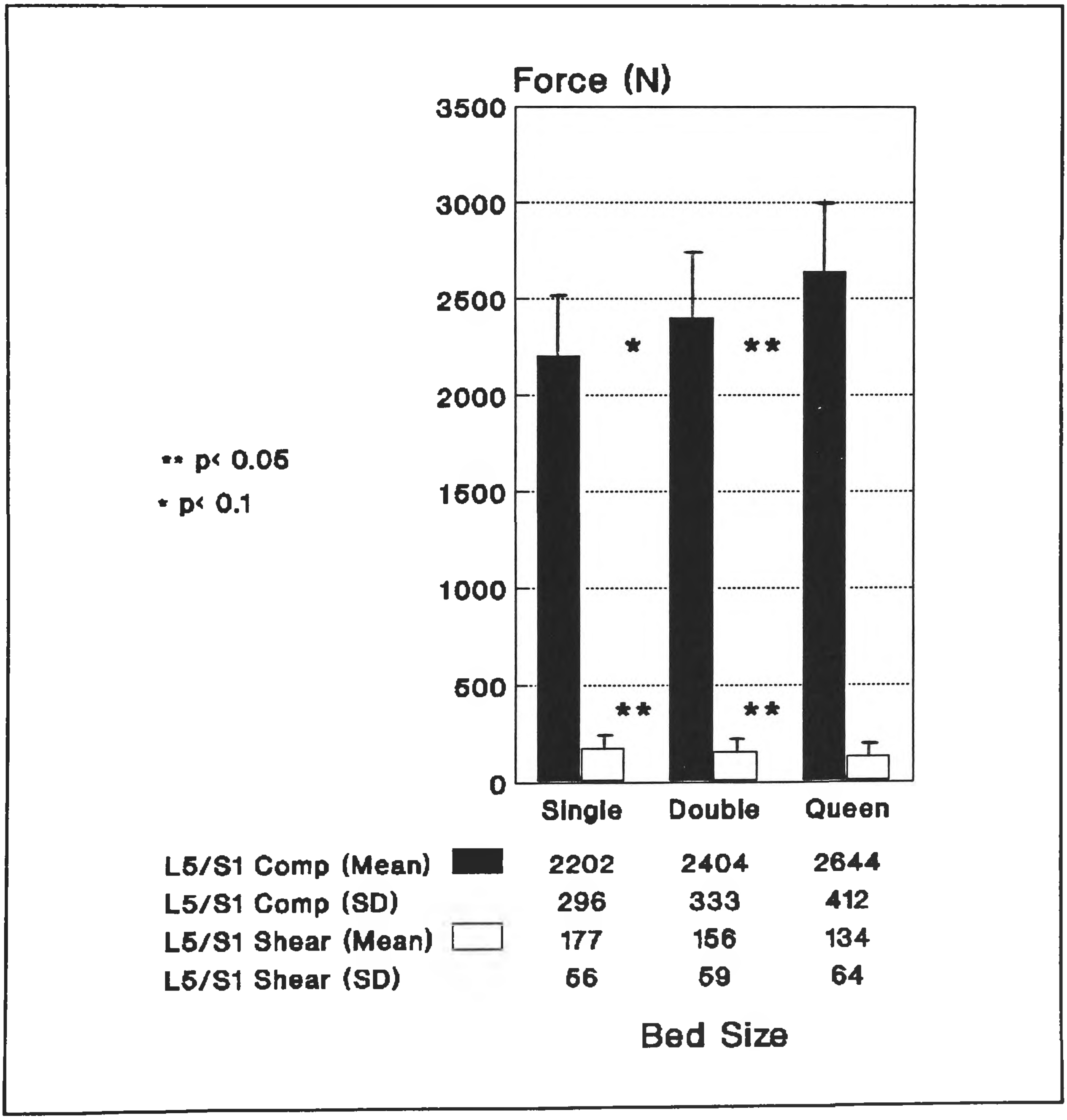
<u>Figure 6</u>. **The effect of bed size on lumbosacral compression and shear force in "bedding-off" (Mean ± SD)**



		Single	Double	Queen
L5/S1 Comp (Mean)	■	1980	2998	3553
L5/S1 Comp (SD)		419	804	1117
L5/S1 Shear (Mean)	□	289	394	446
L5/S1 Shear (SD)		37	47	51

Increased bed size when "pushing the bed" had the effect of significantly increasing L5/S1 Comp and significantly decreasing L5/S1 Shear (Figure 7). The result would appear to arise as a result of postural adjustments made for larger bed conditions as the subject attempted to produce a substantial horizontal effort. This necessitated the adoption of a horizontal trunk position in which L5/S1 Comp due to the action of external forces was maximised and the L5/S1 Shear minimised. It appeared unlikely that the motive force required for larger bed conditions could be efficiently produced using a more upright trunk position.

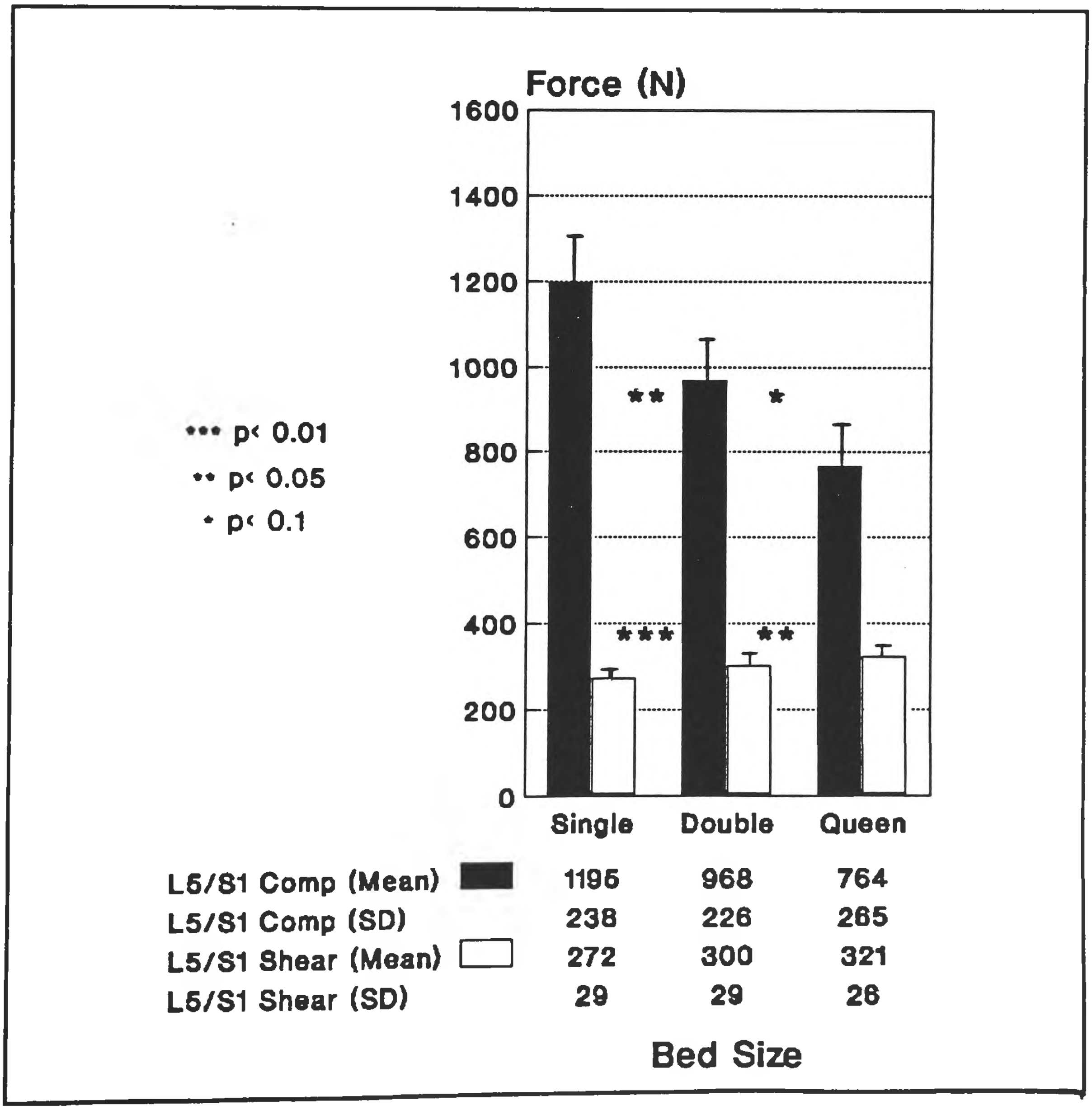
__Figure 7__. **The effect of bed size on lumbosacral compression and shear force when "pushing the bed sideways" (Mean ± SD)**



	Single	Double	Queen
L5/S1 Comp (Mean) ■	2202	2404	2644
L5/S1 Comp (SD)	296	333	412
L5/S1 Shear (Mean) □	177	156	134
L5/S1 Shear (SD)	56	59	64

The observed increase in the L5/S1 Shear component of force when "pulling the bed" (Figure 8) was directly related to the magnitude of the hand-held load. A greater horizontal component of external force was transferred to the L5/S1 joint as a result of the more upright posture used in pulling compared with pushing. Increased bed size was therefore likely to increase the potential for musculoskeletal injury to the low back when "pulling the bed sideways".

Figure 8. The effect of bed size on lumbosacral compression and shear force when "pulling the bed sideways" (Mean ± SD)

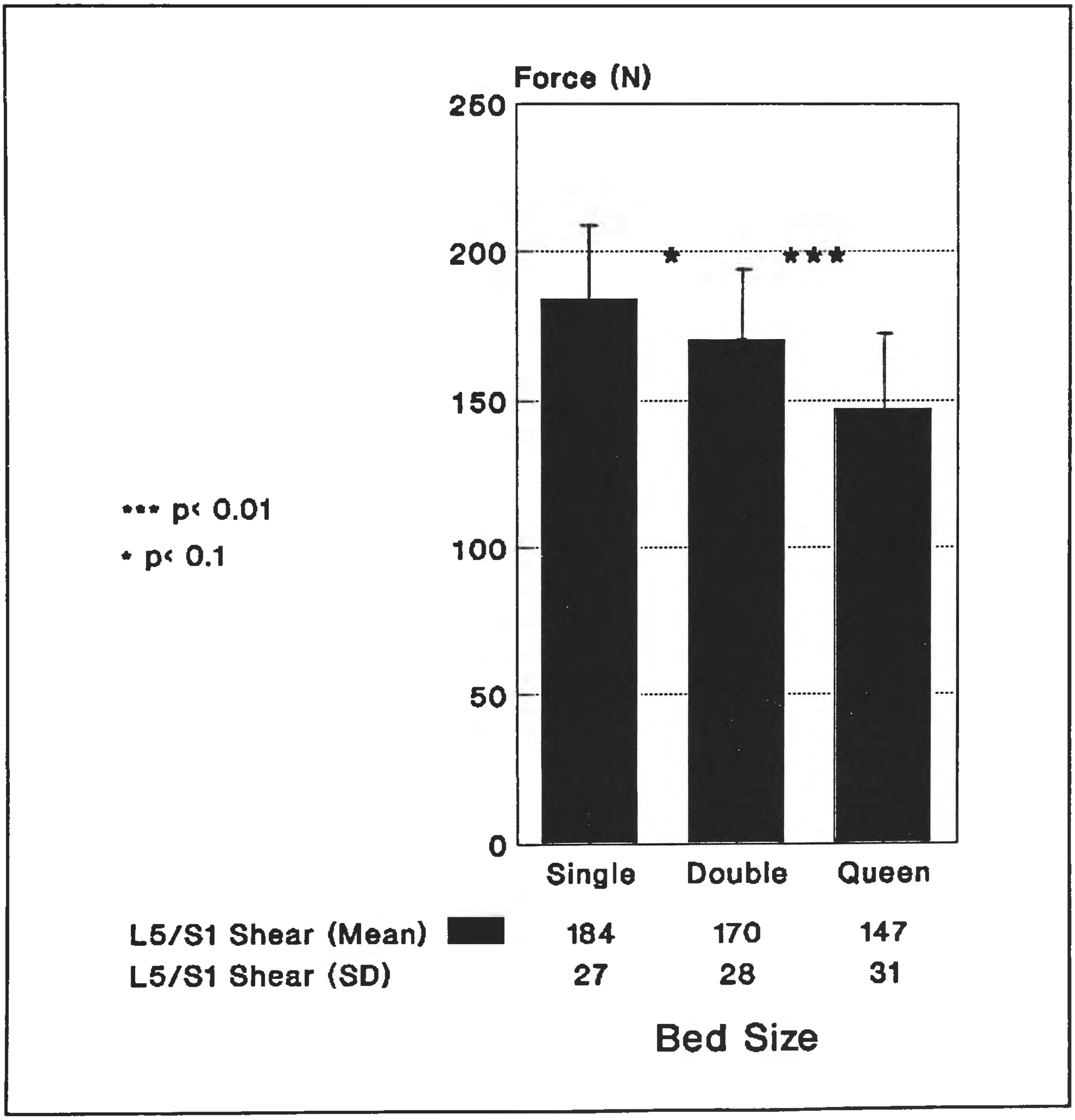


		Single	Double	Queen
L5/S1 Comp (Mean)	■	1195	968	764
L5/S1 Comp (SD)		238	226	265
L5/S1 Shear (Mean)	□	272	300	321
L5/S1 Shear (SD)		29	29	26

It was anticipated that the magnitude of L5/S1 Shear would increase in response to the additional load associated with the larger bed conditions when "bedding-on". The significant decrease in L5/S1 Shear that resulted with increased load was due to differences in posture when the "bedding-on" task was performed at different bed sizes. Given the significant increase in IEMG(ES) and IEMG(AD) with increased bed size in "bedding-on" it is likely that the range of trunk motion was decreased with increased bed size although more muscular force was required. The subjects assumed a more upright working posture that may have been a consequence of the awkwardness associated with the handling of larger and more cumbersome loads. The significant increase in PVGRF with increased bed size was in agreement with this conclusion as it was indicative of a greater component of vertical effort. As "bedding-on" is associated with the greatest load accelerations, a full dynamic analysis is recommended.

Bush-Joseph, Schipplein, Andersson and Andriacchi (1988) found that the peak L5/S1 moment increased linearly with increased lifting speed and was greatest for back lifts (ie. little contribution from the legs as in "bedding-on"). Furthermore, it was recommended that excessive speed of lifting, including jerking, should be avoided. Although "bedding-on" was analysed as a pushing task and that NIOSH limits were not exceeded in the present study, further investigation is warranted in view of the considerable accelerations present and the rapid execution time of the task.

<u>Figure 9</u>. The effect of bed size on lumbosacral shear force with "bedding-on" (Mean ± SD)



2. The effect of bed size on Peak Vertical (PVGRF) and Horizontal (PHGRF) Ground Reaction Forces

A significant Task x Size interaction effect was determined for the effect of bed size on PVGRF (Table 8). The tasks of "bedding-on" and "bedding-off" resulted in significantly greater PVGRF values as bed size increased (Figure 10).

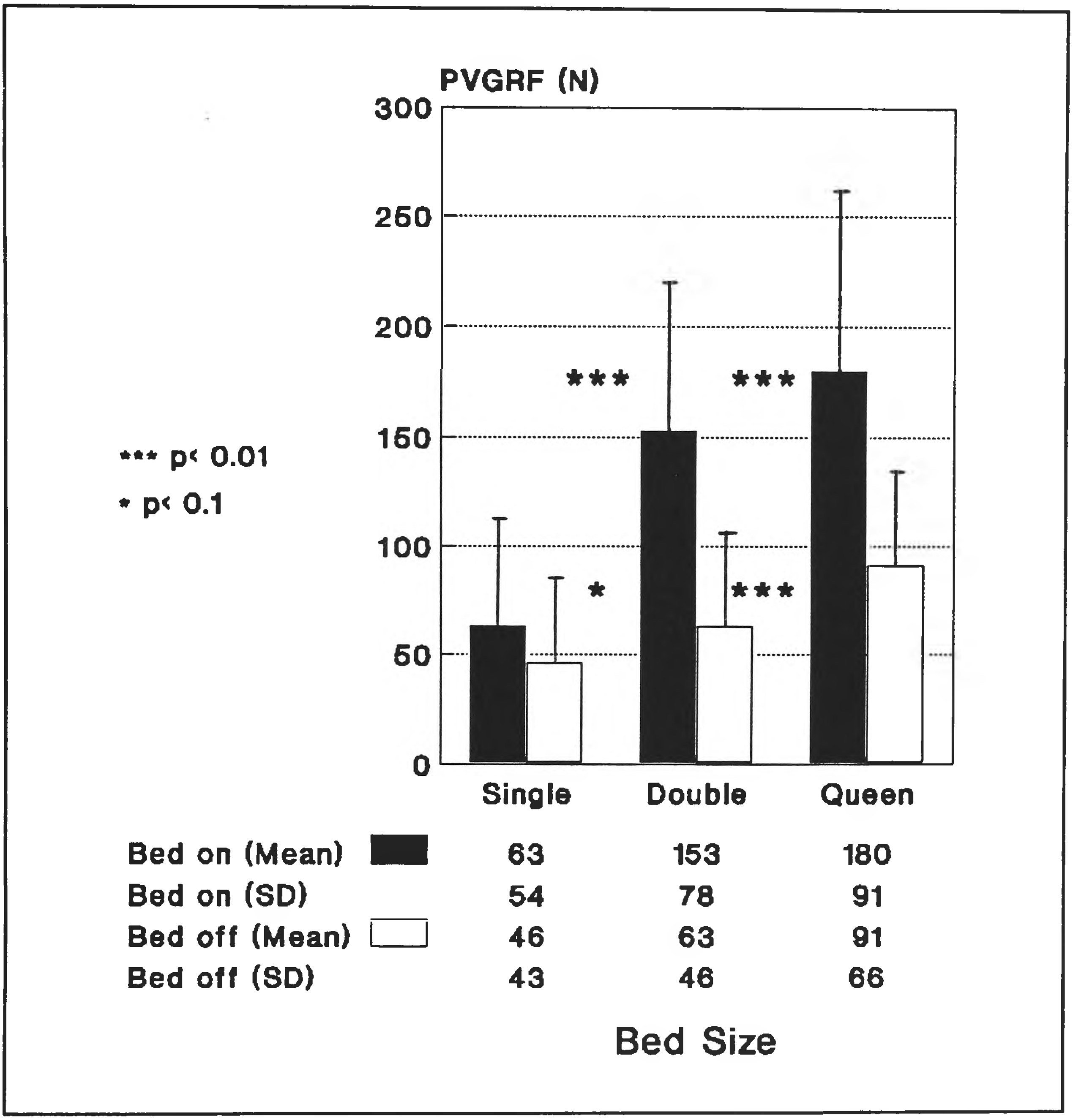
Table 8: ANOVA summary table for bed size on Peak Vertical Ground Reaction Force (PVGRF)

Source	df	SS	MS	F
Task x Size	8	350099	43762	12.32*
Residual	318	1129850	3553	

* $p < 0.01$

As expected, the tasks of "bedding-on" and "bedding-off" ellicited greater PVGRF values with increased bed size. This reponse directly reflects the increase in magnitude of the hand-held load for successively larger beds. No significant difference in PVGRF was determined for the "lift mattress" task in response to increased bed size as the magnitude of the hand-held load was independent of bed size for the lift height of 20 cm.

Figure 10. The effect of bed size on Peak Vertical Ground Reaction Force with "bedding-on" and "bedding-off" (Mean ± SD)



		Single	Double	Queen
Bed on (Mean)	■	63	153	180
Bed on (SD)		54	78	91
Bed off (Mean)	□	46	63	91
Bed off (SD)		43	46	66

A significant main effect was determined for bed size on PHGRF (Table 9) which indicated that as bed size increased, so too did the PHGRF for combined "pushing" and "pulling" (Figure 11).

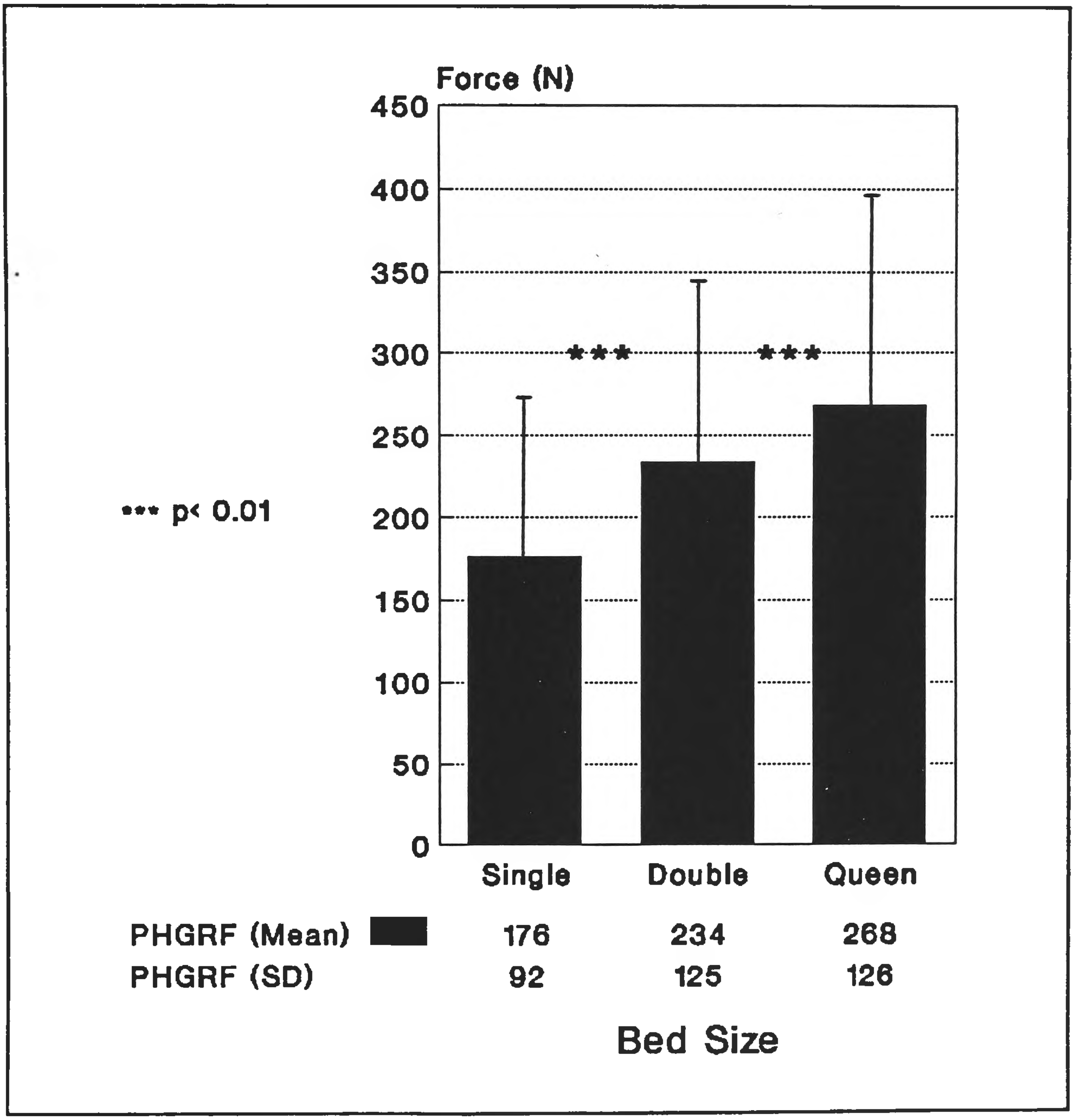
Table 9: ANOVA summary table for bed size on Peak Horizontal Ground Reaction Force (PHGRF)

Source	df	SS	MS	F
Size	2	625862	312931	29.65*
Residual	120	1266656	10555	

* $p < 0.01$

Once again, results indicated that increased bed size resulted in increased stress on the musculoskeletal system when attempting to move the bed. This has important implications for room layout in the hospitality industry such that large beds should be positioned to minimise the need to move them. A central position that provided access to both long sides of the bed is recommended.

<u>Figure 11</u>. **The effect of bed size on Peak Horizontal Ground Reaction force for "pushing" and "pulling the bed sideways" (Mean ± SD)**



	Single	Double	Queen
PHGRF (Mean) ■	176	234	268
PHGRF (SD)	92	125	126

3. The effect of bed size on integrated EMG activity of the erector spinae (IEMG(ES)) and anterior deltoid (IEMG(AD)) muscles.

A significant difference was determined for the effect of bed size on IEMG(ES) and IEMG(AD) across all tasks (Tables 10 & 11). These variables were significantly greater for larger bed conditions (Figure 12).

Table 10: ANOVA summary table for bed size on integrated EMG activity of the erector spinae muscle (EMG(ES))

Source	df	SS	MS	F
Size	2	69206	34603	48.30*
Residual	319	228537	716	

* $p < 0.05$

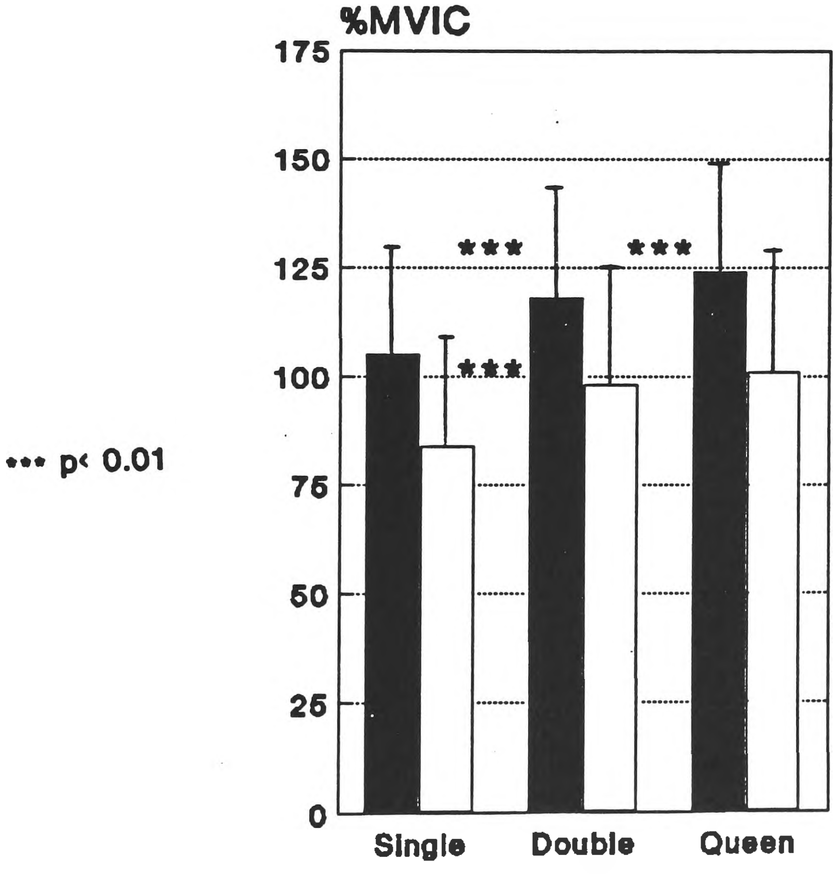
Table 11: ANOVA summary table for bed size on integrated EMG activity of the anterior deltoid muscle (IEMG(AD))

Source	df	SS	MS	F
Size	2	55418	27709	20.59*
Residual	319	429186	1345	

* $p < 0.01$

Significantly increased muscular involvement of the anterior deltoid and erector spinae muscles indicated the increased force required to accomplish each of the five bedmaking tasks with increased bed size. Values of between 105 and 124 %MVIC for erector spinae and 84 and 101 %MVIC for anterior deltoid clearly indicated the magnitude of the contraction required to perform each task and provide an arguement for task modification that decreases the physical demand on the performer.

<u>Figure 12</u>. The effect of bed size on the integrated EMG activity of erector spinae and anterior deltoid muscles across all tasks (Mean ± SD)



		Single	Double	Queen
IEMG(ES) (Mean)	■	105	118	124
IEMG(ES) (SD)		25	27	28
IEMG(AD) (Mean)	□	84	98	101
IEMG(AD) (SD)		29	36	35

(D) The effect of bed height on the dependent variables

Results indicated that bed height either had a significant main or interaction effect on all six dependent variables (L5/S1 Comp, L5/S1 Shear, PVGRF, PHGRF, IEMG(ES), and IEMG(AD)). These are considered as follows:-

1. The effect of bed height on lumbosacral compression (L5/S1 Comp) and shear (L5/S1 Shear) forces

A significant difference was determined for the effect of bed height on L5/S1 Comp (Table 12) and L5/S1 Shear (Table 13). L5/S1 Comp and Shear values were significantly higher in the low bed condition (Figure 13). Gagnon and Lortie (1987) investigated spinal loadings associated with patient handling and established a relationship with bed height. By adjusting the bed to a high position, at about trochanteric level, lumbosacral compression forces were reduced.

Table 12: ANOVA summary table for bed height on lumbosacral compression (L5/S1 Comp)

Source	df	SS	MS	F
Height	1	2638000	2638000	6.24*
Residual	319	134800000	422500	

* $p < 0.025$

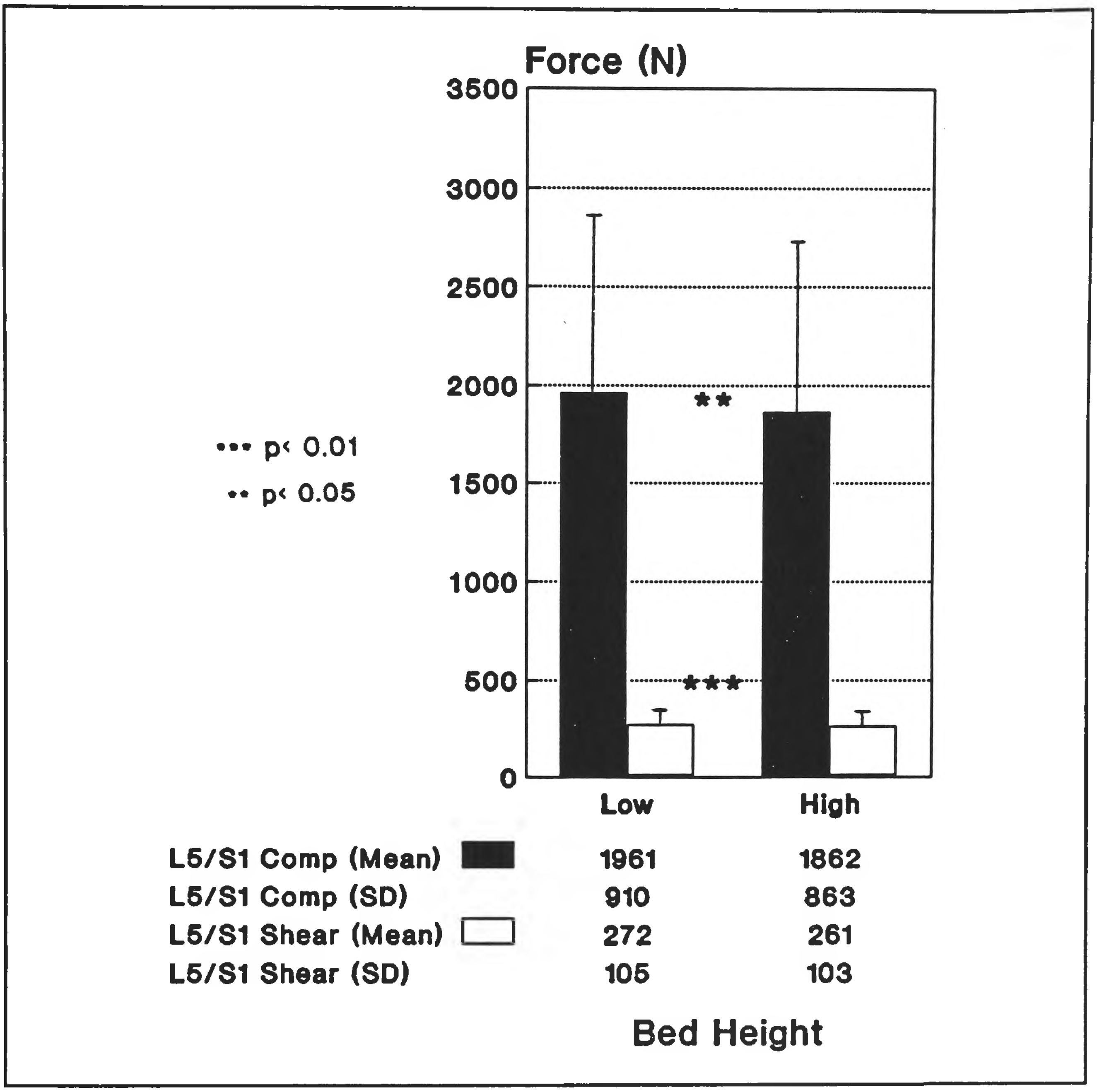
Table 13: ANOVA summary table for bed height on lumbosacral shear (L5/S1 Shear)

Source	df	SS	MS	F
Height	1	32230	32230	13.06*
Residual	319	787000	2467	

* $p < 0.01$

Further to this, Chaffin (1987b) advocated four principles for the prevention of occupational low back pain arising from lifting. Loads should (i) be kept close to the torso; (ii) not be lifted from the floor; (ii) be moved in a slow and well-planned way; and (iv) lifted to avoid twisting and lateral bending. Principle (ii) is particularly pertinent to this result which clearly indicates the importance of work height in minimising stress on the low back in bedmaking. This implies that by increasing the work height by 10cm (which is easily achieved by installing legs and casters on all beds) the worker is at less risk of injury. Increased bed height would reduce the L5/S1 Comp associated with "pushing the bed" to below the AL. However, a combined reduction in bed size and increase in bed height would have the desired effect of limiting musculoskeletal stress for both "bedding-off" and "pushing the bed", particularly since these tasks have the greatest mean L5/S1 Comp values across all bed conditions.

Figure 13. The effect of bed height on lumbosacral compression and shear force across all tasks (Mean ± SD)



		Low	High
L5/S1 Comp (Mean)	■	1961	1862
L5/S1 Comp (SD)		910	863
L5/S1 Shear (Mean)	☐	272	261
L5/S1 Shear (SD)		105	103

2. Bed height and Peak Vertical (PVGRF) and Horizontal (PHGRF) Ground Reaction Forces

A significant Task x Height interaction effect was determined for the effect of bed height on PVGRF (Table 14). The task of "bedding-on" was associated with a significantly greater PVGRF in the high bed condition (Figure 14).

Table 14: ANOVA summary table for bed height on Peak Vertical Ground Reaction Force (PVGRF)

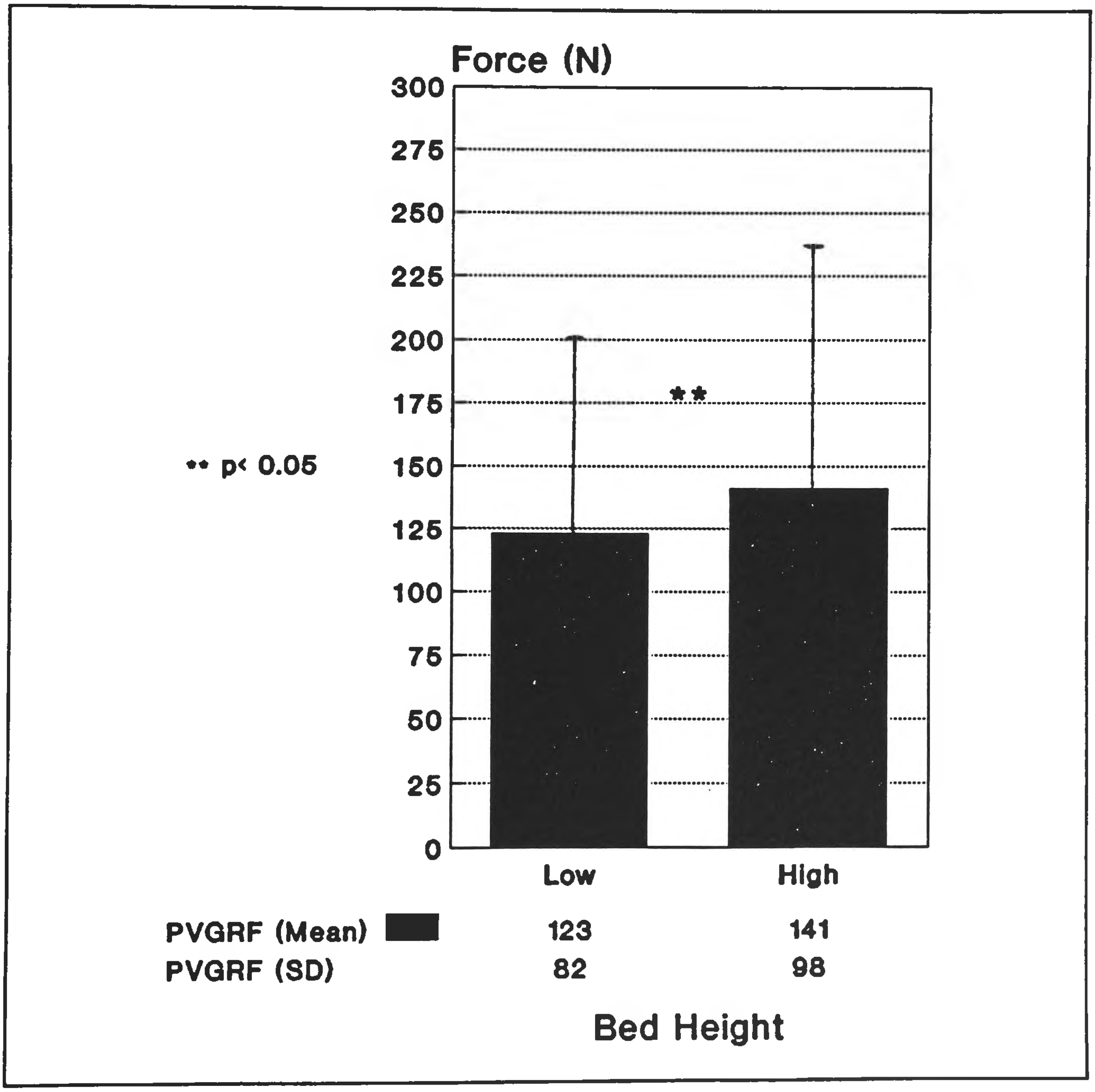
Source	df	SS	MS	F
Task x Height	4	33793	8448	2.38*
Residual	318	1129850	3553	

* p< 0.05

This can be attributed to the greater component of vertical effort required to project the bedding up and over the mattress in the high bed condition. "Bedding-on" in the low bed condition can be performed without this requirement by using a more horizontal arm action that is relatively unobstructed by bed location.

Based on the assumption that loads on the musculoskeletal system should be kept low, to minimise PVGRF in "bedding-on" at the high bed condition workers are advised to place less emphasis on projecting the bedding in the vertical direction and more on a greater horizontal component of effort. This technique would also tend to reduce the amount of forward flexion necessary to perform the task as the motive force could be readily produced using a forward stepping action (relative horizontal effort) rather than through lumbar extension (relative vertical effort). By executing this task from a position near as possible to the side of the bed the problem of achieving clearance over the bed is minimised. Adjustments to the sheet upon landing would be as normal but with the overall effect of decreasing stress on the lumbar spine.

Figure 14. The effect of bed height on Peak Horizontal Ground Reaction Force in "bedding-on" (Mean ± SD)



A significant Task x Height interaction effect was determined for the effect of bed height on PHGRF. The PHGRF for the tasks of "pushing" and "pulling" were significantly higher in the low bed condition (Figure 15).

Table 15: ANOVA summary table for bed height on Peak Horizontal Ground Reaction Force (PHGRF)

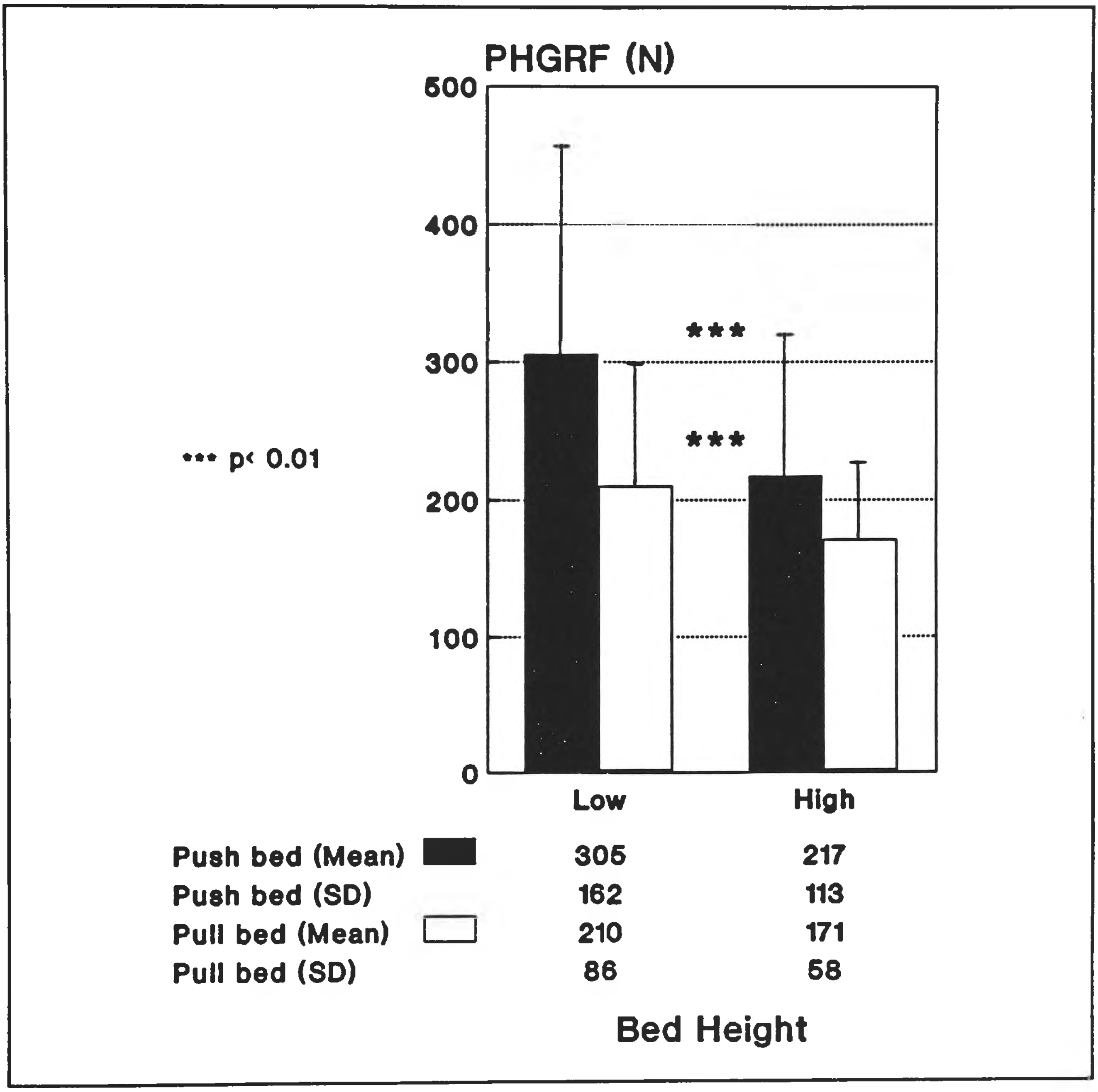
Source	df	SS	MS	F
Task x Height	1	66433	66433	6.29*
Residual	120	1266656	10555	

* $p < 0.025$

"Pushing" and "pulling" the low bed required the subject to flex the trunk to a greater extent than in the high bed condition. This increased stoop appears to have retarded the ability of subjects to generate bed movement as more PHGRF was required to move the same load.

This finding accentuates the issue of bed location as movement of the bed is more difficult under low bed conditions. Clearly it is advisable for beds to be positioned to enable free access and that, under circumstances where bed movement is unavoidable, legs and casters be employed to reduce the potential for physical stress upon the worker.

<u>Figure 15</u>. The effect of bed height on Peak Horizontal Ground Reaction Force for "pushing" and "pulling the bed sideways" (Mean ± SD)



		Low	High
Push bed (Mean)	■	305	217
Push bed (SD)		162	113
Pull bed (Mean)	□	210	171
Pull bed (SD)		86	58

3. The effect of bed height on integrated EMG activity of the erector spinae (IEMG(ES)) and anterior deltoid (IEMG(AD)) muscles.

A significant Task x Height interaction effect was determined for the effect of bed height on IEMG(ES) (Table 16). For the tasks of "pulling" and "pushing" the bed the IEMG(ES) was significantly higher in the low bed condition (Figure 16).

Table 16: ANOVA summary table for bed height in integrated EMG activity of the erector spinae muscle (IEMG(ES))

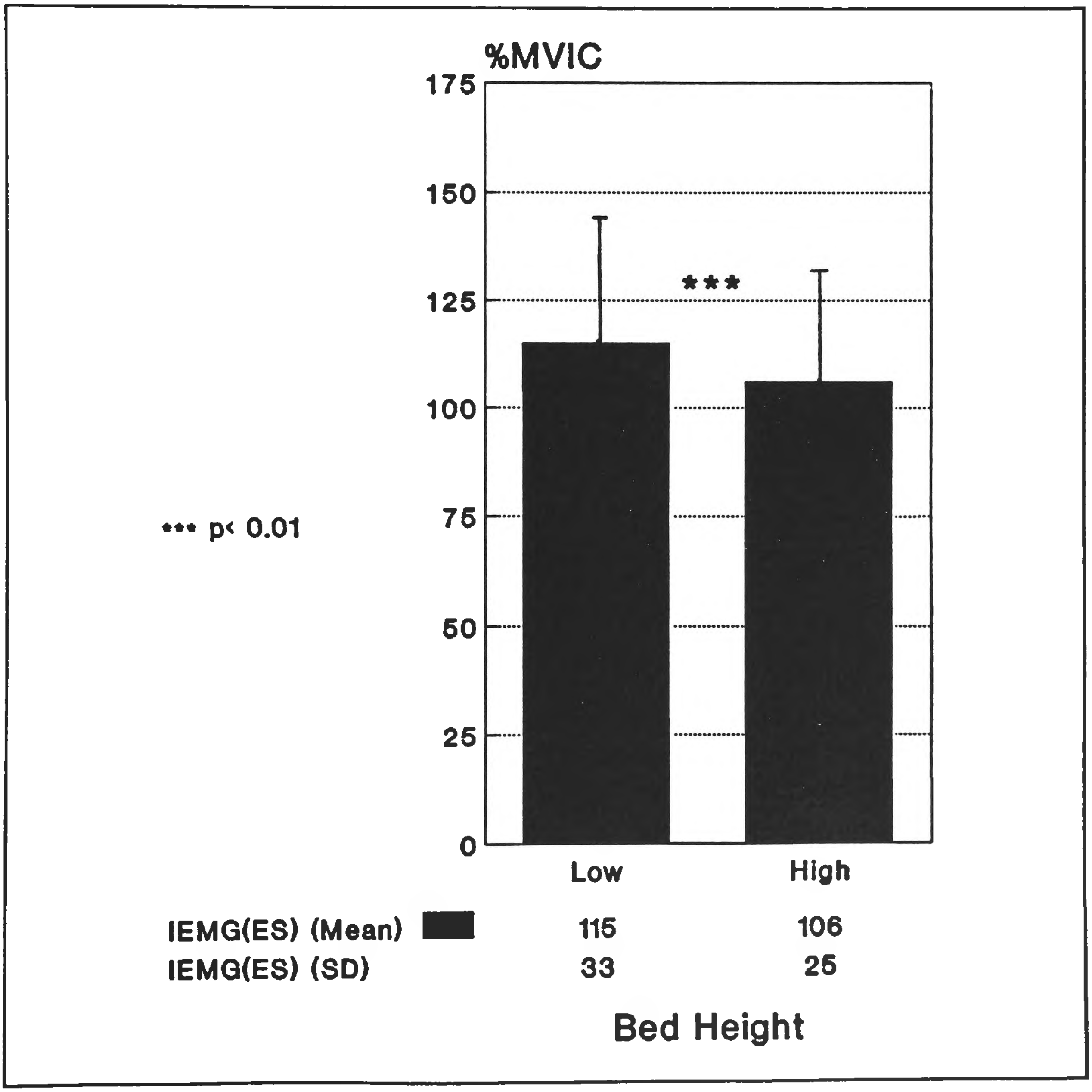
Source	df	SS	MS	F
Task x Height	4	7277	1819	2.54*
Residual	319	228537	716	

* $p < 0.05$

Activity levels in the erector spinae followed the established pattern for lumbosacral and ground reaction forces as bed height was systematically manipulated. Increased L5/S1 Comp, L5/S1 Shear and PHGRF were consistent with increased IEMG(ES) values for reduced bed height. The posture assumed in the performance of these tasks appeared to be less efficient as more stress is placed on the musculoskeletal system in order to produce the same resultant force against the bed.

The increase in IEMG(ES) for "bedding-on", "lifting the corner of the mattress" and "bedding-off" is a direct reflection upon the postures adopted for these tasks as decreased bed height has necessitated or provided the potential to incorporate a greater degree of lumbar flexion into the task performance. This had the effect of increasing the flexion moment thereby increasing the erector spinae contraction force necessary to achieve equilibrium.

Figure 16. The effect of bed height on integrated EMG activity of the erector spinae muscle when "pulling the bed sideways" (Mean ± SD)



A significant Task x Height interaction effect was determined for the effect of bed height on IEMG(AD) (Table 17). The IEMG(AD) was significantly higher when "pushing" the low bed sideways (Figure 17).

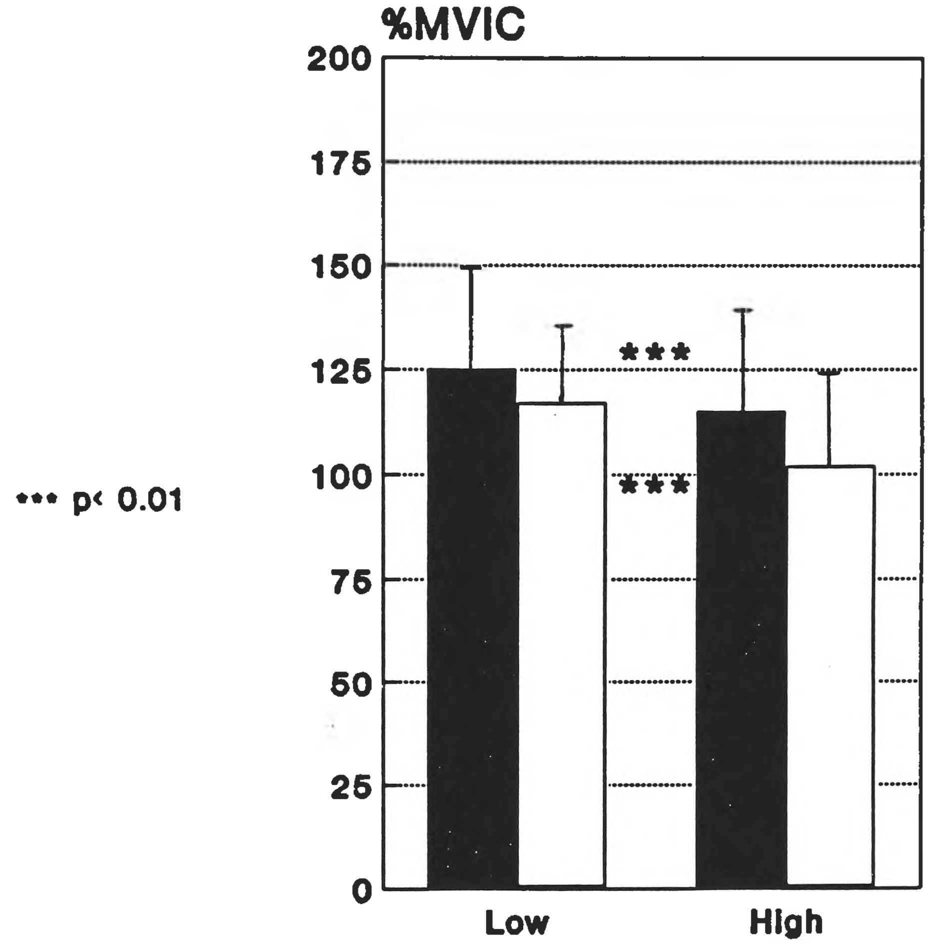
Table 17: ANOVA summary table for bed height on integrated EMG activity of the anterior deltoid muscle (IEMG(AD))

Source	df	SS	MS	F
Task x Height	4	17385	4346	3.23*
Residual	319	429186	1345	

* $p < 0.05$

The anterior deltoid muscle was active in "pulling the bed" as a means of maintaining a firm grip on the load in the pulling action. This appeared to be independent of bed height. However, when "pushing" the low bed, the role of the anterior deltoid was significantly increased (Figure 17). This was probably due to the inability of other muscles implicated in the task to contribute as effectively in the low bed condition due to the extreme posture assumed. It was likely that increased force from shoulder joint flexion could accommodate this difference as in a crouched and forward flexed position, the potential for contribution from knee and hip extension to a horizontal effort was small.

Figure 17. The effect of bed height on integrated EMG activity of the erector spinae and anterior deltoid muscles when "pushing the bed sideways" (Mean ± SD)



		Low	High
IEMG(ES) (Mean)	■	125	115
IEMG(ES) (SD)		26	24
IEMG(AD) (Mean)	□	117	102
IEMG(AD) (SD)		17	23

Bed Height

CHAPTER V

SUMMARY AND CONCLUSIONS

This chapter contains a brief overview of the study and presents the conclusions drawn from the results obtained. Recommendations for future research are also included. The chapter is presented in three sections : (A) Summary, (B) Conclusions; and (C) Recommendations for future study.

(A) Summary

The purpose of this study was to assess the stress imposed on the human musculoskeletal system, particularly the lower back, during bedmaking. Specifically, the aim was to investigate the effect of bed size and bed height on L5/S1 compressive and shear forces, peak vertical and horizontal ground reaction forces and EMG activity of erector spinae, anterior deltoid, rectus abdominus and obliquus externus with the view to proposing alternative courses of action in what has been identified as a work situation with the potential for musculoskeletal injury.

In order to readily quantify the abovementioned variables, the act of bedmaking was reduced to five discrete tasks assumed to represent components of bedmaking associated with the greatest potential for excessive lumbar stress. These were defined in consultation with an experienced linen maid and comprised "bedding-on", "bedding-off", "lifting the mattress" and "pushing" and "pulling the bed".

Three trials of each task were performed by twelve female volunteer subjects ((Age 22.7 ± 4.91) at combinations of three standard bed sizes (single, double and queen) and two standard bed heights (560 and 460 mm).

A Two Dimensional Static Strength Prediction Program (University of Michigan, 1989) was used to determine the L5/S1 compression and shear forces for the initiation phase of each task. The model was two-dimensional (sagittal) and static (inertial forces assumed zero). The model required input describing the load vector at the hands and the posture and anthropometry of the subject. The load parameters were determined for one subject using a quasi-dynamic approach that accounted for the acceleration of the load in each task during the initiation phase of the movement. This involved standard cinematographic procedures and was assumed representative of data for all subjects. Body positions were recorded using a high shutter speed video system enabling landmarks identifying segment endpoints to be transferred to transparencies for the measurement of segment angles. Individual measures of height and weight were used by the model to scale segment length and weight.

A Kistler force platform was used to measure the horizontal and vertical components of the external forces under both feet for all tasks. Peak values were chosen for analysis and were assumed to be indicative of musculoskeletal stress in bedmaking.

Myoelectric activity from erector spinae, anterior deltoid, rectus abdominus and obliquus externus were recorded as mean rectified signals. These signals were integrated and expressed as a percentage of previously recorded maximum voluntary isometric contraction.

A three factor analysis of variance (ANOVA) was used to test the effect of task, bed size and bed height on the dependent measures of musculoskeletal stress. Two-sample post-hoc t-tests were conducted to determine specific differences amongst grouping factors.

Results indicated that the independent measures of task, bed size and bed height all had a significant main or interaction effect on the selected indicators of musculoskeletal stress in bedmaking, and are summarised as follows:-

<u>The effect of increased bed size on the dependent variables</u>

1. L5/S1 Compression was greater for "bedding-off" and "pushing the bed".

2. L5/S1 Compression was decreased for "pulling the bed".

3. L5/S1 Shear was increased when "bedding-off" and "pulling the bed".

4. L5/S1 Shear was decreased for "bedding-on" and "pushing the bed".

5. PVGRF was higher for "bedding-on" and "bedding off".

6. PHGRF was higher for combined "pushing" and "pulling".

7. IEMG(ES) and IEMG(AD) was increased across all tasks.

8. For "bedding-off" the NIOSH Action Limit was exceeded by seven subjects in the queen low bed condition and five subjects in the double low bed condition.

9. For "pushing the bed" the NIOSH Action Limit was exceeded by one subject in the queen low bed condition.

The effect of decreased bed height on the dependent variables

1. L5/S1 Compression and Shear were higher across all tasks.

2. PVGRF was lower for "bedding-on".

3. PHGRF was higher for "pushing" and "pulling the bed".

4. IEMG(ES) was higher for "pushing" and "pulling the bed".

5. IEMG(AD) was higher when "pushing the bed".

These findings were discussed in relation to the literature reviewed, with implications for safer work practices for linen maids in the hospitality industry.

(B) Conclusions

Increased bed size and reduced bed height appeared to increase lumbar stress in bedmaking as indicated by lumbosacral forces, forces measured beneath the feet and integrated EMG activity of implicated musculature. This supports the notion that trends in the hospitality industry toward the use of larger and heavier beds increase the physical stress on the employee. In some cases this stress was potentially hazardous as indicated by NIOSH safe lifting limits (NIOSH, 1981).

In order to minimise the physical stress, particularly to the low back, during bedmaking it is recommended that several changes to current work conditions and practice be implemented. The conclusions drawn from this study are as follows:-

1. The trend toward the use of larger and heavier beds in the hospitality industry be reversed;

2. All beds be fitted with legs and casters to produce a safer working height;

3. Beds be positioned to minimise the need to move them;

4. Fitted sheets be introduced to minimise the requirement to lift the mattress;

5. Work performed from the forward flexed position be minimised.

According the NIOSH Action Limit the tasks of "bedding-off" and "pushing the bed sideways" were associated with the greatest risk of musculoskeletal injury.

The task of "bedding-off" as defined in this study comprised a vertical effort performed using a stooped lifting posture. This technique has been identified as hazardous to the low back but is necessitated in bedmaking by the distance between the base of support (feet) and the point of application of the load (mid-surface of bed). In order to overcome this problem it is recommended that the sheets be dislodged in all four corners prior to removing the sheet from the bed. This would significantly reduce the magnitude of the load in "bedding-off". Adherence to this technique would be improved by the introduction of fitted sheets that could not be easily dislodged merely by pulling the sheets. Fitted sheets would also benefit the worker by decreasing the frequency and amplitude of the lift mattress task. The height of lift would be reduced as fitted sheets are placed over the corners of the mattress and in some and in some circumstances, may not require a lift at all.

The stresses imposed on the low back when "pushing" and "pulling the bed" could easily be avoided if the bed was readily accessible from at least three sides. This is easily achieved by positioning the bed away from walls or other obstructions.

Although the PVGRF was greater for the high bed condition in "bedding-on", this does not necessarily reflect a general increase in musculoskeletal stress. It is merely a reflection of the direction of the applied force and indicates the greater vertical component of effort required to position the load for the horizontal projection over the surface of the bed. This does not constitute a valid reason for recommending a lower bed height.

Working in pairs may circumvent many of the problems associated with current work practice as the external load borne by the individual would be reduced and the postures adopted in performing each task would become less extreme. However, this suggestion would need to be assessed in view of the actual techniques adopted and the additional number of beds to be made per individual.

(C) Recommendations for Future Study

On the basis of the findings in the present study, the following recommendations are made as a guide to future research:

1. assessment of the bedmaking task be conducted using a dynamic (sagittal and/or three dimensional) biomechanical model;

2. investigation of other working heights (higher and lower) common to the hospitality industry;

3. investigation of other bed sizes (eg. King size) common to the hospitality industry;

4. use of subjects with work experience as linen maids in the hospitality industry;

5. analysis of the bedmaking task as a whole.

6. investigation of the feasibility of working in pairs.

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APPENDICES

APPENDIX A

RAW DATA

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
1	1	1	1	1	1	1104	192	-7	•	87	86
2	1	1	1	1	2	1098	194	0	•	91	101
3	1	1	1	1	3	1259	209	70	•	86	77
4	1	2	1	1	1	2504	345	5	•	110	64
5	1	2	1	1	2	2670	353	13	•	101	51
6	1	2	1	1	3	2657	356	17	•	115	47
7	1	3	1	1	1	1983	418	•	•	71	44
8	1	3	1	1	2	2235	399	-15	•	53	29
9	1	3	1	1	3	2056	401	-3	•	69	47
10	1	4	1	1	1	1347	281	19	229	101	117
11	1	4	1	1	2	1377	288	-2	234	94	101
12	1	4	1	1	3	•	•	57	230	82	114
13	1	5	1	1	1	1033	99	23	129	99	91
14	1	5	1	1	2	1900	118	121	145	116	106
15	1	5	1	1	3	•	•	89	192	111	87
16	1	1	1	2	1	1070	187	69	•	89	111
17	1	1	1	2	2	950	196	82	•	102	90
18	1	1	1	2	3	[illegible]	188	41	•	79	71
19	1	2	1	2	1	2400	323	24	•	119	69
20	1	2	1	2	2	2001	318	19	•	102	51
21	1	2	1	2	3	2339	335	29	•	107	59
22	1	3	1	2	1	1079	384	6	•	69	16
23	1	3	1	2	2	1090	389	•	•	43	57
24	1	3	1	2	3	1009	397	10	•	58	34
25	1	4	1	2	1	1302	276	2	234	72	114
26	1	4	1	2	2	1412	270	44	186	86	96
27	1	4	1	2	3	1478	265	56	118	77	99
28	1	5	1	2	1	1735	127	•	•	100	84
29	1	5	1	2	2	1020	104	46	153	90	96
30	1	5	1	2	3	1025	134	36	133	80	79
31	1	1	2	1	1	1012	169	157	•	106	100
32	1	1	2	1	2	1012	156	111	•	94	106
33	1	1	2	1	3	1061	184	103	•	92	112
34	1	2	2	1	1	4007	468	60	•	117	84
35	1	2	2	1	2	4304	455	42	•	123	86
36	1	2	2	1	3	4063	465	31	•	111	89
37	1	3	2	1	1	2225	397	-4	•	68	49
38	1	3	2	1	2	2641	385	48	•	39	33
39	1	3	2	1	3	2235	380	6	•	47	38
40	1	4	2	1	1	1185	307	17	270	116	110
41	1	4	2	1	2	1143	310	59	216	99	113
42	1	4	2	1	3	1093	302	21	249	127	101
43	1	5	2	1	1	2294	139	103	265	129	106
44	1	5	2	1	2	•	•	•	201	114	104
45	1	5	2	1	3	•	•	•	193	100	110
46	1	1	2	2	1	1178	191	108	•	101	117
47	1	1	2	2	2	1130	184	209	•	110	99
48	1	1	2	2	3	1217	197	212	•	96	106
49	1	2	2	2	1	3608	458	-4	•	109	91
50	1	2	2	2	2	3954	464	39	•	124	81
51	1	2	2	2	3	4595	471	71	•	114	81
52	1	3	2	2	1	2031	382	-7	•	69	36
53	1	3	2	2	2	2043	382	0	•	61	44
54	1	3	2	2	3	2001	395	7	•	73	59
55	1	4	2	2	1	1171	294	67	166	123	97
56	1	4	2	2	2	1265	294	19	210	111	109
57	1	4	2	2	3	1317	293	91	234	84	109
58	1	5	2	2	1	1846	70	107	•	101	90
59	1	5	2	2	2	1470	41	76	138	110	77
60	1	5	2	2	3	1811	56	69	227	75	81
61	1	1	3	1	1	1003	139	140	•	111	117
62	1	1	3	1	2	1128	132	199	•	118	126
63	1	1	3	1	3	903	155	197	•	131	119
64	1	2	3	1	1	4867	533	78	•	117	89
65	1	2	3	1	2	4400	543	-4	•	137	89
66	1	2	3	1	3	5233	530	62	•	123	84
67	1	3	3	1	1	1909	406	6	•	84	41
68	1	3	3	1	2	2079	388	45	•	90	37

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVERF	PHGRF	EMG(ES)	EMG(AD)
69	1	3	3	1	3	2051	390	•	•	61	61
70	1	4	3	1	1	977	333	130	287	111	107
71	1	4	3	1	2	924	335	64	347	128	103
72	1	4	3	1	3	870	329	88	313	124	116
73	1	5	3	1	1	1765	62	•	•	129	116
74	1	5	3	1	2	2051	44	120	258	137	123
75	1	5	3	1	3	2015	43	96	261	118	124
76	1	1	3	2	1	1316	156	149	•	138	131
77	1	1	3	2	2	1160	143	176	•	106	140
78	1	1	3	2	3	1207	138	265	•	126	106
79	1	2	3	2	1	4844	521	•	•	141	91
80	1	2	3	2	2	5144	522	42	•	108	87
81	1	2	3	2	3	5794	523	82	•	129	94
82	1	3	3	2	1	2020	378	•	•	85	37
83	1	3	3	2	2	1938	362	22	•	84	49
84	1	3	3	2	3	•	•	21	•	72	55
85	1	4	3	2	1	1220	324	5	309	104	10[illegible]
86	1	4	3	2	2	1160	327	-7	302	99	97
87	1	4	3	2	3	1001	315	-22	235	87	102
88	1	5	3	2	1	2269	105	18	281	113	109
89	1	5	3	2	2	2700	192	-7	277	109	92
90	1	5	3	2	3	2616	139	66	197	120	97
91	2	1	1	1	1	1357	184	36	•	96	62
92	2	1	1	1	2	1232	172	59	•	100	92
93	2	1	1	1	3	1240	174	3	•	93	96
94	2	2	1	1	1	2073	286	38	•	93	92
95	2	2	1	1	2	2018	302	•	•	112	81
96	2	2	1	1	3	•	•	23	•	117	65
97	2	3	1	1	1	2038	373	27	•	96	111
98	2	3	1	1	2	2082	367	45	•	103	84
99	2	3	1	1	3	2076	377	16	•	105	77
100	2	4	1	1	1	948	292	31	209	94	110
101	2	4	1	1	2	1048	284	39	106	101	113
102	2	4	1	1	3	1032	282	24	139	92	113
103	2	5	1	1	1	2406	224	•	•	119	99
104	2	5	1	1	2	2432	207	•	•	113	120
105	2	5	1	1	3	2380	210	•	•	115	119
106	2	1	1	2	1	1431	157	18	•	92	97
107	2	1	1	2	2	1373	151	11	•	83	102
108	2	1	1	2	3	1388	160	54	•	96	61
109	2	2	1	2	1	2072	278	24	•	119	97
110	2	2	1	2	2	1980	280	16	•	106	91
111	2	2	1	2	3	1968	272	8	•	95	75
112	2	3	1	2	1	2079	352	33	•	114	63
113	2	3	1	2	2	2029	347	22	•	96	26
114	2	3	1	2	3	2039	359	33	•	89	39
115	2	4	1	2	1	1019	291	16	136	70	117
116	2	4	1	2	2	1062	284	16	94	89	123
117	2	4	1	2	3	•	•	12	101	•	•
118	2	5	1	2	1	2288	210	49	92	103	109
119	2	5	1	2	2	2285	212	•	•	104	113
120	2	5	1	2	3	2260	208	54	101	89	109
121	2	1	2	1	1	1620	161	143	•	107	111
122	2	1	2	1	2	1362	147	91	•	106	101
123	2	1	2	1	3	1521	161	123	•	127	114
124	2	2	2	1	1	3357	412	•	•	136	108
125	2	2	2	1	2	2960	398	•	•	126	92
126	2	2	2	1	3	3303	375	78	•	112	111
127	2	3	2	1	1	2015	375	52	•	97	36
128	2	3	2	1	2	1949	369	41	•	64	31
129	2	3	2	1	3	2066	361	52	•	102	41
130	2	4	2	1	1	643	309	6	248	113	116
131	2	4	2	1	2	758	306	1	197	139	120
132	2	4	2	1	3	697	305	•	295	82	99
133	2	5	2	1	1	2409	208	60	146	130	113
134	2	5	2	1	2	•	•	83	156	107	93
135	2	5	2	1	3	2338	228	94	168	144	125
136	2	1	2	2	1	1477	162	78	•	106	99

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
137	2	1	2	2	2	1206	144	103	•	117	107
138	2	1	2	2	3	•	•	71	•	112	102
139	2	2	2	2	1	2991	391	55	•	125	94
140	2	2	2	2	2	3142	370	52	•	136	100
141	2	2	2	2	3	3242	365	52	•	151	102
142	2	3	2	2	1	1947	345	30	•	103	42
143	2	3	2	2	2	1898	357	33	•	119	23
144	2	3	2	2	3	2012	350	38	•	76	15
145	2	4	2	2	1	895	305	17	197	122	108
146	2	4	2	2	2	892	303	13	132	129	118
147	2	4	2	2	3	697	308	4	129	79	113
148	2	5	2	2	1	2408	212	66	126	86	106
149	2	5	2	2	2	2535	223	70	97	133	100
150	2	5	2	2	3	•	•	59	86	98	101
151	2	1	3	1	1	1704	136	52	•	108	109
152	2	1	3	1	2	1692	133	71	•	110	103
153	2	1	3	1	3	1669	138	70	•	105	109
154	2	2	3	1	1	3820	451	108	•	130	93
155	2	2	3	1	2	3411	459	61	•	158	99
156	2	2	3	1	3	3684	471	56	•	114	75
157	2	3	3	1	1	1916	371	36	•	86	32
158	2	3	3	1	2	2028	365	66	•	83	42
159	2	3	3	1	3	1957	375	49	•	91	30
160	2	4	3	1	1	241	324	-3	284	125	114
161	2	4	3	1	2	457	326	11	301	118	118
162	2	4	3	1	3	380	326	11	•	176	123
163	2	5	3	1	1	2914	229	103	208	146	117
164	2	5	3	1	2	2976	209	109	127	145	116
165	2	5	3	1	3	•	•	93	116	123	110
166	2	1	3	2	1	1552	118	95	•	118	129
167	2	1	3	2	2	1527	118	129	•	116	116
168	2	1	3	2	3	1426	124	84	•	130	109
169	2	2	3	2	1	4478	438	131	•	158	94
170	2	2	3	2	2	3578	447	89	•	161	119
171	2	2	3	2	3	4416	447	93	•	155	118
172	2	3	3	2	1	1985	343	8	•	88	54
173	2	3	3	2	2	1933	345	21	•	114	50
174	2	3	3	2	3	1949	348	21	•	108	72
175	2	4	3	2	1	430	326	10	172	86	119
176	2	4	3	2	2	405	326	12	163	89	109
177	2	4	3	2	3	458	326	-2	193	108	115
178	2	5	3	2	1	2615	168	67	135	138	101
179	2	5	3	2	2	2803	180	66	139	127	113
180	2	5	3	2	3	2666	165	68	142	123	113
181	3	1	1	1	1	1229	212	42	•	97	96
182	3	1	1	1	2	1220	214	45	•	111	105
183	3	1	1	1	3	1323	225	41	•	•	•
184	3	2	1	1	1	2274	333	5	•	117	28
185	3	2	1	1	2	2315	328	27	•	100	57
186	3	2	1	1	3	2338	332	45	•	100	56
187	3	3	1	1	1	2333	402	38	•	122	53
188	3	3	1	1	2	2528	405	35	•	132	59
189	3	3	1	1	3	2408	382	33	•	131	59
190	3	4	1	1	1	1556	299	47	280	131	81
191	3	4	1	1	2	1561	301	52	226	140	92
192	3	4	1	1	3	1497	290	45	264	137	77
193	3	5	1	1	1	2807	266	109	240	147	121
194	3	5	1	1	2	2758	246	106	285	131	132
195	3	5	1	1	3	2835	253	133	212	127	109
196	3	1	1	2	1	1113	208	26	•	96	97
197	3	1	1	2	2	1299	221	10	•	88	100
198	3	1	1	2	3	992	205	7	•	78	105
199	3	2	1	2	1	2283	338	2	•	104	41
200	3	2	1	2	2	2159	326	3	•	107	34
201	3	2	1	2	3	2054	313	-1	•	87	25
202	3	3	1	2	1	2356	374	46	•	120	59
203	3	3	1	2	2	2485	380	74	•	124	425
204	3	3	1	2	3	2359	385	28	•	111	50

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(RD)
205	3	4	1	2	1	1456	281	18	192	131	79
206	3	4	1	2	2	1565	284	31	138	127	95
207	3	4	1	2	3	1521	282	44	185	133	73
208	3	5	1	2	1	2681	255	111	•	116	125
209	3	5	1	2	2	2830	252	110	171	118	111
210	3	5	1	2	3	2709	231	67	156	105	114
211	3	1	2	1	1	1349	206	64	•	131	111
212	3	1	2	1	2	1530	197	•	•	119	121
213	3	1	2	1	3	1570	204	101	•	101	100
214	3	2	2	1	1	2906	434	1	•	125	33
215	3	2	2	1	2	2010	422	-3	•	112	16
216	3	2	2	1	3	2940	436	64	•	106	21
217	3	3	2	1	1	2401	382	29	•	120	60
218	3	3	2	1	2	2349	382	29	•	130	45
219	3	3	2	1	3	2517	383	42	•	140	78
220	3	4	2	1	1	1313	335	67	328	136	82
221	3	4	2	1	2	1370	338	193	346	125	107
222	3	4	2	1	3	1293	342	86	344	124	98
223	3	5	2	1	1	3000	256	147	323	123	109
224	3	5	2	1	2	3057	217	116	346	134	111
225	3	5	2	1	3	3047	196	178	446	134	124
226	3	1	2	2	1	1400	199	41	•	122	109
227	3	1	2	2	2	1451	208	139	•	121	108
228	3	1	2	2	3	1432	213	88	•	109	112
229	3	2	2	2	1	2742	436	85	•	128	49
230	3	2	2	2	2	2457	435	12	•	125	15
231	3	2	2	2	3	2680	448	10	•	134	19
232	3	3	2	2	1	2088	381	71	•	125	70
233	3	3	2	2	2	2199	390	33	•	132	66
234	3	3	2	2	3	2202	386	16	•	127	68
235	3	4	2	2	1	1142	362	18	184	146	111
236	3	4	2	2	2	1222	357	71	241	137	111
237	3	4	2	2	3	1158	358	55	247	137	102
238	3	5	2	2	1	2975	259	95	203	139	129
239	3	5	2	2	2	3107	242	86	205	131	130
240	3	5	2	2	3	3021	254	88	206	111	115
241	3	1	3	1	1	1789	189	154	•	115	113
242	3	1	3	1	2	1775	197	150	•	111	102
243	3	1	3	1	3	1687	175	27	•	109	105
244	3	2	3	1	1	3734	479	57	•	122	52
245	3	2	3	1	2	3543	485	44	•	112	60
246	3	2	3	1	3	3350	480	38	•	109	37
247	3	3	3	1	1	2118	394	32	•	126	49
248	3	3	3	1	2	2248	402	57	•	116	52
249	3	3	3	1	3	2429	395	56	•	143	51
250	3	4	3	1	1	980	358	45	337	132	97
251	3	4	3	1	2	1063	353	138	421	152	135
252	3	4	3	1	3	1043	361	74	416	128	109
253	3	5	3	1	1	3591	242	167	280	122	123
254	3	5	3	1	2	3519	252	115	261	134	128
255	3	5	3	1	3	3519	247	105	437	126	122
256	3	1	3	2	1	1529	171	•	•	94	103
257	3	1	3	2	2	1365	169	30	•	111	103
258	3	1	3	2	3	1631	193	95	•	115	117
259	3	2	3	2	1	3315	462	77	•	122	49
260	3	2	3	2	2	3409	482	58	•	103	22
261	3	2	3	2	3	2909	464	8	•	98	60
262	3	3	3	2	1	2379	387	73	•	120	48
263	3	3	3	2	2	2258	367	38	•	119	55
264	3	3	3	2	3	2302	361	36	•	132	59
265	3	4	3	2	1	1217	350	56	279	131	92
266	3	4	3	2	2	1214	353	70	300	119	76
267	3	4	3	2	3	1277	349	74	278	123	77
268	3	5	3	2	1	3063	151	79	265	126	114
269	3	5	3	2	2	3347	192	153	249	125	110
270	3	5	3	2	3	3375	193	225	253	134	115
271	4	1	1	1	1	1385	238	69	•	94	109
272	4	1	1	1	2	1067	208	45	•	84	107

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
273	4	1	1	1	3	1317	230	41	•	101	96
274	4	2	1	1	1	1777	352	61	•	83	57
275	4	2	1	1	2	1741	339	17	•	104	66
276	4	2	1	1	3	1811	335	27	•	76	40
277	4	3	1	1	1	2200	425	74	•	64	35
278	4	3	1	1	2	2250	424	40	•	84	35
279	4	3	1	1	3	2190	423	15	•	77	37
280	4	4	1	1	1	1237	336	11	278	66	89
281	4	4	1	1	2	1269	332	97	297	91	100
282	4	4	1	1	3	1212	338	116	290	74	102
283	4	5	1	1	1	2334	260	72	163	102	105
284	4	5	1	1	2	2297	266	119	181	90	118
285	4	5	1	1	3	2345	228	77	119	80	119
286	.	1	1	2	1	1241	227	20	•	111	121
287	4	1	1	2	2	1221	225	25	•	95	99
288	4	1	1	2	3	1175	223	17	•	71	112
289	4	2	1	2	1	1616	313	15	•	66	55
290	4	2	1	2	2	1599	307	34	•	60	66
291	4	2	1	2	3	1488	303	20	•	89	67
292	4	3	1	2	1	2176	406	14	•	71	22
293	4	3	1	2	2	2027	413	15	•	56	24
294	4	3	1	2	3	2088	404	20	•	44	28
295	4	4	1	2	1	1460	312	-6	262	64	117
296	4	4	1	2	2	1382	325	-14	120	53	78
297	4	4	1	2	3	1388	329	-6	136	50	80
298	4	5	1	2	1	2216	280	38	89	91	32
299	4	5	1	2	2	2176	216	60	132	70	77
300	4	5	1	2	3	2270	238	77	147	81	110
301	4	1	2	1	1	1512	237	9	•	127	104
302	4	1	2	1	2	1516	233	95	•	100	127
303	4	1	2	1	3	1586	220	107	•	111	108
304	4	2	2	1	1	3097	472	38	•	116	142
305	4	2	2	1	2	2438	428	17	•	79	62
306	4	2	2	1	3	2384	448	-11	•	132	76
307	4	3	2	1	1	2270	426	111	•	73	37
308	4	3	2	1	2	2323	419	56	•	75	34
309	4	3	2	1	3	2269	419	•	•	66	29
310	4	4	2	1	1	947	357	22	239	112	104
311	4	4	2	1	2	871	355	57	•	87	126
312	4	4	2	1	3	919	354	45	251	100	103
313	4	5	2	1	1	2537	228	•	•	100	98
314	4	5	2	1	2	2585	258	98	231	121	98
315	4	5	2	1	3	2483	258	200	206	104	97
316	4	1	2	2	1	1185	196	39	•	106	113
317	4	1	2	2	2	1237	221	98	•	99	116
318	4	1	2	2	3	1163	196	•	•	115	115
319	4	2	2	2	1	1776	383	55	•	100	94
320	4	2	2	2	2	1917	377	19	•	124	114
321	4	2	2	2	3	1899	384	15	•	84	74
322	4	3	2	2	1	2312	404	52	•	84	34
323	4	3	2	2	2	2291	387	53	•	69	24
324	4	3	2	2	3	2259	384	53	•	80	43
325	4	4	2	2	1	1169	347	19	163	51	107
326	4	4	2	2	2	1204	349	6	143	64	92
327	4	4	2	2	3	1160	346	35	188	98	97
328	4	5	2	2	1	2362	195	112	184	134	106
329	4	5	2	2	2	2501	219	86	163	109	132
330	4	5	2	2	3	2463	201	111	179	91	95
331	4	1	3	1	1	1562	203	79	•	111	132
332	4	1	3	1	2	1385	190	87	•	121	119
333	4	1	3	1	3	1472	190	85	•	119	115
334	4	2	3	1	1	2670	480	63	•	132	112
335	4	2	3	1	2	2678	486	49	•	127	113
336	4	2	3	1	3	2720	481	89	•	124	113
337	4	3	3	1	1	2222	415	20	•	44	35
338	4	3	3	1	2	2198	424	50	•	81	35
339	4	3	3	1	3	2170	412	43	•	90	34
340	4	4	3	1	1	588	371	84	389	101	112

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
341	4	4	3	1	2	617	371	35	379	106	120
342	4	4	3	1	3	640	371	33	413	111	126
343	4	5	3	1	1	2759	210	99	265	141	136
344	4	5	3	1	2	2834	242	102	271	137	116
345	4	5	3	1	3	2702	244	65	296	126	125
346	4	1	3	2	1	1493	197	155	•	107	136
347	4	1	3	2	2	1333	200	86	•	132	141
348	4	1	3	2	3	1326	180	102	•	117	119
349	4	2	3	2	1	2394	492	50	•	117	86
350	4	2	3	2	2	2361	469	14	•	105	114
351	4	2	3	2	3	2295	476	3	•	139	120
352	4	3	3	2	1	2101	404	86	•	61	31
353	4	3	3	2	2	2126	404	29	•	67	30
354	4	3	3	2	3	2051	404	42	•	79	29
355	4	4	3	2	1	803	369	58	312	100	123
356	4	4	3	2	2	851	367	46	303	117	99
357	4	4	3	2	3	793	371	31	303	99	118
358	4	5	3	2	1	2486	194	66	221	100	85
359	4	5	3	2	2	2338	185	79	175	114	103
360	4	5	3	2	3	•	•	39	248	96	100
361	5	1	1	1	1	863	155	194	•	84	104
362	5	1	1	1	2	891	152	220	•	93	97
363	5	1	1	1	3	872	151	164	•	89	96
364	5	2	1	1	1	1486	260	140	•	108	48
365	5	2	1	1	2	1466	267	140	•	110	31
366	5	2	1	1	3	1386	251	140	•	115	36
367	5	3	1	1	1	1810	322	176	•	72	44
368	5	3	1	1	2	1742	328	163	•	56	33
369	5	3	1	1	3	1776	320	184	•	74	35
370	5	4	1	1	1	940	231	182	590	80	110
371	5	4	1	1	2	930	230	197	584	101	117
372	5	4	1	1	3	847	228	172	581	94	100
373	5	5	1	1	1	2182	165	234	330	104	122
374	5	5	1	1	2	2215	162	216	228	111	124
375	5	5	1	1	3	2038	185	276	321	99	127
376	5	1	1	2	1	543	137	188	•	87	114
377	5	1	1	2	2	677	145	174	•	103	109
378	5	1	1	2	3	771	151	226	•	87	112
379	5	2	1	2	1	1433	239	160	•	91	54
380	5	2	1	2	2	1173	226	147	•	102	39
381	5	2	1	2	3	1298	234	160	•	108	24
382	5	3	1	2	1	1718	310	165	•	84	45
383	5	3	1	2	2	1707	309	260	•	77	32
384	5	3	1	2	3	1764	311	171	•	90	48
385	5	4	1	2	1	950	245	174	464	84	125
386	5	4	1	2	2	857	247	143	432	73	110
387	5	4	1	2	3	789	249	170	429	60	108
388	5	5	1	2	1	1884	170	232	376	84	97
389	5	5	1	2	2	1784	172	221	287	79	120
390	5	5	1	2	3	1902	164	222	204	96	128
391	5	1	2	1	1	1027	126	250	•	96	112
392	5	1	2	1	2	1078	131	225	•	104	114
393	5	1	2	1	3	1056	126	321	•	110	121
394	5	2	2	1	1	1820	346	162	•	126	67
395	5	2	2	1	2	1930	340	180	•	121	39
396	5	2	2	1	3	1706	353	143	•	117	48
397	5	3	2	1	1	1649	315	199	•	61	47
398	5	3	2	1	2	1630	327	205	•	69	48
399	5	3	2	1	3	1640	323	192	•	79	28
400	5	4	2	1	1	589	266	202	783	114	113
401	5	4	2	1	2	749	252	228	907	97	105
402	5	4	2	1	3	640	255	234	848	126	104
403	5	5	2	1	1	2080	155	246	•	100	120
404	5	5	2	1	2	2144	120	283	400	119	129
405	5	5	2	1	3	2295	131	172	248	98	121
406	5	1	2	2	1	896	126	219	•	98	145
407	5	1	2	2	2	963	118	344	•	106	156
408	5	1	2	2	3	834	143	210	•	118	174

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
409	5	2	2	2	1	1959	336	175	•	108	60
410	5	2	2	2	2	1670	317	155	•	105	55
411	5	2	2	2	3	1458	310	137	•	117	44
412	5	3	2	2	1	1651	293	192	•	90	51
413	5	3	2	2	2	1772	307	179	•	82	37
414	5	3	2	2	3	1747	310	158	•	75	46
415	5	4	2	2	1	642	270	158	568	82	121
416	5	4	2	2	2	868	261	142	586	109	123
417	5	4	2	2	3	761	262	163	583	120	118
418	5	5	2	2	1	1975	124	187	292	91	108
419	5	5	2	2	2	2194	152	234	262	101	121
420	5	5	2	2	3	2142	152	234	252	75	116
421	5	1	3	1	1	1148	103	302	•	111	107
422	5	1	3	1	2	1044	108	285	•	126	111
423	5	1	3	1	3	1378	107	261	•	131	114
424	5	2	3	1	1	1942	386	152	•	137	25
425	5	2	3	1	2	1743	389	140	•	141	23
426	5	2	3	1	3	2167	404	297	•	109	28
427	5	3	3	1	1	1864	321	257	•	84	45
428	5	3	3	1	2	1811	309	209	•	61	48
429	5	3	3	1	3	1780	310	302	•	85	46
430	5	4	3	1	1	497	288	166	877	113	111
431	5	4	3	1	2	495	289	167	872	115	108
432	5	4	3	1	3	439	289	186	850	143	129
433	5	5	3	1	1	2291	132	302	545	133	136
434	5	5	3	1	2	2391	156	148	248	136	137
435	5	5	3	1	3	2304	163	214	357	118	127
436	5	1	3	2	1	1197	94	333	•	106	120
437	5	1	3	2	2	897	100	•	•	118	129
438	5	1	3	2	3	860	93	319	•	138	113
439	5	2	3	2	1	2112	376	190	•	117	74
440	5	2	3	2	2	2353	376	153	•	141	49
441	5	2	3	2	3	2197	387	237	•	133	64
442	5	3	3	2	1	1813	306	197	•	90	62
443	5	3	3	2	2	1879	315	192	•	81	52
444	5	3	3	2	3	1782	303	277	•	72	36
445	5	4	3	2	1	613	286	193	649	106	118
446	5	4	3	2	2	750	280	243	516	140	103
447	5	4	3	2	3	609	283	134	535	121	114
448	5	5	3	2	1	2325	111	224	296	114	106
449	5	5	3	2	2	2504	109	221	245	126	129
450	5	5	3	2	3	2622	129	223	390	109	121
451	6	1	1	1	1	1310	163	22	•	141	65
452	6	1	1	1	2	1221	153	44	•	127	81
453	6	1	1	1	3	1468	170	35	•	136	77
454	6	2	1	1	1	1846	265	48	•	155	46
455	6	2	1	1	2	1949	277	39	•	139	38
456	6	2	1	1	3	1904	262	11	•	138	32
457	6	3	1	1	1	2084	303	66	•	110	24
458	6	3	1	1	2	2131	310	35	•	124	29
459	6	3	1	1	3	2188	299	27	•	112	15
460	6	4	1	1	1	1006	227	28	195	114	123
461	6	4	1	1	2	911	235	46	219	98	59
462	6	4	1	1	3	952	232	15	225	122	95
463	6	5	1	1	1	2199	160	52	129	146	87
464	6	5	1	1	2	2143	147	47	179	109	87
465	6	5	1	1	3	2135	152	89	179	108	71
466	6	1	1	2	1	1119	152	7	•	145	74
467	6	1	1	2	2	1149	156	26	•	134	99
468	6	1	1	2	3	1054	155	6	•	134	86
469	6	2	1	2	1	1482	257	-11	•	150	65
470	6	2	1	2	2	1316	244	49	•	149	88
471	6	2	1	2	3	1415	246	4	•	146	58
472	6	3	1	2	1	1874	285	18	•	102	21
473	6	3	1	2	2	1867	279	23	•	121	15
474	6	3	1	2	3	1733	276	37	•	117	26
475	6	4	1	2	1	988	217	17	156	106	43
476	6	4	1	2	2	1034	219	3	86	83	51

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
477	6	4	1	2	3	1095	221	22	84	95	72
478	6	5	1	2	1	2001	129	42	117	126	46
479	6	5	1	2	2	1798	99	42	133	93	49
480	6	5	1	2	3	1773	97	55	174	103	46
481	6	1	2	1	1	1402	142	99	•	168	117
482	6	1	2	1	2	1460	142	61	•	141	97
483	6	1	2	1	3	1433	143	76	•	143	94
484	6	2	2	1	1	2763	401	63	•	162	55
485	6	2	2	1	2	2956	373	77	•	149	71
486	6	2	2	1	3	2495	367	55	•	138	50
487	6	3	2	1	1	2288	319	84	•	122	52
488	6	3	2	1	2	2108	282	56	•	145	37
489	6	3	2	1	3	2186	295	44	•	110	40
490	6	4	2	1	1	750	273	36	226	111	87
491	6	4	2	1	2	691	265	42	300	93	105
492	6	4	2	1	3	•	•	41	310	91	93
493	6	5	2	1	1	2480	153	57	199	165	109
494	6	5	2	1	2	2463	164	62	125	164	109
495	6	5	2	1	3	2624	169	89	146	164	105
496	6	1	2	2	1	1223	132	37	•	135	80
497	6	1	2	2	2	1284	142	29	•	132	98
498	6	1	2	2	3	1415	144	52	•	138	101
499	6	2	2	2	1	2268	361	36	•	•	•
500	6	2	2	2	2	2336	345	49	•	167	89
501	6	2	2	2	3	2345	367	44	•	146	89
502	6	3	2	2	1	1874	285	57	•	138	53
503	6	3	2	2	2	1867	279	70	•	116	38
504	6	3	2	2	3	1733	276	47	•	122	45
505	6	4	2	2	1	885	262	4	237	118	83
506	6	4	2	2	2	930	259	35	196	109	57
507	6	4	2	2	3	904	261	19	192	•	57
508	6	5	2	2	1	2565	145	•	•	147	86
509	6	5	2	2	2	2542	139	62	176	136	66
510	6	5	2	2	3	2532	141	112	145	117	69
511	6	1	3	1	1	1316	107	125	•	148	92
512	6	1	3	1	2	1469	117	138	•	131	97
513	6	1	3	1	3	1434	131	119	•	150	91
514	6	2	3	1	1	2779	423	60	•	149	83
515	6	2	3	1	2	2913	398	75	•	148	58
516	6	2	3	1	3	•	•	•	•	148	88
517	6	3	3	1	1	1777	244	53	•	121	18
518	6	3	3	1	2	1764	249	56	•	145	50
519	6	3	3	1	3	1890	267	58	•	160	15
520	6	4	3	1	1	600	286	60	313	184	66
521	6	4	3	1	2	699	289	21	334	239	71
522	6	4	3	1	3	727	296	52	321	278	67
523	6	5	3	1	1	2571	94	50	257	153	110
524	6	5	3	1	2	2497	73	8	298	170	115
525	6	5	3	1	3	2672	74	70	387	138	112
526	6	1	3	2	1	1489	113	191	•	131	96
527	6	1	3	2	2	1357	109	98	•	148	111
528	6	1	3	2	3	1187	112	196	•	137	108
529	6	2	3	2	1	2889	385	54	•	139	101
530	6	2	3	2	2	2685	376	106	•	145	88
531	6	2	3	2	3	•	•	78	•	145	89
532	6	3	3	2	1	1790	259	80	•	124	25
533	6	3	3	2	2	1805	259	34	•	148	27
534	6	3	3	2	3	1719	254	33	•	143	51
535	6	4	3	2	1	732	277	3	214	90	45
536	6	4	3	2	2	764	280	24	133	101	52
537	6	4	3	2	3	811	282	35	138	102	62
538	6	5	3	2	1	2237	56	44	179	106	41
539	6	5	3	2	2	2308	75	36	181	112	48
540	6	5	3	2	3	2119	46	36	181	104	61
541	7	1	1	1	1	1393	218	52	•	134	114
542	7	1	1	1	2	1346	216	43	•	113	111
543	7	1	1	1	3	1346	213	31	•	145	122
544	7	2	1	1	1	1932	311	91	•	128	94

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
545	7	2	1	1	2	1827	334	35	•	150	96
546	7	2	1	1	3	1832	296	90	•	160	147
547	7	3	1	1	1	2030	337	51	•	101	118
548	7	3	1	1	2	2071	345	53	•	118	99
549	7	3	1	1	3	2040	359	48	•	117	89
550	7	4	1	1	1	918	300	73	254	93	107
551	7	4	1	1	2	1080	296	106	166	126	117
552	7	4	1	1	3	918	300	65	190	113	116
553	7	5	1	1	1	2272	268	46	133	141	120
554	7	5	1	1	2	2152	268	123	153	110	115
555	7	5	1	1	3	2228	255	105	150	105	104
556	7	1	1	2	1	1313	206	86	•	132	107
557	7	1	1	2	2	1126	212	61	•	136	108
558	7	1	1	2	3	1236	212	80	•	158	149
559	7	2	1	2	1	1366	261	123	•	157	106
560	7	2	1	2	2	1510	271	77	•	130	105
561	7	2	1	2	3	1562	275	39	•	181	134
562	7	3	1	2	1	2015	330	40	•	124	87
563	7	3	1	2	2	1855	331	29	•	124	89
564	7	3	1	2	3	1807	321	45	•	120	83
565	7	4	1	2	1	1119	299	55	256	121	139
566	7	4	1	2	2	1029	300	62	249	105	113
567	7	4	1	2	3	1029	300	96	199	110	113
568	7	5	1	2	1	2249	240	110	140	132	119
569	7	5	1	2	2	2186	247	102	123	108	91
570	7	5	1	2	3	2255	250	110	128	128	118
571	7	1	2	1	1	1561	192	178	•	137	106
572	7	1	2	1	2	1497	193	79	•	158	176
573	7	1	2	1	3	1489	205	80	•	139	151
574	7	2	2	1	1	3098	428	66	•	173	106
575	7	2	2	1	2	3107	430	56	•	130	77
576	7	2	2	1	3	2936	415	49	•	169	131
577	7	3	2	1	1	2100	349	52	•	132	80
578	7	3	2	1	2	2043	354	79	•	115	91
579	7	3	2	1	3	2025	348	37	•	120	166
580	7	4	2	1	1	729	310	79	286	164	125
581	7	4	2	1	2	694	312	64	288	145	117
582	7	4	2	1	3	963	313	54	314	140	119
583	7	5	2	1	1	2560	259	105	186	170	147
584	7	5	2	1	2	2569	248	105	168	158	138
585	7	5	2	1	3	2218	206	134	161	162	141
586	7	1	2	2	1	1517	189	152	•	134	147
587	7	1	2	2	2	1404	190	161	•	146	153
588	7	1	2	2	3	1409	196	150	•	159	156
589	7	2	2	2	1	2044	355	63	•	186	242
590	7	2	2	2	2	1972	348	68	•	155	269
591	7	2	2	2	3	1840	362	15	•	136	181
592	7	3	2	2	1	2103	338	48	•	156	120
593	7	3	2	2	2	2092	326	22	•	178	92
594	7	3	2	2	3	1892	331	35	•	135	87
595	7	4	2	2	1	865	313	53	232	123	127
596	7	4	2	2	2	898	313	44	204	137	147
597	7	4	2	2	3	695	313	43	195	123	114
598	7	5	2	2	1	2487	219	76	136	151	120
599	7	5	2	2	2	2355	209	137	137	138	110
600	7	5	2	2	3	2357	202	48	96	142	118
601	7	1	3	1	1	1585	202	136	•	147	109
602	7	1	3	1	2	1829	164	138	•	149	103
603	7	1	3	1	3	1781	201	170	•	142	128
604	7	2	3	1	1	2672	431	25	•	178	116
605	7	2	3	1	2	2362	409	46	•	193	96
606	7	2	3	1	3	2358	418	56	•	153	155
607	7	3	3	1	1	2171	361	19	•	132	86
608	7	3	3	1	2	2239	360	25	•	105	80
609	7	3	3	1	3	1933	344	32	•	114	104
610	7	4	3	1	1	337	320	20	330	142	106
611	7	4	3	1	2	509	327	65	398	142	125
612	7	4	3	1	3	398	316	69	396	142	131

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
613	7	5	3	1	1	3022	241	105	203	174	146
614	7	5	3	1	2	2679	209	113	179	171	152
615	7	5	3	1	3	2596	204	57	156	186	155
616	7	1	3	2	1	1745	167	231	•	118	115
617	7	1	3	2	2	1761	171	205	•	146	186
618	7	1	3	2	3	1436	190	115	•	146	131
619	7	2	3	2	1	2381	404	70	•	177	116
620	7	2	3	2	2	2321	398	72	•	153	131
621	7	2	3	2	3	•	•	117	•	167	187
622	7	3	3	2	1	2179	333	46	•	145	135
623	7	3	3	2	2	2053	331	70	•	111	113
624	7	3	3	2	3	2024	333	34	•	150	151
625	7	4	3	2	1	359	327	64	294	131	159
626	7	4	3	2	2	522	328	30	264	151	137
627	7	4	3	2	3	•	•	47	315	143	153
628	7	5	3	2	1	2116	127	114	176	174	148
629	7	5	3	2	2	2760	184	35	133	158	126
630	7	5	3	2	3	2796	200	83	147	139	122
631	8	1	1	1	1	937	190	71	•	110	103
632	8	1	1	1	2	1046	190	112	•	104	92
633	8	1	1	1	3	1052	195	174	•	112	100
634	8	2	1	1	1	2270	272	8	•	111	45
635	8	2	1	1	2	2256	286	6	•	115	61
636	8	2	1	1	3	2473	282	-1	•	112	71
637	8	3	1	1	1	1898	307	67	•	106	33
638	8	3	1	1	2	1916	311	45	•	102	15
639	8	3	1	1	3	1915	311	71	•	113	10
640	8	4	1	1	1	1178	290	4	119	65	110
641	8	4	1	1	2	1179	285	110	223	63	98
642	8	4	1	1	3	1168	278	67	204	84	115
643	8	5	1	1	1	2085	177	60	123	65	78
644	8	5	1	1	2	2155	181	38	161	85	85
645	8	5	1	1	3	2173	160	97	128	96	92
646	8	1	1	2	1	919	186	41	•	114	102
647	8	1	1	2	2	1136	204	50	•	146	95
648	8	1	1	2	3	915	184	69	•	99	91
649	8	2	1	2	1	2264	274	50	•	112	52
650	8	2	1	2	2	2361	298	24	•	104	71
651	8	2	1	2	3	2302	275	22	•	111	76
652	8	3	1	2	1	1573	291	63	•	112	17
653	8	3	1	2	2	1515	287	86	•	134	14
654	8	3	1	2	3	1642	288	103	•	147	13
655	8	4	1	2	1	1311	277	47	148	87	106
656	8	4	1	2	2	1338	276	61	167	91	104
657	8	4	1	2	3	1288	263	64	140	113	79
658	8	5	1	2	1	1968	149	83	109	122	78
659	8	5	1	2	2	2070	128	79	121	134	111
660	8	5	1	2	3	2167	138	82	128	127	119
661	8	1	2	1	1	1481	187	126	•	134	115
662	8	1	2	1	2	1504	195	275	•	172	95
663	8	1	2	1	3	1223	188	163	•	144	95
664	8	2	2	1	1	3598	376	60	•	113	71
665	8	2	2	1	2	4031	387	50	•	137	77
666	8	2	2	1	3	3287	396	25	•	146	63
667	8	3	2	1	1	1863	294	60	•	122	37
668	8	3	2	1	2	2225	305	40	•	144	55
669	8	3	2	1	3	2029	298	28	•	107	30
670	8	4	2	1	1	968	312	68	274	76	99
671	8	4	2	1	2	1015	312	65	335	109	100
672	8	4	2	1	3	•	•	106	384	98	95
673	8	5	2	1	1	2468	126	75	133	123	124
674	8	5	2	1	2	2356	113	59	249	106	122
675	8	5	2	1	3	•	•	60	291	104	116
676	8	1	2	2	1	1086	176	95	•	149	95
677	8	1	2	2	2	1362	182	211	•	108	89
678	8	1	2	2	3	1342	190	190	•	144	100
679	8	2	2	2	1	3447	408	11	•	112	68
680	8	2	2	2	2	3367	428	42	•	134	108

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
681	8	2	2	2	3	3236	409	54	•	128	60
682	8	3	2	2	1	1935	311	44	•	112	23
683	8	3	2	2	2	1899	300	23	•	98	19
684	8	3	2	2	3	2017	291	47	•	100	50
685	8	4	2	2	1	1127	314	122	232	96	86
686	8	4	2	2	2	1161	310	89	184	112	88
687	8	4	2	2	3	1301	308	135	145	112	87
688	8	5	2	2	1	2520	146	74	237	113	95
689	8	5	2	2	2	2572	165	57	157	90	80
690	8	5	2	2	3	2351	119	126	164	123	103
691	8	1	3	1	1	1706	173	263	•	173	97
692	8	1	3	1	2	1532	167	140	•	221	92
693	8	1	3	1	3	1510	149	210	•	234	85
694	8	2	3	1	1	3920	483	38	•	117	67
695	8	2	3	1	2	3777	489	26	•	186	68
696	8	2	3	1	3	4050	490	22	•	121	51
697	8	3	3	1	1	1976	285	59	•	133	37
698	8	3	3	1	2	1873	292	67	•	98	21
699	8	3	3	1	3	1957	280	•	•	140	46
700	8	4	3	•	1	781	343	94	312	144	79
701	8	4	3	1	2	810	343	74	340	88	103
702	8	4	3	1	3	802	344	111	324	97	101
703	8	5	3	1	1	3119	163	51	275	133	114
704	8	5	3	1	2	2955	135	85	260	109	122
705	8	5	3	1	3	3101	159	60	291	120	118
706	8	1	3	2	1	1416	148	124	•	120	90
707	8	1	3	2	2	1428	158	206	•	136	99
708	8	1	3	2	3	1462	172	224	•	128	96
709	8	2	3	2	1	3707	454	53	•	130	84
710	8	2	3	2	2	3160	429	59	•	132	91
711	8	2	3	2	3	3767	461	51	•	140	104
712	8	3	3	2	1	1832	294	45	•	101	54
713	8	3	3	2	2	1805	291	63	•	119	53
714	8	3	3	2	3	1827	301	63	•	102	29
715	8	4	3	2	1	928	329	125	235	103	72
716	8	4	3	2	2	851	333	167	254	94	65
717	8	4	3	2	3	848	327	107	232	106	90
718	8	5	3	2	1	2405	61	74	239	106	103
719	8	5	3	2	2	2640	93	63	162	107	106
720	8	5	3	2	3	2508	76	109	196	116	107
721	9	1	1	1	1	923	143	16	•	111	93
722	9	1	1	1	2	798	140	2	•	116	97
723	9	1	1	1	3	860	140	87	•	105	99
724	9	2	1	1	1	1274	215	53	•	94	45
725	9	2	1	1	2	1311	216	78	•	75	58
726	9	2	1	1	3	1518	224	64	•	81	76
727	9	3	1	1	1	1736	255	37	•	123	78
728	9	3	1	1	2	1875	252	39	•	131	73
729	9	3	1	1	3	1882	262	32	•	127	92
730	9	4	1	1	1	988	257	35	145	98	88
731	9	4	1	1	2	1004	255	•	•	132	80
732	9	4	1	1	3	1004	259	59	174	113	83
733	9	5	1	1	1	2034	130	36	154	118	115
734	9	5	1	1	2	2120	139	44	116	127	126
735	9	5	1	1	3	•	•	39	105	•	•
736	9	1	1	2	1	699	151	112	•	111	97
737	9	1	1	2	2	414	139	69	•	92	90
738	9	1	1	2	3	364	136	42	•	82	97
739	9	2	1	2	1	1582	221	46	•	105	48
740	9	2	1	2	2	1397	216	62	•	89	29
741	9	2	1	2	3	1150	214	39	•	68	59
742	9	3	1	2	1	1779	245	50	•	131	92
743	9	3	1	2	2	1450	246	45	•	135	66
744	9	3	1	2	3	1653	248	46	•	129	86
745	9	4	1	2	1	1078	254	38	145	123	93
746	9	4	1	2	2	1105	253	38	116	105	83
747	9	4	1	2	3	1054	254	26	101	125	92
748	9	5	1	2	1	2013	125	34	138	120	118

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
749	9	5	1	2	2	1973	129	21	127	120	96
750	9.	5	1	2	3	1966	125	47	127	113	91
751	9	1	2	1	1	1168	131	137	•	117	106
752	9	1	2	1	2	1169	137	134	•	125	118
753	9	1	2	1	3	1431	147	176	•	118	117
754	9	2	2	1	1	2564	303	38	•	129	152
755	9	2	2	1	2	2286	299	41	•	95	164
756	9	2	2	1	3	2156	296	•	•	114	153
757	9	3	2	1	1	1924	259	57	•	122	148
758	9	3	2	1	2	2030	255	54	•	136	156
759	9	3	2	1	3	2108	279	71	•	138	148
760	9	4	2	1	1	691	272	0	222	95	141
761	9	4	2	1	2	617	277	12	218	108	171
762	9	4	2	1	3	644	280	22	199	111	164
763	9	5	2	1	1	2263	98	49	166	122	146
764	9	5	2	1	2	2471	136	47	140	125	142
765	9	5	2	1	3	2565	130	34	181	129	136
766	9	1	2	2	1	1056	132	207	•	137	149
767	9	1	2	2	2	1007	137	139	•	124	142
768	9	1	2	2	3	637	117	140	•	142	156
769	9	2	2	2	1	2253	306	32	•	119	164
770	9	2	2	2	2	1924	303	41	•	110	159
771	9	2	2	2	3	2369	311	59	•	109	171
772	9	3	2	2	1	1621	240	19	•	131	130
773	9	3	2	2	2	1595	241	61	•	127	144
774	9	3	2	2	3	1631	246	50	•	117	144
775	9	4	2	2	1	847	277	31	211	102	155
776	9	4	2	2	2	772	270	17	171	107	158
777	9	4	2	2	3	807	275	25	75	101	153
778	9	5	2	2	1	2213	101	29	170	126	151
779	9	5	2	2	2	2126	87	13	102	118	144
780	9	5	2	2	3	2144	93	21	138	99	154
781	9	1	3	1	1	1353	119	18	•	122	134
782	9	1	3	1	2	1176	111	116	•	122	134
783	9	1	3	1	3	1207	108	69	•	107	117
784	9	2	3	1	1	2315	350	44	•	129	194
785	9	2	3	1	2	2400	344	72	•	161	146
786	9	2	3	1	3	2524	347	63	•	129	117
787	9	3	3	1	1	1556	252	59	•	119	121
788	9	3	3	1	2	1502	245	66	•	134	112
789	9	3	3	1	3	1799	250	43	•	138	158
790	9	4	3	1	1	591	280	38	264	141	136
791	9	4	3	1	2	671	284	-6	347	140	122
792	9	4	3	1	3	670	279	72	247	133	111
793	9	5	3	1	1	2469	71	27	193	132	133
794	9	5	3	1	2	2596	72	70	324	146	133
795	9	5	3	1	3	•	•	58	284	135	144
796	9	1	3	2	1	1071	105	127	•	116	154
797	9	1	3	2	2	1320	101	117	•	116	154
798	9	1	3	2	3	1088	98	139	•	118	158
799	9	2	3	2	1	1950	337	43	•	121	174
800	9	2	3	2	2	2085	338	29	•	122	141
801	9	2	3	2	3	2342	337	55	•	133	132
802	9	3	3	2	1	1555	237	58	•	130	120
803	9	3	3	2	2	1410	236	92	•	132	155
804	9	3	3	2	3	1539	241	40	•	138	117
805	9	4	3	2	1	709	290	22	224	122	153
806	9	4	3	2	2	675	296	1	184	117	182
807	9	4	3	2	3	605	303	38	184	107	164
808	9	5	3	2	1	2285	60	40	230	127	128
809	9	5	3	2	2	2096	52	51	181	126	128
810	9	5	3	2	3	•	•	27	201	133	144
811	10	1	1	1	1	1073	180	45	•	123	96
812	10	1	1	1	2	1121	176	11	•	123	96
813	10	1	1	1	3	1130	177	37	•	136	92
814	10	2	1	1	1	2435	283	35	•	130	78
815	10	2	1	1	2	2369	288	5	•	138	58
816	10	2	1	1	3	2311	287	13	•	128	54

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
817	10	3	1	1	1	1935	316	53	•	98	62
818	10	3	1	1	2	1960	321	53	•	109	56
819	10	3	1	1	3	2173	319	45	•	132	104
820	10	4	1	1	1	1092	265	35	154	117	98
821	10	4	1	1	2	1128	256	39	147	121	79
822	10	4	1	1	3	1123	259	41	143	112	82
823	10	5	1	1	1	2621	195	71	112	114	123
824	10	5	1	1	2	2654	184	66	99	87	114
825	10	5	1	1	3	2675	181	44	101	86	105
826	10	1	1	2	1	1242	191	73	•	•	•
827	10	1	1	2	2	1204	189	124	•	130	91
828	10	1	1	2	3	1162	185	51	•	121	92
829	10	2	1	2	1	2418	295	18	•	•	•
830	10	2	1	2	2	2298	291	-5	•	119	88
831	10	2	1	2	3	2343	300	-4	•	129	54
832	10	3	1	2	1	1915	315	39	•	110	80
833	10	3	1	2	2	1712	298	32	•	114	54
834	10	3	1	2	3	1869	322	54	•	111	46
835	10	4	1	2	1	1208	280	25	140	•	54
836	10	4	1	2	2	1083	292	48	117	115	96
837	10	4	1	2	3	1021	296	41	117	110	97
838	10	5	1	2	1	2548	188	42	101	124	84
839	10	5	1	2	2	2514	190	30	100	142	95
840	10	5	1	2	3	2544	195	46	113	123	96
841	10	1	2	1	1	1245	171	193	•	125	109
842	10	1	2	1	2	1404	177	173	•	155	111
843	10	1	2	1	3	1302	164	284	•	137	95
844	10	2	2	1	1	3866	423	20	•	172	80
845	10	2	2	1	2	3939	447	44	•	161	85
846	10	2	2	1	3	4077	444	37	•	146	65
847	10	3	2	1	1	2389	345	72	•	132	67
848	10	3	2	1	2	2093	324	•	•	118	65
849	10	3	2	1	3	2095	330	44	•	128	44
850	10	4	2	1	1	963	296	38	240	96	115
851	10	4	2	1	2	897	301	40	251	114	103
852	10	4	2	1	3	776	307	41	210	133	103
853	10	5	2	1	1	2925	169	47	151	128	135
854	10	5	2	1	2	2900	169	38	160	131	130
855	10	5	2	1	3	3004	181	58	163	130	120
856	10	1	2	2	1	990	154	242	•	133	92
857	10	1	2	2	2	1236	166	373	•	137	109
858	10	1	2	2	3	1089	155	189	•	137	107
859	10	2	2	2	1	3695	404	26	•	149	83
860	10	2	2	2	2	3674	415	58	•	160	70
861	10	2	2	2	3	3858	419	37	•	136	99
862	10	3	2	2	1	2031	330	56	•	97	75
863	10	3	2	2	2	2107	325	52	•	118	51
864	10	3	2	2	3	2123	328	61	•	•	50
865	10	4	2	2	1	912	307	25	118	126	111
866	10	4	2	2	2	819	310	35	117	112	108
867	10	4	2	2	3	909	309	44	121	133	110
868	10	5	2	2	1	2813	165	50	118	117	90
869	10	5	2	2	2	2817	175	52	115	128	99
870	10	5	2	2	3	2739	159	39	138	133	92
871	10	1	3	1	1	1407	145	189	•	134	109
872	10	1	3	1	2	1429	133	282	•	133	118
873	10	1	3	1	3	1360	144	231	•	138	110
874	10	2	3	1	1	4875	485	90	•	157	78
875	10	2	3	1	2	5057	480	30	•	145	81
876	10	2	3	1	3	4640	487	24	•	141	•
877	10	3	3	1	1	2137	329	55	•	112	99
878	10	3	3	1	2	2171	336	59	•	92	75
879	10	3	3	1	3	2046	320	71	•	110	77
880	10	4	3	1	1	658	324	32	205	124	119
881	10	4	3	1	2	544	328	51	198	131	115
882	10	4	3	1	3	641	325	40	211	127	129
883	10	5	3	1	1	3282	153	83	152	152	114
884	10	5	3	1	2	3304	168	82	112	133	129

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
885	10	5	3	1	3	3298	159	79	127	119	130
886	10	1	3	2	1	1281	141	451	•	134	102
887	10	1	3	2	2	1368	146	332	•	124	97
888	10	1	3	2	3	1311	144	383	•	130	110
889	10	2	3	2	1	4776	470	61	•	171	82
890	10	2	3	2	2	4729	462	223	•	151	103
891	10	2	3	2	3	4774	476	174	•	147	82
892	10	3	3	2	1	2000	316	51	•	114	72
893	10	3	3	2	2	2094	333	36	•	142	79
894	10	3	3	2	3	2001	322	53	•	120	69
895	10	4	3	2	1	750	326	24	198	101	94
896	10	4	3	2	2	708	327	34	169	126	77
897	10	4	3	2	3	581	328	28	156	113	98
898	10	5	3	2	1	3031	144	34	116	132	108
899	10	5	3	2	2	2944	132	47	119	129	114
900	10	5	3	2	3	3067	147	69	127	150	103
901	11	1	1	1	1	1191	207	65	•	110	107
902	11	1	1	1	2	1276	205	20	•	114	95
903	11	1	1	1	3	1277	195	•	•	112	104
904	11	2	1	1	1	2334	311	65	•	130	69
905	11	2	1	1	2	2442	316	100	•	105	59
906	11	2	1	1	3	2487	302	107	•	126	83
907	11	3	1	1	1	2274	335	33	•	130	58
908	11	3	1	1	2	2201	313	39	•	132	56
909	11	3	1	1	3	2341	326	33	•	130	59
910	11	4	1	1	1	1450	279	-8	105	140	82
911	11	4	1	1	2	1409	263	22	95	138	91
912	11	4	1	1	3	2244	•	33	91	134	65
913	11	5	1	1	1	2244	153	100	179	160	89
914	11	5	1	1	2	2348	166	•	•	150	111
915	11	5	1	1	3	2519	209	136	141	128	111
916	11	1	1	2	1	1121	181	170	•	121	122
917	11	1	1	2	2	933	176	•	•	108	122
918	11	1	1	2	3	841	177	77	•	124	133
919	11	2	1	2	1	2445	289	54	•	130	67
920	11	2	1	2	2	2468	294	102	•	101	90
921	11	2	1	2	3	2233	281	105	•	158	83
922	11	3	1	2	1	3146	357	87	•	117	88
923	11	3	1	2	2	3146	356	60	•	118	91
924	11	3	1	2	3	3316	338	57	•	103	69
925	11	4	1	2	1	1356	247	23	135	148	90
926	11	4	1	2	2	1373	246	16	123	158	131
927	11	4	1	2	3	1547	262	41	162	152	118
928	11	5	1	2	1	2365	193	69	172	142	90
929	11	5	1	2	2	2427	180	102	128	107	120
930	11	5	1	2	3	2398	178	93	143	123	96
931	11	1	2	1	1	1248	167	177	•	140	156
932	11	1	2	1	2	1178	162	201	•	124	135
933	11	1	2	1	3	1248	178	155	•	121	129
934	11	2	2	1	1	4026	398	103	•	152	84
935	11	2	2	1	2	4005	408	58	•	163	71
936	11	2	2	1	3	3706	400	67	•	168	75
937	11	3	2	1	1	2888	342	73	•	131	80
938	11	3	2	1	2	2699	357	81	•	135	101
939	11	3	2	1	3	2832	347	119	•	122	110
940	11	4	2	1	1	1171	285	•	•	156	109
941	11	4	2	1	2	1346	300	68	244	159	118
942	11	4	2	1	3	1376	301	25	295	148	104
943	11	5	2	1	1	2221	108	34	•	199	147
944	11	5	2	1	2	2021	108	131	270	176	133
945	11	5	2	1	3	2146	109	79	269	167	124
946	11	1	2	2	1	1082	154	188	•	160	123
947	11	1	2	2	2	1211	161	223	•	156	118
948	11	1	2	2	3	1160	161	191	•	148	118
949	11	2	2	2	1	2990	363	72	•	148	76
950	11	2	2	2	2	3653	379	53	•	148	112
951	11	2	2	2	3	3688	370	89	•	146	100
952	11	3	2	2	1	2003	279	49	•	155	98

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PVGRF	PHGRF	EMG(ES)	EMG(AD)
953	11	3	2	2	2	2306	300	105	•	143	114
954	11	3	2	2	3	2104	288	78	•	129	99
955	11	4	2	2	1	1393	286	41	185	146	129
956	11	4	2	2	2	1376	284	12	111	132	158
957	11	4	2	2	3	1142	283	21	130	117	148
958	11	5	2	2	1	1859	57	54	173	158	85
959	11	5	2	2	2	2378	118	70	158	132	80
960	11	5	2	2	3	2168	106	75	171	138	86
961	11	1	3	1	1	1811	160	193	•	116	146
962	11	1	3	1	2	1586	145	245	•	118	129
963	11	1	3	1	3	1583	147	246	•	125	130
964	11	2	3	1	1	4728	466	241	•	233	235
965	11	2	3	1	2	5145	481	92	•	192	194
966	11	2	3	1	3	4452	481	132	•	135	136
967	11	3	3	1	1	2487	327	49	•	108	109
968	11	3	3	1	2	2443	327	104	•	117	118
969	11	3	3	1	3	2479	338	35	•	105	106
970	11	4	3	1	1	1283	323	5	277	110	111
971	11	4	3	1	2	1145	332	62	267	132	133
972	11	4	3	1	3	1176	322	37	295	113	114
973	11	5	3	1	1	2547	103	102	207	160	161
974	11	5	3	1	2	2595	96	127	211	140	141
975	11	5	3	1	3	2336	107	151	186	129	130
976	11	1	3	2	1	1257	145	324	•	120	137
977	11	1	3	2	2	1469	149	298	•	128	138
978	11	1	3	2	3	1562	147	269	•	133	131
979	11	2	3	2	1	4778	491	207	•	166	87
980	11	2	3	2	2	5103	473	85	•	155	98
981	11	2	3	2	3	5128	457	118	•	168	114
982	11	3	3	2	1	2223	361	30	•	111	51
983	11	3	3	2	2	2236	347	35	•	127	48
984	11	3	3	2	3	2281	347	80	•	109	79
985	11	4	3	2	1	1167	317	27	223	124	87
986	11	4	3	2	2	1303	323	40	216	125	110
987	11	4	3	2	3	1218	320	40	225	135	116
988	11	5	3	2	1	2743	146	116	182	144	130
989	11	5	3	2	2	2703	126	132	202	153	125
990	11	5	3	2	3	3129	167	118	178	137	132
991	12	1	1	1	1	1264	196	35	•	86	97
992	12	1	1	1	2	1257	197	69	•	80	90
993	12	1	1	1	3	1291	195	72	•	83	95
994	12	2	1	1	1	2614	311	83	•	103	94
995	12	2	1	1	2	2149	318	29	•	88	82
996	12	2	1	1	3	2204	330	26	•	81	99
997	12	3	1	1	1	2291	331	57	•	69	84
998	12	3	1	1	2	2373	347	75	•	63	67
999	12	3	1	1	3	2354	353	45	•	47	90
1000	12	4	1	1	1	1185	251	91	138	64	84
1001	12	4	1	1	2	1149	251	159	187	70	91
1002	12	4	1	1	3	1171	251	121	290	62	90
1003	12	5	1	1	1	•	•	78	93	67	117
1004	12	5	1	1	2	2060	100	154	152	69	94
1005	12	5	1	1	3	2061	93	113	112	79	87
1006	12	1	1	2	1	1011	170	34	•	82	90
1007	12	1	1	2	2	1228	181	131	•	92	97
1008	12	1	1	2	3	1089	178	45	•	90	90
1009	12	2	1	2	1	2245	308	69	•	88	112
1010	12	2	1	2	2	2071	301	20	•	61	69
1011	12	2	1	2	3	2067	296	43	•	88	86
1012	12	3	1	2	1	2201	320	54	•	71	72
1013	12	3	1	2	2	2167	327	39	•	59	72
1014	12	3	1	2	3	2214	292	38	•	58	84
1015	12	4	1	2	1	1332	248	168	170	78	78
1016	12	4	1	2	2	1299	244	93	137	85	103
1017	12	4	1	2	3	1200	238	121	129	61	93
1018	12	5	1	2	1	1531	62	214	138	80	88
1019	12	5	1	2	2	1749	87	185	162	58	87
1020	12	5	1	2	3	1915	93	196	124	94	65

	Subject	Task	Bed size	Bed height	Trial	Fcomp	Fshear	PUGRF	PHGRF	EMG(ES)	EMG(AD)
1021	12	1	2	1	1	1402	168	109	•	79	91
1022	12	1	2	1	2	1354	180	314	•	104	106
1023	12	1	2	1	3	1354	182	169	•	105	105
1024	12	2	2	1	1	4286	421	114	•	94	92
1025	12	2	2	1	2	4429	432	161	•	109	97
1026	12	2	2	1	3	3954	426	189	•	87	114
1027	12	3	2	1	1	2397	321	113	•	53	101
1028	12	3	2	1	2	2175	314	50	•	66	74
1029	12	3	2	1	3	•	•	109	•	76	54
1030	12	4	2	1	1	940	285	160	375	61	61
1031	12	4	2	1	2	1038	281	159	332	72	72
1032	12	4	2	1	3	1008	285	146	337	66	66
1033	12	5	2	1	1	2095	90	194	262	82	82
1034	12	5	2	1	2	2234	91	242	318	100	100
1035	12	5	2	1	3	1962	66	303	214	101	101
1036	12	1	2	2	1	1278	175	228	•	122	80
1037	12	1	2	2	2	1220	179	251	•	108	123
1038	12	1	2	2	3	1337	175	167	•	117	120
1039	12	2	2	2	1	3512	417	128	•	131	68
1040	12	2	2	2	2	2766	418	145	•	107	94
1041	12	2	2	2	3	2819	407	126	•	102	82
1042	12	3	2	2	1	2256	339	80	•	67	94
1043	12	3	2	2	2	2223	325	51	•	55	77
1044	12	3	2	2	3	2211	330	62	•	78	54
1045	12	4	2	2	1	915	287	179	271	73	91
1046	12	4	2	2	2	1236	265	90	229	76	104
1047	12	4	2	2	3	1053	277	94	•	54	70
1048	12	5	2	2	1	2016	57	217	184	109	113
1049	12	5	2	2	2	2090	73	252	217	101	88
1050	12	5	2	2	3	1939	66	206	190	93	108
1051	12	1	3	1	1	1663	161	242	•	107	102
1052	12	1	3	1	2	1388	162	212	•	107	97
1053	12	1	3	1	3	1260	165	201	•	134	108
1054	12	2	3	1	1	5112	477	205	•	109	121
1055	12	2	3	1	2	4919	464	145	•	98	95
1056	12	2	3	1	3	4805	481	130	•	114	64
1057	12	3	3	1	1	2307	338	76	•	79	93
1058	12	3	3	1	2	2443	338	107	•	52	84
1059	12	3	3	1	3	2322	322	65	•	56	70
1060	12	4	3	1	1	778	298	106	323	56	125
1061	12	4	3	1	2	735	311	188	381	86	82
1062	12	4	3	1	3	567	306	87	280	121	86
1063	12	5	3	1	1	2327	48	113	207	150	102
1064	12	5	3	1	2	2381	55	209	189	103	110
1065	12	5	3	1	3	2641	58	143	194	127	115
1066	12	1	3	2	1	1317	159	264	•	106	100
1067	12	1	3	2	2	1309	167	217	•	115	106
1068	12	1	3	2	3	1123	125	203	•	102	109
1069	12	2	3	2	1	4707	458	133	•	112	102
1070	12	2	3	2	2	4549	460	265	•	114	114
1071	12	2	3	2	3	•	•	205	•	106	80
1072	12	3	3	2	1	2116	296	31	•	79	82
1073	12	3	3	2	2	2133	312	71	•	102	79
1074	12	3	3	2	3	2135	295	59	•	64	94
1075	12	4	3	2	1	976	299	133	282	73	109
1076	12	4	3	2	2	895	291	143	191	85	95
1077	12	4	3	2	3	1089	294	94	199	72	98
1078	12	5	3	2	1	1692	21	172	187	94	116
1079	12	5	3	2	2	2139	32	173	203	102	97
1080	12	5	3	2	3	2227	39	220	170	84	88

APPENDIX B

STATISTICAL REPORT

***** Analysis of Variance *****

Variate : L5/S1 Comp

```
Source of variation              df    SS        MS        F

SUBJECT stratum                  11    5.971E+07 5.428E+06

SUBJECT x TREATMENT stratum

TASK                             4     5.276E+08 1.319E+08 312.2
SIZE                             2     2.523E+07 1.261E+07 29.85
HEIGHT                           1     2.638E+06 2.638E+06 6.24
TASK x SIZE                      8     8.368E+07 1.046E+07 24.76
TASK x HEIGHT                    4     2.586E+06 6.464E+05 1.53
SIZE x HEIGHT                    2     4.503E+05 2.251E+05 0.53
TASK x SIZE x HEIGHT             8     1.284E+06 1.604E+05 0.38
Residual                         319   1.348E+08 4.225E+05

SUBJECT x TREAT x TRIAL stratum

                                 695   1.182E+07 1.701E+04

TOTAL                            1054  8.316E+08
```

***** Tables of means *****

(Standard deviations for significant results in brackets)

Variate : L5/S1 Comp

```
GRAND MEAN      1911.5


TASK      ON        OFF       LIFT      PULL      PUSH
          1262.5    2843.5    2058.5    975.8     2416.8


SIZE           SINGLE         DOUBLE         QUEEN
               1708.4         1948.9         2077.1


HEIGHT              LOW                      HIGH
                    1960.9 (909.80)          1862.1 (862.5)
```

Variate : L5/S1 Comp

TASK x SIZE	SINGLE	DOUBLE	QUEEN
ON	1105.1	1275.5	1406.9
OFF	1980.2	2997.6	3552.9
	(419.2)	(803.7)	(1116.6)
LIFT	2059.4	2098.8	2018.1
PULL	1195.4	968.2	763.7
	(237.7)	(226.6)	(264.6)
PUSH	2202.1	2404.3	2644.1
	(296.4)	(332.7)	(412.0)

TASK x HEIGHT	LOW	HIGH
ON	1325.3	1199.7
OFF	2949.9	2737.2
LIFT	2115.4	2002.1
PULL	934	1017.5
PUSH	2479.9	2353.8

SIZE x HEIGHT	LOW	HIGH
SINGLE	1753.4	1663.5
DOUBLE	2025.2	1872.5
QUEEN	2104.1	2050.2

TASK x HEIGHT x SIZE

	SINGLE		DOUBLE		QUEEN	
	LOW	HIGH	LOW	HIGH	LOW	HIGH
ON	1167.7	1042.6	1343.7	1207.3	1464.6	1349.3
OFF	2063.8	1896.5	3213.3	2781.8	3572.5	3533.2
LIFT	2093.8	2025.0	2195.5	2002.1	2057.0	1979.2
PULL	1178.3	1212.5	922.2	1014.2	701.1	825.9
PUSH	2263.2	2141.0	2451.5	2357.1	2724.9	2563.2

***** Standard errors of differences of means *****

Table	rep.	s.e.d.
TASK	216	62.55
SIZE	360	48.45
HEIGHT	540	39.56
TASK x SIZE	72	108.34
TASK x HEIGHT	108	88.46
SIZE x HEIGHT	180	68.52
TASK x SIZE x HEIGHT	36	153.21

Variate : L5/S1 Comp

```
***** Missing values *****

Estimate              Unit
12                    1362.0
15                    1810.5
44                    2288.0
45                    2288.0
84                    1979.0
96                    2045.5
117                   1040.5
134                   2373.5
138                   1341.5
150                   2471.5
165                   2945.0
360                   2412.0
492                   720.5
516                   2846.0
531                   2787.0
621                   2351.0
627                   440.5
672                   991.5
675                   2412.0
735                   2077.0
795                   2532.5
810                   2190.5
1003                  2060.5
1029                  2286.0
1071                  4628.0
```

Variate : L5/S1 Comp

```
                    ***** Histogram of Residuals *****

                -600      0
-600            -560      1
-560            -520      0
-520            -480      0
-480            -440      3
-440            -400      2
-400            -360      1
-360            -320      3
-320            -280      2
-280            -240      10  *
-240            -200      14  **
-200            -160      18  ***
-160            -120      38  ******
-120            -80       73  ************
-80             -40       140 ***********************
-40             0         231 ************************************
0               40        241 *************************************
40              80        131 *********************
80              120       83  *************
120             160       34  *****
160             200       23  ***
200             240       15  **
240             280       7   *
280             320       1
320             360       1
360             400       3
400             440       0
440             480       2
480             520       0
520             560       3
560             600       0
600             640       0
640-                      0

Scale : 1 asterisk represents 6 units
```

Variate : L5/S1 Shear

```
Source of variation               df    SS         MS         F

SUBJECT stratum                   11    1.129E+06 1.026E+05

SUBJECT x TREATMENT stratum

TASK                              4     8.576E+06 2.144E+06 869.0
SIZE                              2     1.142E+05 5.711E+04 23.15
HEIGHT                            1     3.223E+04 3.223E+04 13.06
TASK x SIZE                       8     1.013E+06 1.266E+05 51.31
TASK X HEIGHT                     4     8.099E+03 2.025E+03 0.82
SIZE X HEIGHT                     2     6.249E+01 3.124E+01 0.01
TASK X SIZE X HEIGHT              8     1.547E+03 1.934E+02 0.08
Residual                          319   7.870E+05 2.467E+03

SUBJECT x TREAT x TRIAL stratum
                                  694   6.760E+04 9.741E+01

TOTAL                             1053  1.139E+07
```

```
                       ***** Tables of means *****

         (Standard deviations for significant results in brackets)

                        Variate : L5/S1 Shear


GRAND MEAN     266.14


TASK      ON        OFF       LIFT      PULL      PUSH
          167.15    376.54    333.63    297.59    155.81


SIZE                SINGLE         DOUBLE         QUEEN
                    251.84         271.01         275.58


HEIGHT              LOW                      HIGH
                    271.61 (104.83)          260.66 (103.49)
```

```
                       Variate : L5/S1 Shear

TASK x SIZE            SINGLE         DOUBLE         QUEEN
ON                     184.32         170.37         146.76
                       (26.74)        (28.37)        (30.75)
OFF                    289.32         393.92         446.39
                       (36.58)        (46.62)        (51.47)
LIFT                   336.81         333.87         330.22
PULL                   271.81         300.46         320.51
                       (28.65)        (28.51)        (26.30)
PUSH                   176.97         156.43         134.03
                       (55.74)        (59.41)        (64.36)


TASK x HEIGHT                LOW                HIGH
ON                           170.22             164.08
OFF                          385.12             367.97
LIFT                         340.15             327.11
PULL                         299.05             296.13
PUSH                         163.50             148.12


SIZE x HEIGHT                LOW                HIGH
SINGLE                       257.05             246.64
DOUBLE                       276.41             265.61
QUEEN                        281.37             269.80


TASK x HEIGHT x SIZE
                SINGLE               DOUBLE               QUEEN
          LOW        HIGH      LOW        HIGH      LOW        HIGH
ON        188.03     180.61    172.47     168.28    150.17     143.36
OFF       297.75     280.89    403.39     384.44    454.21     438.57
LIFT      343.83     329.78    341.04     326.69    335.58     324.86
PULL      273.79     269.82    301.14     299.78    322.22     318.79
PUSH      181.85     172.08    163.99     148.87    144.65     123.40


          ***** Standard errors of differences of means *****


Table                        rep.               s.e.d.

TASK                         216                4.780
SIZE                         360                3.702
HEIGHT                       540                3.023
TASK x SIZE                  72                 8.279
TASK x HEIGHT                108                6.759
SIZE x HEIGHT                180                5.236
TASK x SIZE x HEIGHT         36                 11.708
```

```
         Variate : L5/S1 Shear

       ***** Missing values *****

      Unit                 Estimate
      12                   284.5
      15                   108.5
      44                   139.5
      45                   139.5
      84                   370.0
      96                   294.0
      117                  287.5
      134                  218.0
      138                  153.0
      150                  217.5
      165                  219.0
      360                  189.5
      492                  269.0
      516                  410.5
      531                  380.5
      621                  401.0
      627                  327.5
      672                  312.0
      675                  119.5
      735                  134.5
      795                  71.5
      810                  56.0
      1003                 96.5
      1029                 317.5
      1071                 459.0
```

```
                   Variate : L5/S1 Shear

              ***** Histogram of Residuals *****

                -42        1
-42             -39        1
-39             -36        1
-36             -33        0
-33             -30        1
-30             -27        3
-27             -24        3
-24             -21        6   *
-21             -18        7   *
-18             -15        11  *
-15             -12        16  **
-12             -9         48  ********
-9              -6         90  ***************
-6              -3         144 ************************
-3              0          242 *************************************
0               3          189 *******************************
3               6          128 *********************
6               9          80  *************
9               12         47  *******
12              15         36  ******
15              18         10  *
18              21         6   *
21              24         4
24              27         1
27              30         1
30              33         2
33              36         1
36              39         0
42              45         0
45              48         1
48              51         0
51-                        0

Scale : 1 asterisk represents 6 units
```

```
                           Variate : PVGRF

Source of variation              df    SS         MS         F

SUBJECT stratum                  11    2044859    185896

SUBJECT x TREATMENT stratum

TASK                             4     844931     211233     59.45
SIZE                             2     277102     138551     39.00
HEIGHT                           1     1073       1073       0.30
TASK x SIZE                      8     350099     43762      12.32
TASK x HEIGHT                    4     33793      8448       2.38
SIZE x HEIGHT                    2     7249       3624       1.02
TASK x SIZE x HEIGHT             8     10272      1284       0.36
Residual                         318   1129850    3553

SUBJECT x TREAT x TRIAL stratum
                                 688   617223     897

Total                            1046  5204896


                     ***** Tables of means *****

        (Standard deviations for significant results in brackets)

                           Variate : PVGRF


GRAND MEAN           83.90


TASK                 ON        OFF       LIFT      PUSH      PULL
                     131.94    66.52     60.11     61.59     99.32


SIZE                 SINGLE         DOUBLE         QUEEN
                     61.99          89.83          99.86


HEIGHT               LOW                 HIGH
                     84.89               82.90


TASK x SIZE          SINGLE         DOUBLE         QUEEN
ON                   63.24          152.56         180.03
                     (54.40)        (77.65)        (90.98)
OFF                  45.83          63.16          90.56
                     (43.41)        (46.48)        (65.72)
LIFT                 52.40          63.16          64.76
PUSH                 56.67          63.75          64.36
PULL                 91.84          106.55         99.57
```

```
                          Variate : PVGRF

TASK x HEIGHT                   LOW                   HIGH
ON                              123.06                140.82
                                (82.27)               (98.05)
OFF                             65.35                 67.68
LIFT                            63.15                 57.07
PUSH                            67.93                 55.26
PULL                            104.97                93.67


SIZE x HEIGHT                   LOW                   HIGH
SINGLE                          62.96                 61.03
DOUBLE                          94.02                 85.65
QUEEN                           97.70                 102.02


TASK x HEIGHT x SIZE
                  SINGLE                    DOUBLE                    QUEEN
          LOW         HIGH         LOW         HIGH         LOW         HIGH
ON        58.54       67.93        148.38      156.74       162.28      197.7
OFF       47.60       44.06        65.87       60.44        82.60       98.53
LIFT      50.64       54.17        70.07       56.25        68.74       60.79
PUSH      63.19       50.14        70.94       56.56        69.64       59.08
PULL      94.81       88.87        114.85      98.25        105.25      93.89


          ***** Standard errors of differences of means *****

Table                           rep.                  s.e.d.

TASK                            216                   5.736
SIZE                            360                   4.443
HEIGHT                          540                   3.628
TASK x SIZE                     72                    9.934
TASK x HEIGHT                   108                   8.111
SIZE x HEIGHT                   180                   6.283
TASK x SIZE x HEIGHT            36                    14.049
```

Variate : PVGRF

```
***** Missing values *****

Unit                     Estimate
7                        -9
23                       8
28                       41
44                       102
45                       102
69                       26
73                       108
79                       62
82                       22
95                       31
103                      61
104                      61
105                      61
119                      52
124                      78
125                      78
132                      4
212                      83
256                      63
309                      84
313                      149
318                      6
437                      326
508                      87
516                      68
699                      63
731                      47
756                      38
848                      58
903                      43
914                      11
917                      124
940                      47
```

```
                           Variate : PVGRF

                  ***** Histogram of Residuals *****

                -104      0
-104            -96       0
-96             -88       2
-88             -80       1
-80             -72       3
-72             -64       5
-64             -56       11  *
-56             -48       10  *
-48             -40       20  ***
-40             -32       23  ***
-32             -24       50  ******
-24             -16       84  **************
-16             -8        141 ***********************
-8              0         213 ***********************************
0               8         208 ***********************************
8               16        102 *****************
16              24        72  ************
24              32        49  ******
32              40        28  ****
40              48        20  ***
48              56        16  **
56              64        8   *
64              72        5
72              80        2
80              88        4
88              96        0
96              104       1
104             112       1
112             120       1
120             128       0
128             136       0
136             144       0
144-                      0

Scale : 1 asterisk represents 6 units
```

```
                              Variate : PHGRF

Source of variation              df    SS          MS          F

SUBJECT stratum                  11    2961243     269204

SUBJECT x TREATMENT stratum

TASK                             1     543374      543374      51.48
SIZE                             2     625862      312931      29.65
HEIGHT                           1     433064      433064      41.03
TASK x SIZE                      2     28009       14005       1.33
TASK x HEIGHT                    1     66433       66433       6.29
SIZE x HEIGHT                    2     52504       26252       2.49
TASK x SIZE x HEIGHT             2     1822        911         0.09
Residual                         120   1266656     10555

SUBJECT x TREAT x TRIAL stratum
                                 271   385579      1423

Total                            413   6243133


                         ***** Tables of means *****

          (Standard deviations for significant results in brackets)

                              Variate : PHGRF


GRAND MEAN               225.8


TASK                     PUSH           PULL
                         261.3          190.4


SIZE                     SINGLE         DOUBLE         QUEEN
                         175.8          233.5          268.1
                         (92.3)         (125.3)        (126.1)


HEIGHT                   LOW                 HIGH
                         257.5               194.2


TASK x SIZE              SINGLE         DOUBLE         QUEEN
PUSH                     200.9          270.2          312.8
PULL                     150.7          196.9          223.4
```

Variate : PHGRF

TASK x HEIGHT	LOW	HIGH
PUSH	305.3 (162.6)	217.2 (112.7)
PULL	209.6 (85.5)	171.1 (57.7)

SIZE x HEIGHT	LOW	HIGH
SINGLE	192.0	159.6
DOUBLE	274.6	192.5
QUEEN	305.9	230.3

TASK x HEIGHT x SIZE

	SINGLE		DOUBLE		QUEEN	
	LOW	HIGH	LOW	HIGH	LOW	HIGH
PUSH	226.7	175.1	324.3	216.0	365.0	260.5
PULL	157.3	144.2	224.8	169.0	246.7	200.1

***** Standard errors of differences of means *****

Table	rep.	s.e.d.
TASK	216	9.89
SIZE	144	12.11
HEIGHT	216	9.89
TASK x SIZE	72	17.12
TASK x HEIGHT	108	13.98
SIZE x HEIGHT	72	17.12
TASK x SIZE x HEIGHT	36	24.22

```
     Variate : PHGRF

***** Missing values *****

    Unit                 Estimate
    28                   143.0
    58                   182.5
    73                   259.5
    103                  86.6
    104                  86.6
    105                  86.6
    119                  96.5
    162                  292.5
    208                  163.5
    311                  245.0
    313                  218.5
    403                  324.0
    508                  160.5
    731                  159.5
    914                  160.0
    940                  269.5
    943                  269.5
    1047                 250.0
```

```
                          Variate : PHGRF

                 ***** Histogram of Residuals *****

               -140      0
-140           -130      1
-130           -120      0
-120           -110      0
-110           -100      0
-100           -90       1
-90            -80       1
-80            -70       3
-70            -60       7
-60            -50       9
-50            -40       10  *
-40            -30       21  **
-30            -20       47  ****
-20            -10       133 *************
-10            0         325 ********************************
0              10        302 ******************************
10             20        119 ***********
20             30        54  *****
30             40        11  *
40             50        11  *
50             60        12  *
60             70        3
70             80        4
80             90        4
90             100       0
100            110       0
110            120       1
120            130       0
130            140       0
140            150       1
150            160       0
160            170       1
170-                     0

Scale : 1 asterisk represents 10 units
```

```
                         Variate : IEMG(ES)

Source of variation             df    SS          MS          F

SUBJECT stratum                 11    305761.8    27796.5

SUBJECT x TREATMENT stratum

TASK                            4     69953.7     17488.4     24.41
SIZE                            2     69206.2     34603.1     48.30
HEIGHT                          1     4553.1      4553.1      6.36
TASK x SIZE                     8     11209.6     1401.2      1.96
SIZE x HEIGHT                   2     2656.7      1328.3      1.85
TASK x SIZE x HEIGHT            8     4382.7      547.8       0.76
Residual                        319   228536.9    716.4

SUBJECT x TREAT x TRIAL stratum
                                711   121196.2    170.5

Total                           1070  821329.3


                      ***** Tables of means *****

        (Standard deviations for significant results in brackets)

                         Variate : IEMG(ES)


GRAND MEAN      115.88


TASK            ON        OFF       LIFT      PULL      PUSH
                118.99    126.33    103.39    110.41    120.26


SIZE                 SINGLE          DOUBLE          QUEEN
                     105.06          118.38          124.19
                     (24.95)         (26.60)         (28.15)


HEIGHT               LOW                  HIGH
                     117.93               113.82
```

```
                         Variate : IEMG(ES)

TASK x SIZE               SINGLE          DOUBLE          QUEEN
ON                        106.45          123.87          126.65
OFF                       111.14          129.66          138.18
LIFT                      100.08          104.84          105.25
PULL                      99.85           110.52          120.88
PUSH                      107.80          123.01          129.97


TASK x HEIGHT                  LOW                     HIGH
ON                             119.84                  118.14
OFF                            127.17                  125.49
LIFT                           101.87                  104.91
PULL                           115.31                  105.52
                               (32.94)                 (24.65)
PUSH                           125.47                  115.06
                               (26.05)                 (115.06)


SIZE x HEIGHT                  LOW                     HIGH
SINGLE                         105.93                  104.20
DOUBLE                         119.41                  117.36
QUEEN                          128.46                  119.92


TASK x HEIGHT x SIZE
                   SINGLE                 DOUBLE                 QUEEN
            LOW        HIGH        LOW        HIGH        LOW        HIGH
ON          106.42     106.49      122.69     125.06      130.42     122.89
OFF         112.22     110.06      129.61     129.71      139.67     136.69
LIFT        100.08     100.08      102.89     106.79      102.64     107.86
PULL        101.58     98.11       112.31     108.74      132.03     109.72
PUSH        109.35     106.25      129.53     116.50      137.53     122.42


           ***** Standard errors of differences of means *****

Table                          rep.                    s.e.d.

TASK                           216                     2.576
SIZE                           360                     1.995
HEIGHT                         540                     1.629
TASK x SIZE                    72                      4.461
TASK x HEIGHT                  108                     3.624
SIZE x HEIGHT                  180                     2.821
TASK x SIZE x HEIGHT           36                      6.309
```

Variate : IEMG(ES)

```
***** Missing values *****

    Unit             Estimate
    117              79.5
    183              104.0
    499              156.5
    507              113.5
    735              122.5
    826              125.5
    829              124.0
    835              112.5
    864              107.5
```

```
                         Variate : IEMG(ES)

                  ***** Histogram of Residuals *****

              -60      0
-60           -56      0
-56           -52      0
-52           -48      2
-48           -44      0
-44           -40      0
-40           -36      1
-36           -32      0
-32           -28      5
-28           -24      7  *
-24           -20      20 ***
-20           -16      31 *****
-16           -12      58 *********
-12           -8       96 ****************
-8            -4       142 ***********************
-4            0        187 *******************************
0             4        173 ****************************
4             8        137 **********************
8             12       95 ***************
12            16       63 **********
16            20       38 ******
20            24       10 *
24            28       8  *
28            32       1
32            36       2
36            40       1
40            44       0
44            48       3
48            52       0
52            56       0
56            60       0
60            64       0
64-                    0

Scale : 1 asterisk represents 6 units
```

Variate : IEMG(AD)

Source of variation	df	SS	MS	F
SUBJECT stratum	11	282920.6	25720.1	
SUBJECT x TREATMENT stratum				
TASK	4	351188.0	87797.0	65.26
SIZE	2	55417.5	27708.7	20.59
HEIGHT	1	4.7	4.7	0.00
TASK x SIZE	8	15061.6	1882.7	1.40
TASK x HEIGHT	4	17385.1	4346.3	3.23
SIZE x HEIGHT	2	409.8	204.9	0.15
TASK x SIZE x HEIGHT	8	2454.1	306.8	0.23
Residual	319	429186		
SUBJECT x TREAT x TRIAL stratum	713	216482.7	303.6	
Total	1072	1368330.1		

***** Tables of means *****

(Standard deviations for significant results in brackets)

Variate : IEMG(AD)

GRAND MEAN 94.4

TASK	**ON**	**OFF**	**LIFT**	**PULL**	**PUSH**
	110.02	84.55	63.56	104.43	109.68

SIZE	SINGLE	DOUBLE	QUEEN
	84.40	98.37	100.58
	(29.03)	(36.05)	(34.59)

HEIGHT	**LOW**	**HIGH**
	94.51	94.38

TASK x SIZE	SINGLE	DOUBLE	QUEEN
ON	98.26	115.56	116.24
OFF	66.03	91.01	96.60
LIFT	60.08	65.07	65.54
PULL	96.82	108.96	107.50
PUSH	100.80	111.24	117.01

```
                          Variate : IEMG(AD)

TASK x HEIGHT             LOW                 HIGH
ON                        107.09              112.95
OFF                       80.72               88.38
LIFT                      62.78               64.35
PULL                      104.79              104.06
PUSH                      117.20              102.17
                          (16.89)             (23.41)


SIZE x HEIGHT             LOW                 HIGH
SINGLE                    84.33               84.47
DOUBLE                    97.76               98.98
QUEEN                     101.46              99.70


TASK x HEIGHT x SIZE
               SINGLE                DOUBLE                QUEEN
          LOW       HIGH       LOW       HIGH       LOW       HIGH
ON        95.85     100.68     113.50    117.61     111.92    120.56
OFF       63.78     68.28      83.53     98.50      94.85     98.36
LIFT      58.14     62.03      65.83     64.31      64.36     66.72
PULL      96.92     96.72      107.44    110.47     110.00    105.00
PUSH      106.96    94.64      118.47    104.00     126.17    107.86


         ***** Standard errors of differences of means *****


Table                     rep.                s.e.d.

TASK                      216                 3.530
SIZE                      360                 2.734
HEIGHT                    540                 2.232
TASK x SIZE               72                  6.113
TASK x HEIGHT             108                 4.991
SIZE x HEIGHT             180                 3.866
TASK x SIZE x HEIGHT      36                  8.646
```

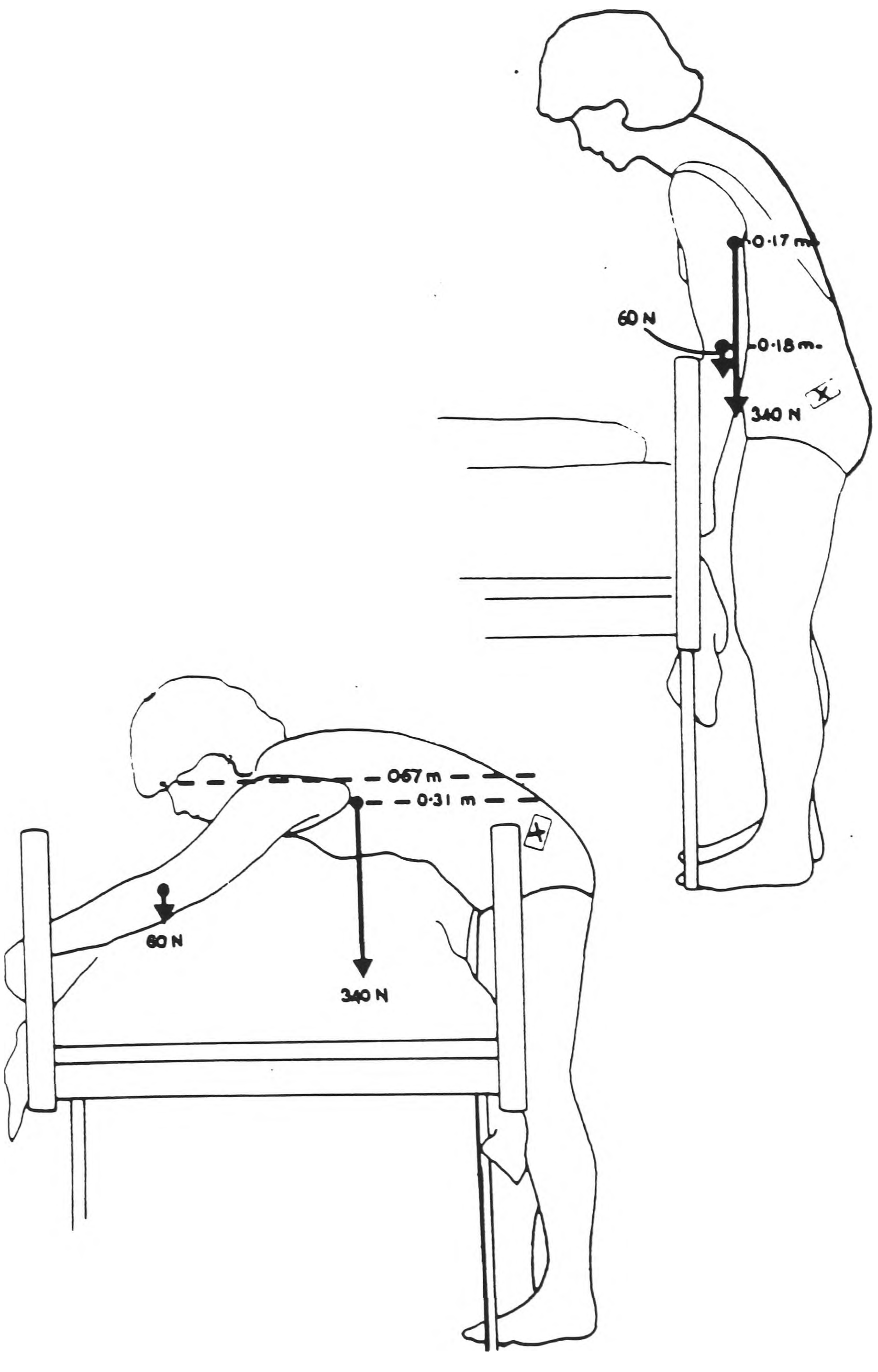
```
***** Missing values *****

    Unit                   Estimate
    117                    120.0
    183                    100.5
    499                    89.0
    735                    120.5
    826                    91.5
    829                    71.0
    864                    79.5
```

Variate : IEMG(AD)

```
                    ***** Histogram of Residuals *****

               -120      1
-120           -108      1
-108           -96       0
-96            -84       0
-84            -72       0
-72            -60       0
-60            -48       2
-48            -36       2
-36            -24       13  *
-24            -12       107 ********
-12            0         420 ***********************************
0              12        420 ***********************************
12             24        90  *******
24             36        15  *
36             48        6
48             60        2
60             72        0
72             84        0
84             96        0
96             108       0
108            120       0
120-                     0

Scale : 1 asterisk represents 12 units
```

APPENDIX C

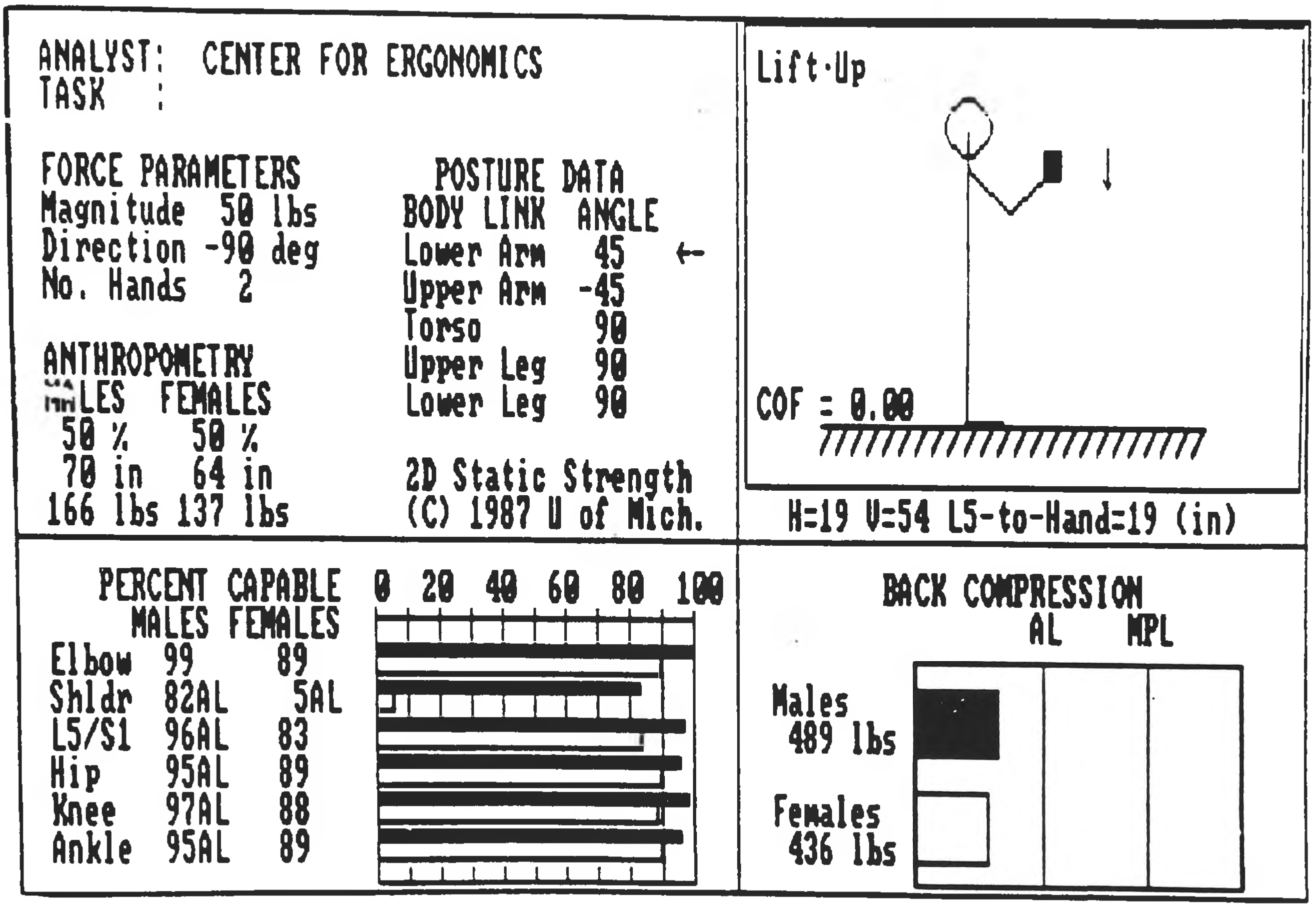
INPUT DATA FOR BEDMAKING CALCULATION



Source: Wiktorin and Nordin (1986). Introduction to problem solving in biomechanics. Lea and Febiger, Philadelphia PA, p 134.

APPENDIX D

SAMPLE SCREEN DUMP FROM THE TWO DIMENSIONAL STATIC STRENGTH PREDICTION PROGRAM

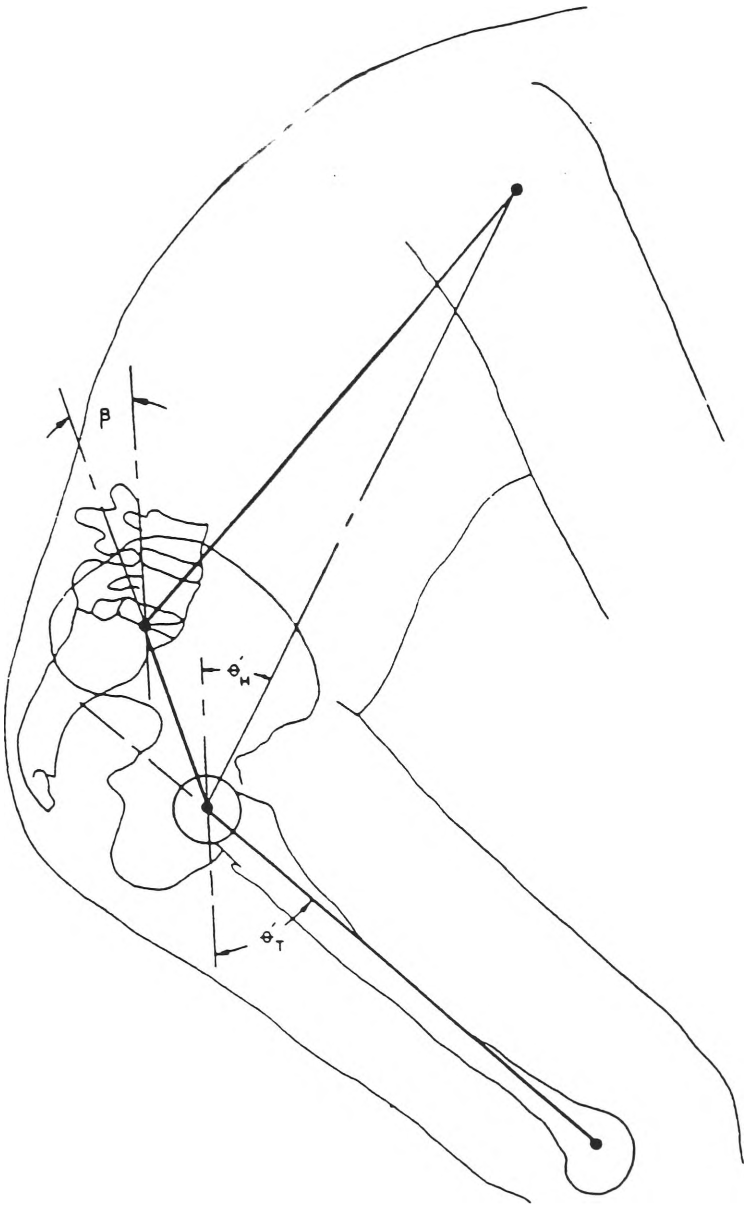


```
ANALYST:  CENTER FOR ERGONOMICS              Lift-Up
TASK    :

FORCE PARAMETERS          POSTURE DATA
Magnitude  50 lbs       BODY LINK  ANGLE
Direction -90 deg       Lower Arm   45   ←
No. Hands   2           Upper Arm  -45
                        Torso       90
ANTHROPOMETRY           Upper Leg   90
MALES  FEMALES          Lower Leg   90       COF = 0.00
 50 %    50 %
 70 in   64 in          2D Static Strength
166 lbs 137 lbs         (C) 1987 U of Mich.  H=19 V=54 L5-to-Hand=19 (in)

   PERCENT CAPABLE  0  20  40  60  80  100       BACK COMPRESSION
    MALES FEMALES                                        AL    MPL
Elbow  99     89
Shldr  82AL    5AL                            Males
L5/S1  96AL   83                               489 lbs
Hip    95AL   89
Knee   97AL   88                              Females
Ankle  95AL   89                               436 lbs
```

Source: University of Michigan (1989). <u>Version 4.0 User's Manual for the Two Dimensional Static Strength Prediction Program</u>, p 45.

APPENDIX E

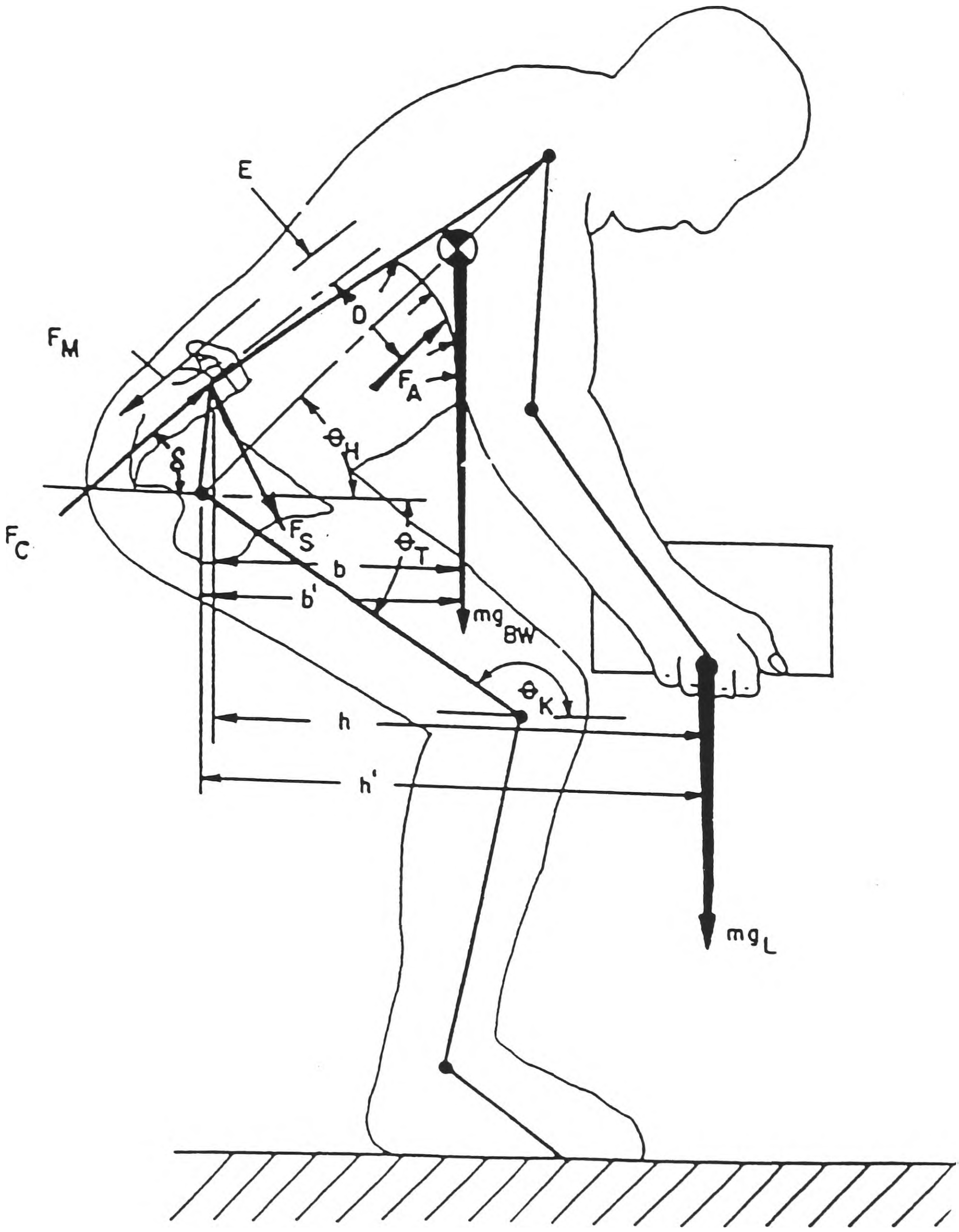
TORSO LINKAGE SYSTEM FOR THE TWO DIMENSIONAL STATIC STRENGTH PREDICTION PROGRAM



Source: Chaffin and Andersson (1984). Occupational Biomechanics. New York NY: John Wiley & Sons, p 193.

APPENDIX F

STATIC STRENGTH PREDICTION MODEL



Source: Chaffin and Andersson (1984). Occupational Biomechanics. New York NY: John Wiley & Sons, p 195.

APPENDIX G

RESEARCH CONSENT FORM
THE MEASUREMENT AND ASSESSMENT OF LUMBAR STRESS DURING BEDMAKING

This study aims to quantify the stresses imposed on the low back by a series of tasks which simulate bedmaking. These results will be compared with safe lifting limits to determine the level of musculoskeletal injury risk associated with each task and may indicate the need for guidelines that minimise the lumbar stress associated with bedmaking.

For the purpose of this study each subject will be required to perform a variety of lifting, lowering, pushing and pulling movements identified with the bedmaking task. These will represent bedding on, bedding off, lifting the corner of the mattress and moving the bed sideways. Each movement will be recorded by way of electromyography, dynamography and cinematography. These techniques are non-invasive and involve minimum inconvenience to the subject. Your time committment to the project will be approximately three hours.

Only subjects in good physical health at the time of testing will be eligible to participate in the project. Although the study involves the performance of a common household task with minimal injury risk to the subject, National Institute of Occupational Safety and Health guidelines (NIOSH, 1981) for safe lifting may be exceeded. As a result, registered medical assistance will be available during testing.

Your participation in this study will be treated with strict confidentiality. Custody and access to photographical material arising from the study will be viewed only by the primary investigator and his academic supervisor. As your participation is voluntary, you are free to withdraw from the study at any time without penalty.

If you have any questions relating to the study please do not hesitate to ask. Thankyou for your interest and assitance.

Rodney S. Barrett (Research co-ordinator)

I ________________ (name) have read the above information pertaining to the bedmaking study. I acknowledge that the experimenter has: (i) fully explained the need for research and the risks involved; (ii) informed me of my right to withdraw from participation at any time; and (iii) offered to answer any questions that relate to the study. I freely and voluntarily agree to participate as a subject within the study.

________________ (signature)	________________ (date)
________________ (investigator)	________________ (date)

APPENDIX H

ERROR ESTIMATES FOR ANGLE DATA AND MOMENT CALCULATIONS

The validity and reliability of lumbosacral compression and shear estimates determined using the Two Dimensional Sagittal Strength Prediction Program (University of Michigan, 1989) as part of this study was contingent on the accuracy of the kinematic input describing body orientation (ie. body segment angles subtended with the horizontal). Using the procedure outlined in Chapter II, it was estimated that segment angles were accurate to plus or minus two degrees (in keeping with traditional digitising methods). In view of this error, the sensitivity of L5/S1 moment calculations to a plus and minus two degree variation in trunk segment angles was investigated from a small representative data sample of 5 subjects across all tasks. Results indicated that a two degree variation either side of the measured trunk segment angle had a minimal effect on the L5/S1 moment. Although these values varied between subjects and tasks, the maximum L5/S1 Comp difference of 50N for subject 1 while "bedding-off" was not considered by the investigator sufficient to compromise the validity of the results.