NR 2003:12

Work technique in lifting and patient transfer tasks

Katarina Kjellberg

The Sahlgrenska Academy at Göteborg University
Department of Occupational Medicine
National Institute for Working Life
Department for Work and Health

ARBETE OCH HÄLSA | VETENSKAPLIG SKRIFTSERIE
ISBN 91-7045-688-7 ISSN 0346-7821

Arbetslivsinstitutet
National Institute for Working Life

Arbete och Hälsa

Arbete och Hälsa (Work and Health) is a scientific report series published by the National Institute for Working Life. The series presents research by the Institute's own researchers as well as by others, both within and outside of Sweden. The series publishes scientific original works, dissertations, criteria documents and literature surveys.

Arbete och Hälsa has a broad target-group and welcomes articles in different areas. The language is most often English, but also Swedish manuscripts are welcome.

Summaries in Swedish and English as well as the complete original text are available at www.arbetslivsinstitutet.se/ as from 1997.

National Institute for Working Life
S-113 91 Stockholm
Sweden

ISBN 91–7045–688–7
ISSN 0346–7821
http://www.arbetslivsinstitutet.se/
Printed at Elanders Gotab, Stockholm

List of papers

This thesis is based on the following papers, which will be referred to by their Roman numerals.

I Kjellberg K, Lindbeck L, Hagberg M. Method and performance: two elements of work technique. *Ergonomics* 1998;41:798-816.

II Lindbeck L, Kjellberg K. Gender differences in lifting technique. *Ergonomics* 2001;44:202-214.

III Kjellberg K, Johnsson C, Proper K, Olsson E, Hagberg M. An observation instrument for assessment of work technique in patient transfer tasks. *Applied Ergonomics* 2000;31:139-150.

IV Kjellberg K, Lagerström M, Hagberg M. Work technique of nurses in patient transfer tasks and associations with personal factors. *Accepted for publication in Scandinavian Journal of Work, Environment & Health*.

V Kjellberg K, Lagerström M, Hagberg M. Patients' safety and comfort during transfers in relation to nurses' work technique. *Submitted.*

List of abbreviations

%RVE	percentage of Reference Voluntary Electrical activation
ANOVA	Analysis of variance
BMI	Body Mass Index
BW	from Bed to Wheelchair (transfer from Bed to Wheelchair)
CV	Coefficient of variation
EMG	Electromyography
FB	Fast Back lift
FL	Fast Leg lift
HB	Higher up in Bed (transfer Higher up in Bed)
κ	Kappa coefficient
L4	Fourth lumbar vertebra
L5	Fifth lumbar vertebra
Md	Median
NIOSH	National Institute for Occupational Safety and Health
OWAS	Ovako Working posture Analysis System
P_o	Overall proportion of agreement
P_{25}	The 25th percentile
P_{75}	The 75th percentile
r	Correlation coefficient
REBA	Rapid Entire Body Assessment
S1	First sacral vertebra
SB	Slow Back lift
SD	Standard Deviation
SL	Slow Leg lift

Contents

1. Introduction

1.1 The scope of this thesis

This thesis will deal with the concept of work technique, methods to assess work technique and applications in lifting and patient transfer tasks. The focus is on work technique features that influence the mechanical load on the musculoskeletal system and may act as preventive or risk factors for musculoskeletal disorders and over-exertion injuries. Particular attention is given to implications for the low back, as this body region is mostly involved in disorders and injuries related to manual handling work.

Methods to describe, analyse and assess work technique have been explored; mainly biomechanical methods in the laboratory and observations in workplaces. As a simple first application of the work technique concept, a symmetrical lifting task was chosen to be analysed in a laboratory set-up. The purpose was to acquire general knowledge about how to perform work technique analyses of manual handling tasks. An observation instrument was developed to meet the need for a field method for detailed registrations and assessments of nursing personnel's work technique in patient transfer tasks with regard to musculoskeletal health and safety. Patient ratings of perceived comfort and safety were applied to evaluate the possible effects of work technique on the patients.

Work technique in lifting and patient transfer tasks have been studied. Inexperienced persons were studied in a lifting task, where instructions were given concerning the lifting methods to be used. Nursing personnel were observed in patient transfer tasks at hospital wards, where no instructions were given concerning how to perform the transfers.

1.2 Concepts and definitions

Work technique is defined in this thesis as the individual's way to perform a given work task in a given work situation. It is suggested that the concept *work technique* be viewed in two basic elements: the method to carry out a work task and the individual performance of a work task (123). The first element, the *method*, refers to general, established work methods taught to workers: for example the squat lift and patient transfer methods taught to nursing personnel during training programmes. The *individual performance* focuses on individual variations when executing a given task, or using a given method.

In this thesis, the term *musculoskeletal disorders* will be used for both musculoskeletal disorders and over-exertion injuries.

Safety will refer to: on the one hand, safety for the worker during manual handling work, and on the other, safety for the object or patient being handled. For the worker this means the condition of being safe from developing or worsening work-related musculoskeletal disorders. For an object this means that there is no risk of damage, and for a patient that there is no risk of being injured. The *safety* *factor of work technique* refers to how safe the work technique is for the worker with regard to the musculoskeletal system.

Manual handling refers to transfer of loads, where employees exert muscle force to lift, deposit, push, pull, roll, carry, hold or support an object or a living being (218). *Lifting* means raising a load from a lower to a higher position and implies that the exerted force must exceed the gravitational force of the load. *Patient transfers* are defined in this thesis as work tasks where nurses assist, lift or carry a patient during transfers from one location to another (e.g. transfer from bed to wheelchair) or from one position to another (e.g. turning from supine to lying on the side in bed). Assistance during locomotion, i.e. during walking and wheelchair propulsion, etc., is not included in the concept. Different terms are used in the literature for patient transfers, for example patient handling, moving, lifting, and repositioning (107; 152; 189; 232). It should be pointed out that, in this thesis, assisting a patient during a transfer is not equivalent to lifting or carrying the patient's total weight.

The term *nurse* is used for nursing personnel assisting the patients during transfers and includes three work categories with different levels of education and training: registered nurses, enrolled nurses, and auxiliary nurses / nurses' aides.

1.3 Manual handling

Manual materials handling

Manual handling of heavy loads implies high physical loads on the musculo-skeletal system of the worker. The tasks are usually highly dynamic in character and involves large muscle groups. In spite of extensive mechanisation and automation in industry, heavy manual handling is still required. Manual materials handling has been reported as a consistent risk factor for low back disorders in several epidemiological studies and reviews (13; 86; 100; 101; 111; 127; 171; 187; 255). However, the exact mechanisms behind these back disorders are not known (103; 158).

Assisting patients during transfers

Giving assistance to patients during transfers constitutes a considerable part of the daily nursing care provided by nursing personnel. The work task is a complex and arduous motor task that often implies high loads on the musculoskeletal system of the nursing personnel. A large part of the physical load is linked to the characteristics and behaviour of the patients. The patients may behave in unpredictable ways in transfer situations; they may suddenly resist the movements, make unforeseen movements, lose their balance, become weak or even faint (49; 214).

In a study of seven different transfer tasks in a laboratory setting it was found that even the safest of the studied tasks, a transfer of a light and cooperative patient higher up in bed, performed by two nurses using a draw sheet, implied high spinal loads and a substantial risk of causing low back disorders (152). Numerous biomechanical studies of various common patient transfer tasks have reported lumbar disc compression forces exceeding the recommended limit of

3400 N from the NIOSH equations (32; 34; 73; 167; 189; 199; 231; 246; 247; 256; 263).

The regular performance of patient transfers has been shown to be a risk factor for low back disorders (13; 50; 51; 86; 90; 101; 105; 132; 201; 202; 209; 250; 255). As with manual materials handling, the injury mechanisms behind the back disorders are not completely understood (90; 105).

Lifting patients is included in the concept of patient transfers in this thesis (see section 1.2). However, a common policy is that patients should only be lifted in emergency situations (a "no-lifting" policy). In cases where the patient is unable to bear weight and/or contribute to the transfer, mechanical hoists, or other transferring aids, should be used. In reality, however, lifting occurs also in these situations. Moreover, in rescue work, mechanical aids will probably never entirely substitute manual lifting. In Sweden, the Swedish Work Environment Authority has stated that manual lifting of persons should normally not be necessary in optimal patient transfer situations (218). Prerequisites for avoiding lifts are that the workplace is spacious and well planned, that appropriate equipment are available, that the nurses can cooperate well with each other and the patients, and that they can perform the transfers with a safe work technique.

1.4 Work technique

The relation between work technique and musculoskeletal load, as well as between work technique and musculoskeletal disorders, has been discussed by several authors (14; 58; 71; 103; 120; 121; 142; 189; 192; 221; 234; 240). However, there is no common definition of the concept and there are no common measuring methods. Even the term used for the concept varies, for example work strategies, handling procedures, lifting pattern, workstyle, postures, movement coordination, motor strategies, performance and skill.

The physical load in a work task is to a large extent determined by work factors. The work factors refers to characteristics of the work task (e.g. the weight of the object or the patient), workplace design (e.g. the amount of space) and work organisation (e.g. the number of patients that require assistance, the number of staff and amount of time available). However, it is a well-known fact that with apparently similar work factors, some employees develop musculoskeletal disorders, while others remain healthy. Inter-individual differences in work technique may partly explain this phenomenon.

Inter-individual variations among employees in the performance of the same work task have been observed in several studies (5; 15; 70; 80; 84; 85; 121; 122; 142; 155; 189; 199; 221; 248). Also, inter-individual variations in work technique within the same work method have been revealed (84; 195). Usually the inter-individual variations are larger than the intra-individual variations (70; 80; 85). Associations between inter-individual differences in work technique and the development or occurrence of musculoskeletal disorders have been suggested (59; 60; 121; 122; 248; 249; 254). However, this relation is far from being fully elucidated. Many of these studies have a cross-sectional design and therefore it is not possible to determine the causality; i.e. if the subjects' work technique has contributed to the musculoskeletal disorders or if ongoing symptoms have affected the work technique. To be able to study the impact of work technique on the risk of musculoskeletal disorders and injuries, prospective longitudinal studies are needed. The only such studies found are one study by Kilbom and Persson (121) on neck and shoulder disorders among female workers in the electronics industry and one study by Videman et al. (254) on back injuries among student nurses after graduation.

The concept of work technique may be compared with the concept of technique in sports. Sport-related definitions of technique often include "a specific sequence of movements in solving movement tasks" (136). In sports, technique seems to be a much more central concept, and there is a greater awareness of its importance for sport achievements, than in working life and, more specifically, than in the field of ergonomics. The performance of athletes is affected by their physical capacity and their technique (29). Technique training aims at optimising performance and precision; for example by using muscle force more efficiently, utilising mechanical principles and muscle properties, moving in an economical way and refining movement coordination. The ability to reproduce movement patterns is crucial. Biomechanical methods provide important tools for technique analyses, where the main goal is to improve performance (136). In sports the reduction of musculoskeletal load is not a primary aim. However, injury prevention is also of interest, though not at the expense of performance (136).

In working life, it is not clear whether a low variability in work technique is favourable regarding musculoskeletal load. A varied movement pattern may distribute the loads over various body structures and thereby prevent musculoskeletal problems. There is also a difference in time perspective between sports and working life. The development of, or recovery from, work-related musculoskeletal disorders is usually a long process, which may make it difficult to recognise effects of work technique training. Sport achievements are easier to detect. Besides, technique training in sports is given more time and is more intensive than work technique training.

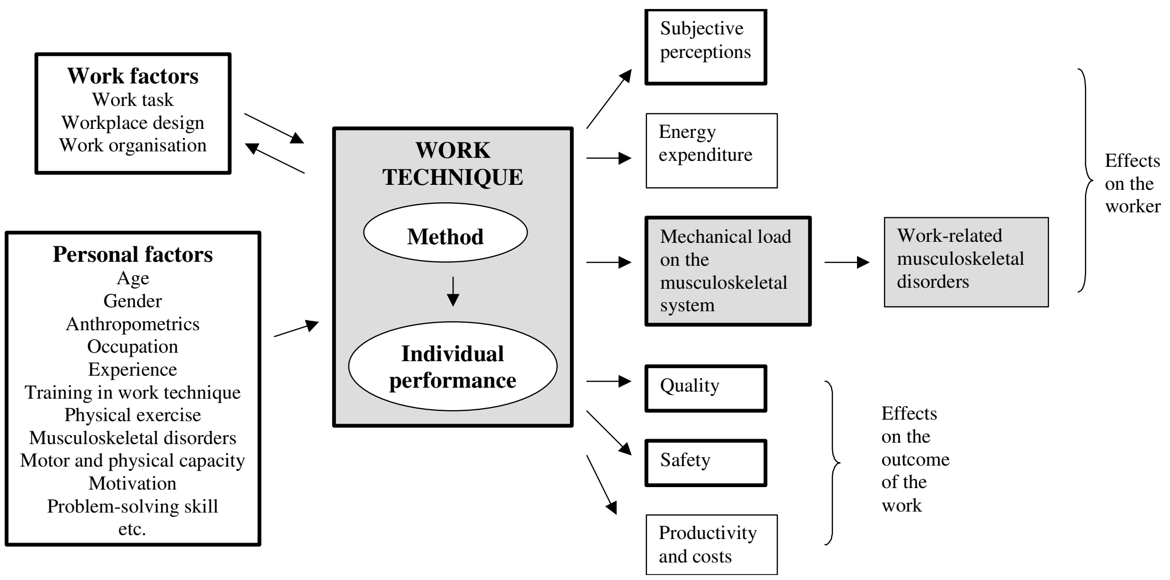

Figure 1. A model of the relation between work technique and work-related musculoskeletal disorders. The elements in the boxes with thick lines have been studied in this thesis. The elements in the shaded boxes constitute the concepts in focus in the thesis. The model is further explained in the text.

1.5 The work technique model in this thesis

A model focusing on work technique is outlined to show the conceptual framework for the relations between the elements studied and presented in this thesis (Figure 1). The model provides an overview of the content of this thesis, and shows the work and personal factors that govern and limit the individual worker's choice of work technique. It also shows the effects of the individual's work technique on the worker and on the outcome of the work task. The focus is mainly on the effects of work technique on the musculoskeletal system of the worker, and also the effects on musculoskeletal disorders. The pathways suggest how musculoskeletal disorders can occur or can be avoided. The model is simplistic. There are probably a number of feedback loops and interactions between the elements in the boxes, that are not marked with arrows in the figure. For example, the effects on the worker and on the outcome of the work, or the expected effects, may lead to changes of the work technique.

The *work factors* refer to the work task, workplace design and work organisation, as exemplified in section 1.4. The work can also be characterised by work demands and decision latitude (235). Decision latitude refers to the extent of autonomy for the worker, i.e. the worker's opportunities to modify and determine over the work factors and to select work technique. The work factors partially determine and limit the individual's choice of work technique. The work factors are not always modifiable; for example there may be a limited space to move in, a non-adjustable hospital bed, a heavy patient and time pressure. Other work situations are more flexible and, for example, allow the worker to adjust the workplace design, to decide over use of aids and how the work should be organised. Different work situations allow a different number of degrees of freedom for the worker's choice of work technique.

The work technique is also governed and limited by *personal factors*. The motor performance of a work task is limited and determined by, for instance, the worker's anthropometrics, physical capacity, motor skill and individual movement patterns. The choice of work technique is presumably also influenced by the worker's experience, training and knowledge in the occupation and of the work task, motivation and problem-solving skill. Studies on manual handling of loads have shown differences in work technique according to gender (150; 151; 236), age (25; 232) and experience (3; 5; 71; 80; 180; 181). The studies in this thesis have mainly been focused on variations in work technique due to personal factors. The work factors have been standardised, since otherwise they will probably account for a large proportion of obtained variations in work technique.

The central concept in this model, that of *work technique*, is divided into two elements: *method* and *individual performance*. The worker may choose to use a specific method, or a specific work method may be inflicted upon him/her, for example by a policy at the workplace. Within the frames of the method the individual will perform the work task in his/her way and with his/her individual movements patterns. Alternatively, no particular work method will be chosen for the execution of the work task and the work technique will only consist of the individual performance element.

The applications of the concept of work technique in this thesis are delimited to studies of (a) modifications by the individual worker of the work factors and (b) motor performance. Examples of modifications of work factors are adjustments of the work space, activation of the patient, use of lifting or transferring aids and asking for help from a fellow worker. The motor performance may be characterised by joint positions, the velocity, acceleration, coordination and smoothness of movements, balance, muscle force, which muscles are active, and lengths of lever arms. Modifications of the work factors will in turn influence the motor performance.

Work technique has *effects on the worker* in terms of mechanical load on the musculoskeletal system, energy expenditure and subjective perceptions. *Mechanical load on the musculoskeletal system* refers to internal forces and moments acting on muscles and joints. The *energy expenditure* during the performance of a work task will affect different physiological factors, for example oxygen consumption, heart rate and muscle fatigue. Examples of *subjective perceptions* are perceptions of exertion, fatigue, comfort and pain. As a consequence of the mechanical load characteristics, *musculoskeletal disorders* may develop or be prevented.

Work technique also has *effects on the outcome of the work* in terms of quality, safety and productivity and costs. In this model *quality* refers to the satisfaction of the needs and expectations of the customer or the patient (6). *Safety* refers to the safety for the object or patient during the manual handling or transfer operation, i.e. that there is no risk for damage of the load or injury of the patient.

Hence, the individual’s performance of a given work task has a certain degree of freedom, regarding what is possible for the individual in the work situation in question. Within these limitations the choice of work technique will be a trade-off between task demands and costs for the individual worker, as suggested by Kilbom (120). The demands, and ambition of the worker, to perform the work task with high quality, safety and productivity are balanced against costs for the worker in terms of energy expenditure, mechanical load and perceptions of exertion, fatigue, pain and discomfort (4; 5; 120; 130). Thus, the individual’s choice of work technique is probably a compromise between several objectives, and not only to keep the musculoskeletal load low. Different workers will presumably give priority to different objectives, and thus favour different work techniques. Some of these objectives may be in conflict with a low musculoskeletal load, for example the perceived demands to perform the work tasks rapidly and without help from co-workers. Therefore, the association between work technique and musculoskeletal load, and the development of musculoskeletal disorders respectively, is not obvious.

Psychological work demands and mental stress have been shown to influence the individual’s work technique (30; 149; 233). However, these aspects are not included in the work technique model, except for those covered by the work organisation element. Examples of aspects not covered are subjectively perceived or self-generated demands, for instance due to high ambitions and fears of job loss. Moreover, time aspects of work technique, such as work pace, pause patterns and cumulative exposure, have not been examined in this thesis. Muscle mechanics, neurophysiology and neuromotor control mechanisms are not covered, except for measurements of electromyography (EMG) amplitudes. Finally, energy expenditure and productivity and costs, as effects of work technique, have not been studied.

1.6 Other models for work technique and musculoskeletal disorders

Several models have been presented on possible pathways between the work factors and the development of musculoskeletal disorders. Some models include work technique, or related terms, in the chain of factors; others do not. Westgaard and Winkel (251; 252) have proposed a model to explain the relationship between mechanical exposure and musculoskeletal health. In their model effect modifiers may influence the coupling between the different elements in the chain of events. Work technique is dealt with as an effect modifier. The work technique may modify the relationship between external and internal exposure. For instance, work height (external exposure) may be modified by the work technique and this will affect the muscle forces (internal exposure). The model has been slightly modified by Dutch researchers (37; 102; 235). The external exposure element has been expanded to include the working method (similar to *method* in Figure 1) and postures, movements and exerted forces (*individual performance* in Figure 1). Work capacity, referring to the physical, cognitive and mental characteristics of the worker (*personal factors* in Figure 1), is a central concept in the model, affecting all couplings between the elements of the model.

Feuerstein (58) has proposed a model for the development of upper extremity disorders, focusing on workstyle. Workstyle is defined as an individual pattern of behaviours, cognitions and physiological reactions to work factors while performing work tasks. The concept resembles the concept of work technique; however it is multidimensional and covers not only behavioural components, but also cognitive and physiological dimensions. Examples of behavioural variables are forces, movements and postures; examples of cognitive variables are fears of performance decrements and of losing one's job; and examples of physiological variables are muscle tension and force on tendons. Individual variations in workstyle are believed to be associated with upper extremity disorders, which has been demonstrated in research on workstyle (59; 60).

1.7 Work technique in lifting tasks

A number of laboratory studies on lifting technique have been performed. Most of them have examined and compared standardised methods for lifting. A majority of the studies compare the squat lift, performed with bent knees and erect trunk, and the stoop lift, performed with straight legs and the trunk bent forward, for sagittal and symmetrical lifting of low-lying objects, i.e. objects at or near the floor, as reviewed by: (14; 103; 192; 210; 211; 240). These two lift methods may be seen as two extremes of lifting technique. Various combinations of the methods, or initial knee and trunk postures in between the postures defined by the stoop and squat methods, have also been studied (210). The two lift methods have usually been compared regarding biomechanical low back load, in order to find out which lift method is least likely to cause injury. Also physiological, psychophysical and motor control factors have been studied. The results have been rather contradictory concerning the biomechanical load; some studies show higher load during the stoop lift, others higher load during the squat lift, and some show no difference at all (2; 19; 43; 82; 138; 140; 227; 238). Different experimental designs, biomechanical models and dependent variables, may explain some of the contradictory results. Advantages and disadvantages of various aspects of lifting technique have been reviewed and presented for both methods (14; 103; 210; 211; 240). It can be summarised that, in terms of net moments and compression forces on the spine, the squat lift is preferable when the load is lifted from a position between the feet. When this is not possible, however, the stoop method obtains slightly lower, or similar, net moments and compression forces. Shear forces and strain on the low back ligaments have been shown to be higher during stoop lifts. Lifting with the squat method entails a higher energetic cost. In squat lifts the knee extensors are used, muscles that are not as strong as the hip and trunk muscles mainly used in stoop lifts, and the squat lift is therefore often perceived as more tiring by the subjects. Also, more work is needed to lift the upper body during the squat lifts due to the fact that the centre of gravity of the upper body is lowered more than during the stoop lift. During prolonged lifting, subjects often change from squat to stoop lifting because of effects of fatigue on the knee extensors. A further advantage of the stoop lift is that it provides better balance.

A third lift method, the semi-squat lift, has been proposed, characterised by a starting posture midway between the stoop and squat posture (14; 197; 210; 211). This method may be a good compromise between the two extreme lift methods. However, few studies have been performed on the semi-squat method, even though in some studies the squat lift seems to have been performed more like a semi-squat lift. Burgess-Limerick (14) suggests that the semi-squat posture adopted at the start of the lift allows a functional pattern of inter-joint coordination, where the mechanical properties of the leg and trunk muscles involved in lifting are utilised in an optimal way. This pattern of coordination thus reduces the muscular effort required to perform the lifts.

Freestyle lifts, i.e. individuals' own choice of lifting technique, have also been studied in laboratory studies. The self-selected lifting techniques show substantial inter- and intra-individual variations, as well as variations due to different lifting conditions. During optimal conditions, i.e. light loads and no muscle weakness or fatigue, it seems that lifting techniques resembling the squat or semi-squat lifting have usually been adopted (10; 15; 16; 18; 210; 260). When the load increases there is a tendency to gradually change the technique towards a stoop lift strategy (190). Also, during quadriceps and gastrocnemius fatigue and weakness the squat lift is modified towards a stoop lift (206; 228; 260). Other variations in the individual lifting techniques have been discovered due to different lifting conditions. For example, variations due to different weights of the load (15; 18; 80; 133) and different initial and final positions of the load (3; 133; 151) have been studied. Changes in movement patterns during prolonged repetitive lifting have been discovered (10; 42; 63; 206; 244). Effects of knowledge of load weight on lifting technique have been found (27; 180; 181). Thus, it seems as if the individual lifter adapts his/her technique according to the context, and that individual lifting technique is flexible and not limited to a single "personal method".

In addition, large variations in the individual performance between workers using the same lift method have been noted (193-196). It has been suggested that the stoop and squat method only designates the initial body postures, and that the lifter can choose between different lifting patterns within these methods (18; 104; 192; 193).

Dissimilarities in lifting technique between subjects who are experienced and inexperienced in lifting have been shown (180; 181; 203). In order to obtain new knowledge on safe lifting methods, and to abandon the traditional stoop and squat method thinking, strategies adopted by experienced manual material handlers have been extensively studied in recent years. These experts' strategies have been contrasted with inexperienced manual material handlers' strategies (3; 5; 71; 80). Generally speaking, what has been found is that in comparison with inexperienced subjects, the experienced workers use special knee movement strategies with reduced knee flexion, special foot orientation and footstep strategies, more smooth and fluid motions, and that they often place their hands on the corners of the box and tilt it. Also, they more often adapt their strategies depending on the situation in comparison with inexperienced lifters (3; 5; 180). However, it is not clear whether experienced workers' techniques are safer, from a musculoskeletal point of view, as the findings regarding the effects of the different lifting strategies on musculoskeletal load are not conclusive (38; 39; 67; 68; 71; 80; 180). Other advantages of the experts' handling techniques than effects on spinal loads have also been demonstrated, such as reductions of asymmetrical postures, reduced effort, reduced mechanical energy expenditure, improved balance and better control of the load, indicating that other factors than low back load determine the experts' choice of work technique (5; 39).

In conclusion, from the extensive literature on different lift methods, there is little evidence to prescribe a single lift method in education and training programmes in lifting technique as a means of preventing low back disorders (14; 103; 210; 240). Rather, it may be preferable to teach general lifting principles, for example keeping the load close, raising the initial height of low-lying loads, reducing the load mass, avoiding lifting from extreme stoop postures, avoiding trunk rotation and avoiding high movement velocities and accelerations (14; 158; 240). Also, from the studies of expert handlers' lifting techniques it could be learned that the lifting technique should be adapted to the work situation. Moreover, although lifting is one of the best-documented risk factors for low back disorders, there is still little scientific evidence that a specific lifting technique is a risk factor (103; 192; 240). There is a lack of prospective epidemiological research on mechanical factors related to lifting technique as predictors of low back disorders.

1.8 Work technique in patient transfer tasks

Most studies on work technique in patient transfer tasks have examined standardised transfer methods for the execution of specific transfer tasks in laboratory settings. Often different transfer methods and transferring aids have been compared, by biomechanical evaluations of the load on the nurses, ratings of perceived exertion by the nurses, and in some of the studies, ratings of safety and comfort by the patients being transferred (20; 34; 45; 69; 72; 73; 75-77; 141; 152; 164; 173-176; 189; 199; 231; 246; 256; 262; 263). The subjects have, for the most part, been given careful instructions concerning how the transfers should be executed. In addition, in some studies the subjects have been given training in the transfer methods before the experiments, in order to secure that the studied methods are standardised. In other experiments it has been taken for granted that the methods instructed are known to the subjects, and no training has been given (152). The notion of individual performance has been overlooked.

Many of the examined transfer methods have been shown to generate high spinal loads and have been found to be potentially hazardous for the musculo-skeletal system (32; 34; 73; 152; 189; 199; 231; 246; 256; 263). There is no international consensus on which transfer methods can be recommended. More general principles of transfer technique may be generated from the results of the laboratory studies above, for example using transferring aids (75-77; 152; 173-176; 231; 262; 263), adjusting the bed height (20; 34; 35), not performing the transfers alone (152) and pulling the patient instead of lifting (75-77; 174). Concerning transferring aids, the use of a draw sheet by two nurses to perform transfers of a patient higher up in bed, and the use of a walking belt with two nurses for transfers between wheelchair and other locations, can be recommended (75-77; 92-94; 152; 262). For non-weight-bearing patients, a mechanical hoist should be used (76; 77; 92-94; 231; 263).

Within one specific transfer method, variations in the individual performance between nurses could be anticipated to be much larger than in lifting methods, as handling a living person is a more complex motor task than lifting a box. Few studies on individual work technique during patient transfer tasks have been found, except for evaluations of training programmes in work technique. A Danish research group have studied self-selected techniques in common patient transfer tasks in experimental set-ups (189; 199). Skotte et al. (199) found larger variations in compression forces and net joint moments at the L4/L5 joint between transfer tasks than between the individual nurses' performances. In contrast, the EMG measurements from the erector spinae and ratings of perceived exertion varied more between individuals than between tasks. However, it is noteworthy that the nurses' free choice of technique was limited by not having access to any transferring aids. Schibye et al. (189) compared the self-selected techniques used by nine untrained nurses in eight transfer tasks, with the performance of a recommended transfer method for each task. The measurements of the recommended transfer methods were performed on the same nurses, after half a year of training in these methods. For most of the tasks compression forces and net joint moments at the L4/L5 joint, as well as perceived exertion decreased with the recommended transfer methods.

As with lifting, associations between features of individual work technique during patient transfers and musculoskeletal disorders have seldom been examined. Videman et al. (254) found in a prospective study on student nurses that a poor patient handling skill was associated with an increased occurrence of self-reported back injuries during their first year as a qualified nurse. In conclusion, although the regular performance of patient transfer tasks has been shown to be a risk factor for low back disorders, the role of work technique as a preventive or risk factor has not been fully elucidated (51; 90; 92; 94).

1.9 Methods for evaluation of work technique

Methods for detailed registrations of individual work technique during manual handling are needed. In biomechanical studies, the role of motion patterns in injury mechanisms should be further investigated. In epidemiological studies, the relation of work technique to musculoskeletal health needs to be further explored. In ergonomic intervention studies, methods are needed to evaluate the effects of programmes aiming at improving work technique. In the present thesis the literature review of existing methods for evaluation of work technique has focused on laboratory motion analyses methods and observation methods. The review of methods was restricted to manual handling work.

Biomechanical methodology

Biomechanics has been defined as *the application of the principles of mechanics to the study of biological systems* (52). Human movements can be described, analysed and assessed by means of biomechanical methods and may involve kinematics, kinetics and EMG (257). Kinematics is the study of movements without consideration of the forces associated with the movements. Kinetics is the study of the forces that cause movements. By biomechanical modelling and inverse dynamics*, forces acting on joints and muscles can be calculated from movement and external force data. EMG, the measured electrical activity associated with muscle activation, provides information about which muscles are active, when and how much they are active, and thereby contributes to knowledge of movement patterns and coordination. From data about position, force and myoelectric activity a large number of variables describing the movement can be derived.

In the literature, work technique in manual handling tasks has been examined by means of kinematic variables (e.g. displacement, velocity and acceleration), kinetic variables (e.g. compressive forces, shear forces, net joint moments and ground reaction forces), mechanical work and energy variables, and amplitudes of muscular activity. The work technique during different handling methods, work conditions, for different subject categories and as a result of ergonomic interventions, has been studied (as described in sections 1.7, 1.8 and 4.3).

Not only mean and peak values of the kinesiological variables have been applied to evaluate lifting technique, but also kinematic and EMG patterns have been examined with the aim of identifying subject-specific movement patterns. Sommerich and Marras (205) tried to identify typical patterns of EMG activity during different lifting conditions and for individuals. Motion patterns of the lifted load have been studied as measures of lifting techniques (104; 181).

Individual work technique may also be characterised by movement coordination. The inter-joint coordination, i.e. the sequencing between motions in different joints, in lifting has been studied by several authors (16; 26; 83; 190; 192; 193; 260; 261). Calculations of relative phase angles, which relate the instantaneous states of motion in two joints to each other, have been used to detect changes in lifting technique: changes caused, for example, by increased weights to lift, fatigue or pain (17; 18; 26; 194-196; 243; 244).

---

* A dynamic analysis can be performed with basically two approaches: inverse dynamics and forward dynamics. In models based on inverse dynamics the position-time data is measured and the net joint reaction forces and moments calculated. Forces acting on the body, such as from the ground, may be measured to improve the accuracy of the calculations. In forward dynamics, information about the segmental movements is determined from measured or known forces and moments.

In epidemiological studies of risk factors for work-related musculoskeletal disorders biomechanical measures are used. Mostly rather crude measures have been studied, such as body postures (108; 119; 139). For example, strong evidence exists for flexion and rotation of the trunk as risk factors for low back disorders (13; 86; 100; 101; 255). As manual handling work is highly dynamic in nature, also dynamic aspects such as movement velocity and acceleration presumably influence the risk, but have seldom been studied in epidemiological studies (108; 119; 146; 235). More complex movement patterns in manual handling, for example inter-joint coordination and EMG patterns, may also have to be included in epidemiological studies in order to fully elucidate the role of work technique as a preventive or risk factor for musculoskeletal disorders.

Some attempts have been made to utilise other biomechanical measures than body postures in epidemiological studies. Kumar (128) found associations between cumulative disc compression and shear forces and back pain for nurses' aides. Punnett et al. (186) used disc compression forces in a case-referent study in the automotive industry, but obtained no effect of this measure on back disorders. An American research group showed that a combination of five three-dimensional trunk kinematic variables and workplace factors, including trunk velocity in lateral bending and trunk velocity in twisting, could predict risk of work-related low back disorders in a cross-sectional study of industrial manual handling jobs (54; 153; 154). In a subsequent prospective study they were able to show that the risk model was capable of predicting changes in incidence rates of low back disorders due to ergonomic interventions in manual handling jobs (147). A Canadian group conducted biomechanical analyses of work tasks in the automotive industry in a case-control study (114; 165; 166; 168). Norman et al. (168) found that the integrated lumbar moment, peak lumbar shear force, peak trunk angular velocity and hand force, were predictors of reported low back pain. In subsequent analyses within the same study, performed with various approaches and objectives, similar, but not identical, trunk kinematic and spinal loading variables were identified as risk factors for reporting low back pain (114; 165; 166).

Observation methods

Observation methods offer simple and practical tools for studying work performance in the field. Observations of physical work characteristics have mainly been performed for three purposes: in *epidemiological studies* for physical exposure assessments to identify risk factors for work-related musculoskeletal disorders (65; 108; 119; 139); in *ergonomic evaluations* of workplaces to identify musculoskeletal hazards (95; 99; 110; 112; 116); and for evaluation of *ergonomic interventions* (1; 23; 55; 88; 172; 213).

In studies of nursing work, different types of observation instruments have been applied. A general observation method for registration and classification of postures, OWAS (Ovako Working posture Analysis System) (110), have been used to characterise nursing work and assess physical load (47; 89; 134; 143). Observations have been performed over time to obtain measurements of duration and frequency of poor postures. However, the application of observations over time in the health care sector has been criticised, due to the large variation in exposure over time (44). Most transfers last only a few seconds, and different transfer tasks vary considerably from each other. An observation method such as OWAS are not able to register sudden and occasional motions and forces, common in patient work. Instead, observations should be performed on single patient transfer tasks. A few instruments have been found in the literature which register individual workers' manual handling techniques during single handling tasks (5; 8; 23; 64; 144; 213), of which two were developed specifically for patient transfer tasks (64; 213).

One risk assessment tool, REBA, has been found, developed for use in the health care sector and industry, which takes the dynamics of the performance into consideration (95). The instrument provides a rapid risk assessment of the performance of a given work task, in terms of an action level.

To evaluate training programmes in patient transfer technique, a general observation method for registrations of postures and lifts has been applied (88). A few specific instruments to study patient transfer technique have been developed. Checklists have been constructed, based on specific transfer methods, to examine if nurses have assimilated the transfer methods entirely after training (1; 46; 48; 55; 56; 232). These checklists only cover the features of the methods, and are not capable of assessing individual performance characteristics. Work technique features, referring to both the method and performance element of a transfer task, were found in two instruments, which were used as a basis for the instrument developed in study III (64; 213). Subjective overall assessment of patient transfer skill by an observer on a rating scale has been used to evaluate a training programme within the nursing education (230; 254).

These specific instruments for observations of work technique during patient transfer tasks do not provide any assessment with regard to the level of musculo-skeletal hazard and safety. Also, the descriptions of work technique have not been very elaborate, especially not concerning the dynamics of the performance. Furthermore, they have not usually been tested for validity. This motivates the efforts to develop a new observation instrument that provides a detailed description of nursing personnel's work technique in patient transfer tasks, together with an assessment of work technique with regard to musculoskeletal hazard and safety.

1.10 Work technique and patients' perceptions during patient transfers

The work technique of the nursing personnel is not only important for the personnel 's health, but probably also influences the safety and well-being of the patient being transferred; in other words it is a matter of quality of care. However, research into patient handling has seldom dealt with the impact that different transfer techniques, or training in transfer techniques, have on patient care (12). The focus has merely been on preventing musculoskeletal disorders among the nursing personnel. Little is known about how patients perceive the transfers. It has been shown that a patient transfer is a risky activity, not only for the nursing personnel, but also for patients. Wanklyn et al. (245) reported that stroke patients who were dependent on assistance during transfers were more likely to develop pain in the hemiplegic shoulder than those who did not need help. The probable explanation was incautiousness with the hemiplegic arm of the nurses during transfers, for example pulls on the arm and lifts under the axilla. This indicates that the safety for patients during assisted transfers depends on the transfer technique of the personnel.

Thomsen and co-workers (224; 225) have pointed to the importance of expanding the traditional research about the work environment in the health care sector to include the patient perspective. Likewise, Kristensen (125) has proposed that measures of quality of care and patient satisfaction should be included as endpoint variables when evaluating intervention programmes in the health care sector. So far, the outcome for the patient has seldom been considered.

Ratings of safety and comfort by patients have been used to compare different transfer methods and transferring aids for the execution of specific patient transfer tasks in laboratory studies (75-77; 173-176; 262). Patients' perceptions have appeared to be influenced by the transfer methods and transferring aids used. Also, their perceptions often agree with the nurses' perceptions of physical exertion, and with biomechanical evaluations of the load on the nurses, regarding which transfer methods and aids are favourable. These results support the notion that a work technique that is safe for the nursing personnel is also safe and comfortable for the patient being transferred.

Patient ratings of safety and comfort during transfers have also been used in a few evaluations of intervention programmes, aiming at preventing musculo-skeletal disorders among nursing personnel due to patient transfer work (107; 177). Positive effects have been demonstrated with regard to: changes in the nurses' work technique; the nurses' perceptions of comfort, physical exertion and assessment of their own work technique; the patient's perceptions of safety and comfort; and the number of back and shoulder injuries related to patient handling tasks. Thus, there are indications that such intervention programmes also improve the quality of the transfers for the patients.

In this thesis it was hypothesised that there is an association between a work technique that is safe for the nursing personnel, i.e. does not lead to excessive load on the musculoskeletal system, and a work technique that is safe and comfortable for the patient.

1.11 Aims

The overall aim of this thesis was to explore and develop methods for describing, analysing and assessing work technique in lifting and patient transfer tasks, and to study how the work technique is related to personal factors and aspects of patient quality and safety.

The specific aims were:

- to explore the capability of some selected kinesiological variables to distinguish between different lift methods and between different performances in lifting tasks (Study I)
- to investigate whether gender differences in lifting technique could be detected by some kinematic variables (Study II)
- to construct an observation instrument for description and assessment of nursing personnel's work technique in patient transfer tasks with regard to musculoskeletal health and safety, and to evaluate the validity and reliability of the instrument (Study III)
- to explore the work technique applied by nurses in patient transfer tasks (Study IV)
- to investigate whether different personal factors were associated with the safety factor of work technique (Study IV)
- to study whether the patients' perceptions of safety and comfort during the transfers were related to (a) an objective assessment of the work technique with regard to musculoskeletal safety for the nurses and (b) the nurses' own subjective assessments of their work technique (Study V).

2. Subjects and methods

In studies I and II, lifting technique was studied by kinesiological variables in laboratory settings. The notion to resolve work technique in two basic elements, method and performance, was applied. The methods were represented by stoop and squat lifts, respectively, while two different lifting velocities were thought of as qualities of the performance. Study I consists of lifting experiments on twelve women. In study II the data from these experiments were compared with the corresponding data from a previous study on ten male subjects (140). In studies III - V, the individual work technique of nursing personnel performing patient transfers was observed in field studies at hospital wards. Study III concerns the construction and evaluation of an observation instrument for assessment of work technique in patient transfer tasks. In study IV and V the observation instrument was used in a cross-sectional study.

2.1 Subjects

Twelve women volunteered to participate in the experiments presented in studies I and II. In study II ten men were also studied. The subjects were all office employees with no professional experience in manual handling work. None of the subjects had any ongoing symptoms from the musculoskeletal system. Basic characteristics of the subjects are given in Table 1.

In study III 23 nurses at four wards in two geriatric hospitals were videotaped during their ordinary work (Table 2). Among these, there were 18 women and 5 men, and 5 registered nurses and 18 enrolled nurses and nurses' aides.

In studies IV and V nurses at nine orthopaedic wards in five hospitals were asked to volunteer. Of the total number of 224 nurses employed, 102 nurses volunteered to participate (Table 3). Among these, there were 86 women and 16 men, and 44 registered nurses and 58 enrolled nurses. The participants and non-participants had the same characteristics except that the participants were somewhat younger and included a higher proportion of men.

Table 1. Basic characteristics of the subjects in studies I and II in means, ranges and standard deviations (SD).

	Women (n=12)			Men (n=10)		
	Mean	Range	SD	Mean	Range	SD
Age (years)	39	22 - 60	12.1	37	28 - 45	6.1
Length (m)	1.67	1.57 - 1.74	0.05	1.77	1.69 - 1.85	0.05
Weight (kg)	63.8	53.4 - 82.5	7.6	72.2	62.5 - 83.5	8.3

Table 2. Basic characteristics of the subjects in study III in means, ranges and standard deviations (SD).

	Mean	Range	SD
Age (years)	36	20 - 57	10.5
Length (m)	1.68	1.50 - 1.88	0.10
BMI (kg/m^2)	23.3	18.6 - 28.9	3.5

Table 3. Basic characteristics of the subjects in studies IV-V in means, ranges and standard deviations (SD) or in numbers.

	Participants (n=102)			Non-participants (n=95)*		
	Mean	Range	SD	Mean	Range	SD
Age (years)	35	20 - 63	10.0	41	22 - 60	9.8
Sex (women/men)	86/16			87/8		
Length (m)	1.68	1.53 - 1.93	0.080	1.67	1.62 - 1.87	0.065
BMI (kg/m^2)	23.7	18.4 - 38.4	3.5	23.9	14.9 - 32.7	3.4
Occupation (registered nurses/enrolled nurses)	44/58			43/52		
Experience (number of years performing patient transfer tasks)	11	0.2 - 39	8.7	10	1.3 - 20	7.3

* 95 out of 122 non-participants answered a questionnaire.

Ethical approval

All of the studies were approved by the regional ethical committees. All subjects were given oral and written information about the studies and gave their consent to participate. In study III also the hospital directors, head nurses of the wards and the patients were given written and oral information and gave their consent. Only patients who were able to give their permission were videotaped. In studies IV and V the head nurses of the wards were informed and gave their approval.

2.2 Data collection methods

An overview of the data collection methods used in the different studies is given in Table 4.

Lifting experiments (studies I and II)

Experimental procedures. The subjects stood on a force plate and sagittal, symmetrical lifting tasks were performed (Figure 2). The object to be lifted was a

Table 4. Overview of data collection methods in studies I-V.

	Study I	Study II	Study III	Study IV	Study V
Optoelectronic three-dimensional motion capture systems	X	X			
Force plate	X				
EMG	X				
Video recordings			X	X	X
Observation instrument			X	X	X
Questionnaire				X	
Subjective ratings					X

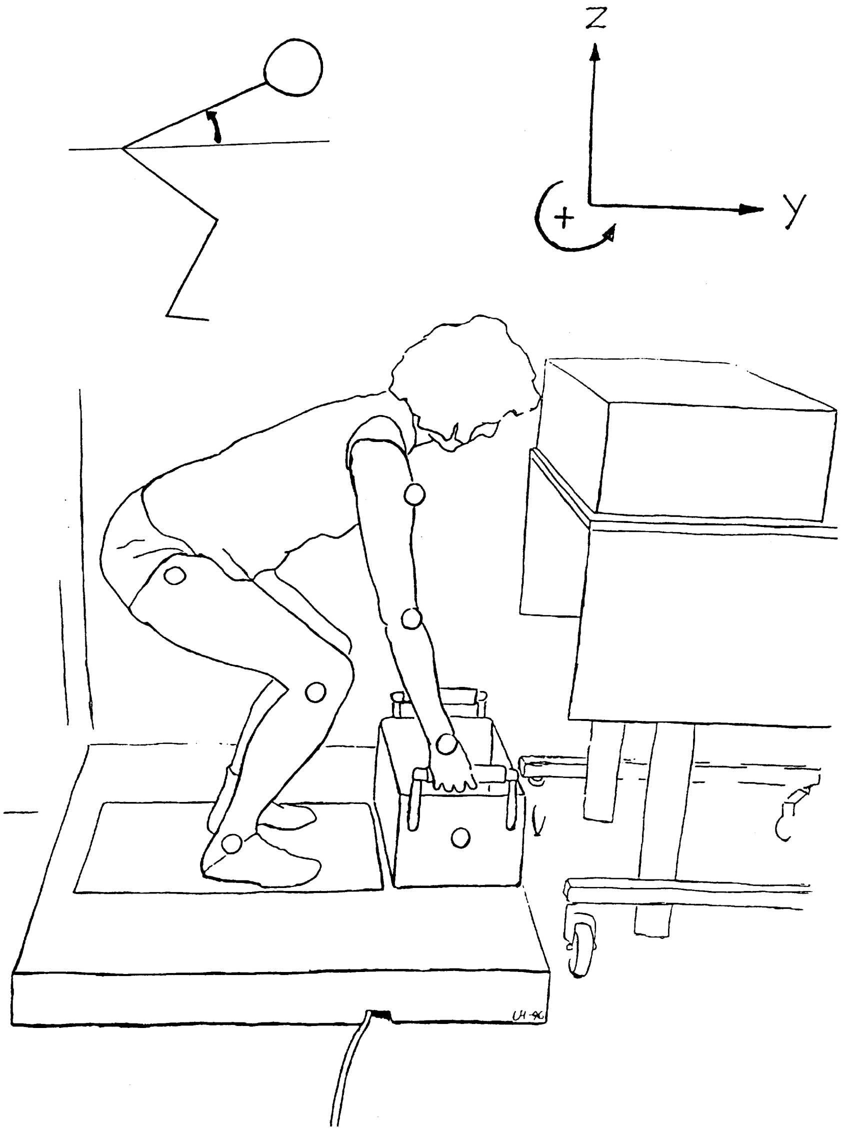

Figure 2. The experimental set-up from the experiments on female subjects showing a leg lift. The location of the markers on the subject and on the box is indicated. The angular orientation of the body segments is measured with respect to a horizontal reference line. Definitions of movement directions are shown. An anticlockwise angular direction is conventionally designated as positive.

box measuring 0.40 x 0.20 x 0.25 m, with handles placed 0.25 m above the base of the box. The box was placed with its rear 0.30 m in front of the subject's ankle and lifted from the level of the force plate to a table adjusted to navel height. The weight of the box was 12.8 kg for the male subjects and 8.7 kg for the women. The difference in load was assumed to correspond approximately to differences in physical capacity between men and women. Each subject was instructed and briefly trained to use two different lift methods, squat or leg lift (bent knees and straight back) and stoop or back lift (straight legs and bent back), and two different velocities, a fast lift of approximately 1 s and a slow lift of 2 s. The lifting time was defined as the time the box was in motion. The four lift types will be referred to as Fast Leg lift (FL), Slow Leg lift (SL), Fast Back lift (FB) and Slow Back lift (SB), respectively. The men performed three trials of each lift type, and the women five trials. All lifts started from an upright position.

The experiments on men were not designed for the purpose of comparing lifting techniques of men and women. The aim was to investigate the contribution of inertia from single body segments to the total dynamic effects in lifting, in order to simplify the biomechanical analysis (140). The subsequent experiments on women were designed to make the data on men and women comparable.

Measurements. The movements were registered by means of optoelectronic three-dimensional motion capture systems. In the experiments on women the MacReflex system (Qualisys AB, Sävedalen, Sweden), with three cameras and reflective passive markers, was used. The experiments on men were carried out with a Selspot II system (Selcom AB, Partille, Sweden) with two cameras and active markers (light-emitting diodes). The markers were attached to the subjects' right ankle, knee, hip, shoulder, elbow and wrist joints, and to the box (Figure 2). Three-dimensional coordinate data was collected.

The ground reaction forces were measured with a force plate (Kistler 9281 B, Winterthur, Switzerland).

In study I, EMG was registered from the right lumbar portion of the erector spinae at the L4 level with Ag/AgCL surface electrodes (E-10-VS, Medicotest A/S, Ølstykke, Denmark) and a telemetry system (MEGA 4000, Mega Electronics Ltd, Kuopio, Finland). The raw EMG signal was high-pass filtered (cut-off frequency 25 Hz) to eliminate movement artefacts and RMS-detected with a time constant of 50 ms. All EMG signals were normalised to reference contractions recorded with the subject in an upright position and the arms straight forward in 90 degrees shoulder flexion, holding a 2 kg dumbbell in each hand.

All data was sampled at 50 Hz.

Biomechanical model. A two-dimensional dynamic biomechanical model, earlier presented by Lindbeck and Arborelius (140), was used. The model has been developed for analyses of symmetrical lifts in the sagittal plane (Figure 2). The model comprises six segments: feet, lower legs, thighs, head-neck-trunk, upper arms and lower arms-hands. The segments are assumed to be rigid bodies connected by frictionless hinge joints. All segmental angles were calculated as angles defined by a link between two adjacent joint markers and a horizontal reference line (Figure 2). A free body diagram technique was used to calculate joint reaction forces and net moments for all segments, starting with the foot segment. The measured ground reaction force was used to solve the equations of motion for the feet. Masses, mass moments of inertia, locations of mass centres and lengths for the body segments, were calculated according to the literature (183). To calculate net moments at L5/S1, assumptions from Freivalds et al. (66) concerning pelvic rotation and the position of L5/S1 relative to hip and shoulder joints were used.

Treatment of data. The lift cycle was divided into three phases (Figure 3):

(I) The preparatory movement phase: from standing upright to grasping the box on the floor.

(II) The box lift phase: from a stoop or squat position where the box is grasped to an upright posture.

(III) The box placement phase: a slight forward bending of the trunk to reach the table and place the box.

The start of the lift cycle was defined as the first change in position of the hand marker, and the end of the lift cycle as when the marker on the box stops moving. The first two phases are separated by lift off: the time when the box marker starts to move. Phase II and III did not have such a distinct demarcation. On the trunk angular velocity curves it could be seen that the direction of the trunk motion changed from extension, during phase II, to flexion during phase III. This transition from positive to negative angular velocity defines the demarcation between the last two phases.

In study I the complete lift cycle, including all three phases, was analysed, while in study II only the actual lift, delimited in time by the lift off and the placement events, respectively, was considered. Furthermore, in study I all five trials were analysed, while in study II only the third trial of each lift type was used.

Coordinate data was digitally filtered using a fourth-order Butterworth filter, with a cut-off frequency of 6 Hz (257). Velocities and accelerations were calculated from the filtered position data using Lanczos' forms as described by Lees (135).

All EMG values were expressed as a percentage of the reference contraction, %RVE (percentage of Reference Voluntary Electrical activation) (156) (study I). The mean EMG amplitude for one lift trial was calculated as the root mean square value of all samples from a complete lift cycle. The peak EMG amplitude was calculated as the highest mean of 5 successive samples.

Phase plane analysis (study II). To compare the degree of synchronisation of hip-knee coordination in men and women, the inter-joint coordination was quantified as a relative phase angle between the knee joint and the hip joint, respectively, as suggested by Burgess-Limerick et al. (17; 18). Because of the small range of knee joint motion in back lifts, inter-joint coordination was studied only for the leg lifts. The analysis was performed in four steps:

1) Angles and angular velocities for the hip and knee joints were normalised to the interval [-1,1]. The normalised knee angles were then plotted as functions of the normalised hip angles, i.e. in *angle-angle diagrams*, for all subjects (Figure 4a). A diagonally straight line with a positive slope would imply that the two joint angles change at a constant ratio and that they are coordinated in phase. A curved line indicates alteration in the relative rates of change of the two joint angles.

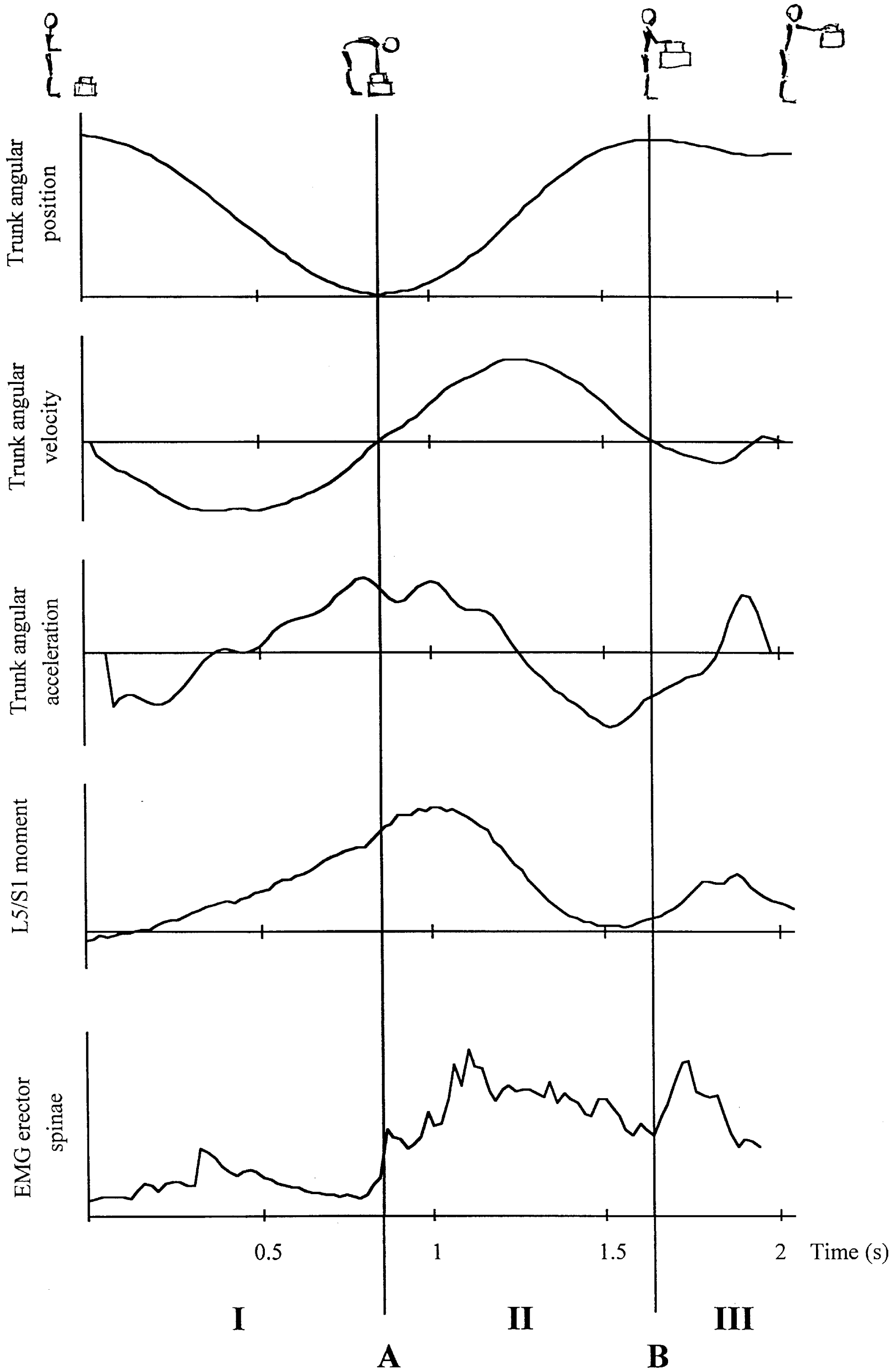

Figure 3. The three phases of the lift cycle: (I) the preparatory movement phase, (II) the box lift phase and (III) the box placement phase. The phases are separated by (A) lift off and (B) the transition from positive to negative angular velocity. An example of the qualitative appearance of five dependent variables during a fast back lift is plotted.

2) To define the state of the joint motion at a specific time, the angular position was paired with the velocity. *Phase plane plots*, i.e. graphs of joint angles versus joint angular velocities, were made for the knee and hip joints, respectively, and the corresponding phase angles, α, were also produced for all subjects (Figure 4b).

3) The *relative phase angles*, i.e. the knee joint phase angle subtracted from the hip joint phase angle, were calculated and used as a measure of the coordination between the knee joint and the hip joint (Figure 4c). A positive value of the relative phase angle means that the hip angle has covered a larger portion of its cycle of motion than the knee angle at the time in question; the hip angle "leads" the knee angle. A relative phase angle equal to zero implies a perfectly synchronised hip-knee coordination.

4) Finally max and min values of the relative phase angles were calculated for all subjects.

Dependent variables. From the measurements and the analyses some selected kinematic, kinetic and EMG variables were determined (Table 5). The variables were chosen to cover different aspects of work technique such as movement patterns, coordination, load on the locomotor system and muscle activity.

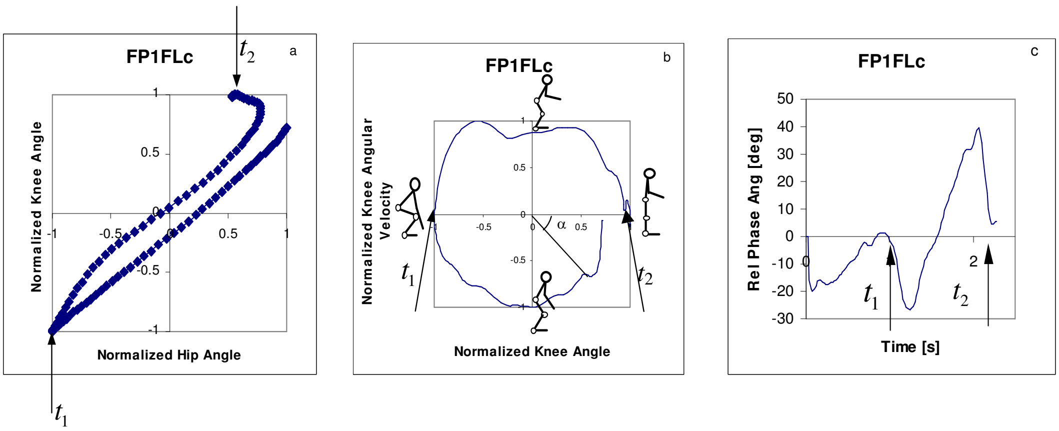

Figure 4. Angle-angle diagram (a), phase plane plot including the phase angle α (b) and relative phase angle (c) for an example of a full lifting cycle. The preparatory movement phase is included (even if it is not included in the presented analyses) in order to give a notion of the point of time of a full lift cycle for basic events such as start, lift off and placing the box on the table. The lift off (t_1) and the box placement event (t_2) in this example are indicated by arrows.

In (a) the lower left corner and the upper right corner correspond to the maximum joint flexion and extension, respectively.

In (b) the right and left midpoints represent maximum and minimum angles, respectively. On the lower half the angular velocity is negative and the joint flexes; on the upper half the joint extends.

Table 5. Selected variables to describe the lifts

Variables		Study I	Study II
Kinematic	Time for the maximum box height (s)		x
	Peak vertical velocity of the box (m/s)		x
	Peak vertical acceleration of the box (m/s^2)		x
	Trunk angle range of motion * (deg)	x	x
	Peak trunk angular velocity (rad/s)	x	x
	Peak trunk angular acceleration (rad/s^2)	x	x
	Knee joint angle range of motion * (deg)		x
	Relative phase angle between the hip and knee joints (deg)		x
Kinetic	Peak L5/S1 moment (Nm)	x	
EMG	Mean EMG erector spinae (%RVE)	x	
	Peak EMG erector spinae (%RVE)	x	

* The angle range of motion is defined as the angular distance between the minimum and maximum angle during the lift.

Kinematic, kinetic and EMG patterns (study I). Trunk angle, trunk angular velocity and acceleration, L5/S1 moment and EMG data from all lifts in study I were plotted as a function of time and qualitatively examined to look for characteristic patterns.

Observations of patient transfer tasks (studies III-V)

Video recordings. In study III a large number of patient transfers of frequent occurrence were videotaped in authentic work situations in geriatric hospitals. The recordings were made with one camera, mainly capturing a sagittal view and the whole body of the nurse when possible. These recordings were used during the construction of the observation instrument and for validity and reliability testing.

In studies IV and V 204 patient transfers were recorded with two video cameras on stands in an arranged set-up. One camera was recording towards the side of a hospital bed, and one slightly obliquely towards the foot-end of the bed. The whole body of the nurse was in the picture all the time, together with the scene of the transfer.

Development of an observation instrument (study III). An expert group, consisting of one physiotherapist experienced in patient transfer training and two researchers, studied the scientific literature and other relevant sources. Observation items were selected according to work technique features*:*

- related to musculoskeletal load
- shown to be risk factors for musculoskeletal disorders and injuries
- related to generally accepted ergonomic, biomechanical and neuromotor principles, which transfer methods are based on, and which could be expected to be influenced by training in transfer technique.

Furthermore, the focus was on the low back. Items from two observation methods in the literature were considered to be useful and were used as a basis for the instrument (64; 213). Additional items were constructed by the expert group.

Table 6. Principal aspects of the observation instrument.

Transfer phase	Description	Scale for assessment
Preparation phase	7 items describing preparatory actions	Nominal (2-4 categories)
Starting position	7 items describing initial postures and positions	Ordinal (5 items) Nominal (2 items)
Actual performance	10 items describing the actual transfer	Nominal (2-4 categories)

The observation items were tested on the videotaped patient transfers. After having thoroughly discussed relevance, phrasing, definitions etc. the expert group eventually arrived at a selection of 24 items, which were arranged in three phases of a transfer: the preparation phase, the starting position and the actual performance (Table 6, Table 14). The items of the preparation phase describe if actions are taken by the nurse to activate the patient, to correct the physical environment, to use a transferring aid and to obtain assistance from a co-worker. By the starting position items, the body position and posture of the nurse at the start of the transfer are observed. The actual performance items describe the movements and exerted forces by the nurse during the transfer. In addition, the interaction with the patient and any assisting co-worker is observed. All items and categories were defined in a key, which accompanies the instrument.

The items were assessed on different types of scales. The items of the preparation and actual performance phases, and a few items of the starting position phase, were assessed on a nominal scale, either with dichotomies (yes/no) or with three or four categories (Table 6). Most of the starting position items were assessed on an ordinal scale with categories representing angular sectors.

The instrument registers the work technique of one nurse during one patient transfer. Observations are made from video recordings.

Quantification of the assessments (study III). An attempt was made to quantify the assessments of the observed work technique, by calculating an overall score with regard to musculoskeletal hazard and safety. To calculate the score, 17 items from the instrument were used (Table 7). The categories of each of these items were scored by the expert group: 1 for a safe technique and 0 for a hazardous technique. This was accomplished by studying the associations between work technique characteristics and musculoskeletal load and hazards, described in the studied literature. Seven items were omitted from the calculations, due to lack of consistent findings in the literature regarding the association to musculoskeletal load and/or the fact that the scoring could not be generalised to all transfer situations.

The scores were multiplied by weights chosen by five physiotherapists, all experienced teachers in transfer technique (Table 7). The physiotherapists were asked to independently judge the importance of each item for the musculoskeletal health and safety of the nurse when performing a patient transfer, by applying a

Table 7 Quantification of work technique assessments. Scores of the categories and weights of the items are presented.

Items	Scores of categories 0	1	Weights
Preparation phase			
1. Encourages patient to cooperate	no	yes	2
2. Creates space	no	yes	1.25
3. Corrects positions of objects	no	yes	1.25
4. Corrects bed height	no	yes	1
5. Uses transferring aid	no	yes	1.25
6. Corrects transferring aids	no	yes	1.25
7. Transfers alone	yes	no	1
Starting position			
8. Feet distance	< hip width	= hip width > hip width	1
13. Back sagittal bending	≥ 45°	0 - 10° > 10°, < 45°	1
14. Curved back	yes	no	1
Actual performance			
15. Starts after a starting sign	no	yes	1.25
17. Effort direction	vertical	horizontal both	1
18. Back motion	sagittal lateral bending twisting	no angular motion	1
19. Main motor components	arms back	legs	1
21. Moves the feet	no	yes	1
22. Quality of motion	jerky	smooth	1.5
24. Loss of balance	yes	no	1.5

Note: Seven items from the observation instrument are omitted. The item texts are abbreviated.

magnitude rating procedure with the item "back motion" chosen as a reference item. Finally a consensus discussion was held about the weights.

The weighted scores from all relevant items were summed. An item was omitted when the particular work technique aspect was not applicable; for example, if a hospital bed was not adjustable, the item about correcting the height of the bed was disregarded. The overall score was "normalised" by dividing the sum by the maximum possible score, with regard to any omitted items for this particular transfer. This was done in order to make comparisons possible between different transfer situations. The overall score assumes a value between 0 and 1, where 1 is postulated to correspond to an ideal work technique. This work technique score is suggested as a crude summary measure of the performance with regard to musculoskeletal hazard and safety.

Validity and reliability evaluation of the observation instrument (study III). The reliability and validity tests of the observation instrument were performed by the expert group and two observers, experienced physiotherapists and teachers in transfer technique. The observers were trained during two four-hour sessions. Video recordings of 35 patient transfers, mostly transfers in bed, were observed. The criterion-related validity was evaluated by comparing the two observers' registrations with the expert observations, treated as the "gold standard". The inter-observer reliability was evaluated as comparisons of the two observers' registrations with each other, and the intra-observer reliability as comparisons of registrations of one observer on two occasions.

Procedure field study (studies IV and V). The nurses were asked to perform two standardised patient transfers: one transfer of a patient from a supine position to higher up in bed, and one transfer of a patient sitting on the edge of the bed to a wheelchair. The transfers took place in a room, arranged as a patient room for the purpose of the registrations, close to the orthopaedic wards. The participants left their ordinary work tasks temporarily. Everything in the registration set-up was arranged in a standardised way. One person was available in the room to assist the participant during the transfer, if the participant requested assistance. An adjustable standard hospital bed equipped with a draw sheet and a monkey pole, in addition to five different transferring aids, were provided. The bed was adjusted to a constant height before each transfer task. The nurse was free to choose how to perform the transfer, including the option of using a transferring aid or not, and of asking for assistance or not. The oral instruction to the participants was that they were to perform the transfers as if this was a normal work situation in their own ward, but taking into consideration the situation in the room and the conditions given. Three healthy women of normal weight (56 kg, 64 kg and 67 kg), two physiotherapists and one registered nurse, took it in turns to act as the patient: an 80-year-old woman with a left-side collum femoris fracture. Standardised information about the patient's diagnosis and function was given orally. The women acting as the patient simulated these patient characteristics.

Subjective ratings (study V). Immediately after each transfer the patient and the nurse were asked to rate their perceptions of the transfer. The patient rated the perceived safety and comfort on bipolar scales graded from - 4 to + 4 with the verbal endpoints "very unsafe" to "very safe" and "very uncomfortable" to "very comfortable". The nurse assessed his or her own work technique on a bipolar scale graded from - 4 to + 4 with the verbal endpoints "very poor" to "excellent".

Questionnaire (study IV). The participants filled in a questionnaire after the video registrations. The questionnaire concerned individual factors, experience in patient transfer work, previous training in patient transfer technique, physical exercise habits and musculoskeletal symptoms. Musculoskeletal symptoms were rated by a modified version of the Nordic Musculoskeletal Questionnaire (129). The questions and the response scales are presented in Table 8.

Table 8. The independent variables in study IV, their response scales in the questionnaire and the cut-off points for categorisation.

Independent variables	Response scales	Categories		
Age (years)	Continuous scale	18-34	35-44	≥ 45
Sex	Dichotomous	Women	Men	
Length (m)	Continuous scale	1.53 - 1.62	1.63 - 1.70	1.71 - 1.93
BMI (kg/m2)	Continuous scale	<25	≥25	
Ocupation	Dichotomous	Registered nurses	Enrolled nurses	
Number of years performing patient transfer tasks	Continuous scale	≤ 1	≤ 5	> 5
Amount of training in patient transfer technique	4-point scale[a]	No training	A few hours	≥ 1 day
Number of years since the latest training occasion in transfer technique	Continuous scale	0-2	3-6	7-18
Practical training by instructor in the use of transferring aids	Dichotomous	No	Yes	
Physical exercise during the last three months	6-point scale[b]	No exercise (1-2)	Regular exercise (3-6)	
Ongoing musculoskeletal symptoms (low back, neck and shoulders)	10-point scale[c]	No symptoms (0-1)	Symptoms (2-9)	
Musculoskeletal symptoms during the last 30 days (low back, neck and shoulders)	Dichotomous	No symptoms	Symptoms	

[a] 1 = none at all, 2 = a few hours, 3 = a few days, 4 = approximately one week or more

[b] 1 = no exercise, 2 = no regular exercise, but have taken walks and/or the like every day, 3 = exercise about once a week, 4 = exercise two or three times a week, 5 = exercise more than three times a week, 6 = hard exercise with competition

[c] A scale 0-9 with the verbal endpoints “not at all” and “very much”.

Observations and work technique assessment (studies IV and V). The 204 videotaped patient transfers were viewed by two observers and the work technique was assessed for each transfer by making registrations with the observation instrument. Two physiotherapists, independent of the project, were given seven hours of training as observers. They separately observed about half of the 204 transfers each. The observers watched one transfer at a time by alternating between the views of the two video recordings on a video monitor.

Data treatment (study IV and V). From the questionnaire, data on the following personal factors were used: age, sex, body length, body weight, occupation, number of years performing patient transfer tasks, training in patient transfer technique, practical training in the use of transferring aids, physical exercise habits and musculoskeletal symptoms. From the body weight and body length, the body mass index (BMI) was calculated. These personal factors were treated as independent variables in study IV (Table 8). All continuous variables and variables with ordinal scales were categorised into two or three classes for univariate analyses (Table 8). Age and BMI were categorised according to common methods in epidemiological studies. The cut-off points for the variables physical exercise habits and ongoing musculoskeletal symptoms were chosen from a previous study (131). The cut-off points for the remaining variables were determined from the distribution in the studied group. In the multivariate analyses, age and BMI were kept continuous.

The work technique of the participants was described according to the 24 items in the observation instrument. Also, a work technique score was calculated for each transfer. The work technique score was treated as the dependent variable. In the multivariate analyses in study IV, and for the Mann-Whitney test in study V, the work technique score was dichotomised into a poor and a safe work technique according to the distributions for each transfer. The dichotomisation was performed with different cut-off points in the two studies: a poor technique was defined as the lower quartile in both studies, while a safe technique was defined as the three upper quartiles in study IV and the two upper quartiles in study V.

2.3 Statistical analyses

An overview of the statistical analyses used in the different studies is shown in Table 9.

Data from the lifting experiments was analysed by performing analyses of variance (ANOVA). In study I three-way ANOVA with repeated measures on the factors lift methods, lift velocities and repetitions (2 x 2 x 5 factorial design) were performed for the selected variables, except the EMG variables. Because of missing data a 2 x 2 factorial design was applied and one subject was excluded from the ANOVA for the EMG variables. In cases of interaction effects, contrasts were tested among combinations of the conditions according to beforehand expected differences between these lift combinations. In study II three-way ANOVA with repeated measures on the factors lift methods and lift velocities, and one between-groups factor, gender, (2 x 2 x 2 factorial design) were performed for the seven selected kinematic variables. Two-way ANOVA was used to test for gender differences in the relative phase angles during leg lifts.

The variation in the data in study I was presented as the coefficient of variation (CV), i.e. the SD expressed as a percentage of the mean.

For evaluation of validity and reliability of the observation instrument in study III, calculations of the overall proportion of agreement (P_o), the kappa coefficient (κ) and the intraclass correlation coefficient were performed. P_o and κ were calculated for the observations of each item separately (61). The kappa value was interpreted on a three-degree scale: kappa > 0.75 = excellent agreement, 0.40 - 0.75 = fair to good agreement, < 0.40 = poor agreement (61). For kappa values above 0.40 the reliability and validity were considered satisfactory. The intraclass correlation coefficient was calculated to evaluate the quantitative assessments by the overall scores. The intraclass correlation coefficient was computed using one-way analysis of variance with repeated measures and a “raters random” model (62).

In studies IV and V the two studied patient transfers: the transfer higher up in bed and the transfer from bed to wheelchair, were analysed separately.

To explore the relationship between work technique and personal factors, initially univariate analyses were performed (study IV). The Mann-Whitney test (dichotomous variables) and the Kruskal-Wallis test (variables with three categories) were used to compare the work technique score between groups, based on categories of the personal factors, e.g. different age groups. Finally, multivariate analyses were carried out using multiple logistic regression modelling. Factors with p-values less than 0.25 for at least one of the studied transfers in the univariate analyses were included in the logistic regression, with the exception of the factor “low back symptoms during the last 30 days”. The same factors were included in the separate analyses for the two transfers. The effects of personal factors on having a poor technique were estimated with odds ratios with 95% confidence intervals.

To examine the relationship between work technique, in terms of the work technique score and the nurses’ assessments of their own work technique, and the ratings of safety and comfort of the patients, Spearman’s rank correlation coefficient was used (study V). The Mann-Whitney test was used to compare the patients’ ratings between transfers performed with a poor technique and transfers performed with a safe technique.

Table 9. Overview of dependent variables, their measurement scales and statistical analyses used in studies I-V.

Study	Dependent variables	Measurement scales	Statistical analyses	Parametric or non-parametric statistics
Study I	Kinematic	Ratio	ANOVA	Parametric
	Kinetic	Ratio	ANOVA	Parametric
	EMG	Ratio	ANOVA	Parametric
Study II	Kinematic	Ratio	ANOVA	Parametric
Study III	Observation items	Nominal and ordinal	Overall proportion of agreement	-
			Kappa coefficient	Non-parametric
	Work technique score	Ordinal	Intraclass correlation coefficient (based on ANOVA)	Parametric
Study IV	Work technique score	Ordinal	Mann-Whitney	Non-parametric
			Kruskal-Wallis	Non-parametric
	Poor work technique	Dichotomous	Logistic regression	-
Study V	Work technique score	Ordinal	Spearman’s rank correlation coefficient	Non-parametric
	Subjective ratings	Ordinal		
	Subjective ratings	Ordinal	Mann-Whitney	Non-parametric

3. Results

3.1 Kinesiological variables to detect differences in lifting technique (studies I and II)

The lifting times, i.e. the times the box was in motion, were on average slightly longer than 1 s for the fast lifts, and shorter than 2 s for the slow lifts. The ranges of registered time values overlapped for fast and slow leg lifts (Table 10).

Differences between lift methods and performances (study I)
The trunk angle range and trunk angular velocity clearly separated the lift methods. To distinguish between the two lift velocities, the most useful variables were the trunk angular velocities and accelerations, the L5/S1 moments and the EMG variables. Comparisons between lift methods and lift velocities are summarised in Table 11.

Trunk angular motion. The ranges of trunk angular motion were naturally greater during the back lifts than the leg lifts, $F(1,11)=202.5$, $p<0.0001$. The ANOVA also revealed an effect of lift velocity, $F(1,11)=6.26$, $p=0.029$. However, this velocity effect seemed to apply only to the leg lifts, discerned by the interaction

Table 10. Lifting times for all four lift types. Mean values, ranges and standard deviations (SD) of the third trial are given for all subjects.

	Lifting times (s)					
	Women			Men		
	Mean	Range	SD	Mean	Range	SD
Fast back lifts	1.1	1.0-1.4	0.1	1.0	0.8-1.2	0.1
Slow back lifts	1.8	1.5-2.2	0.2	1.7	1.5-2.0	0.2
Fast leg lifts	1.1	1.0-1.5	0.2	1.1	0.9-1.4	0.1
Slow leg lifts	1.7	1.3-2.0	0.2	1.8	1.3-2.3	0.3

Table 11. Values for selected kinesiological variables for the lift methods and lift velocities for the female subjects. Mean values and standard deviations (in brackets) for each lift combination are shown.

Variables	Back lifts		Leg lifts	
	Fast	Slow	Fast	Slow
Trunk angle range of motion (deg)	91 (4.5)	91 (4.2)	59 (7.3)	56 (6.7)
Peak trunk angular velocity (rad/s)	3.5 (0.43)	2.3 (0.40)	2.8 (0.58)	1.8 (0.23)
Peak trunk angular acceleration (rad/s^2)	15.7 (3.0)	7.7 (1.8)	15.1 (4.0)	7.5 (1.7)
Peak L5/S1 moment (Nm)	166 (22)	134 (16)	160 (22)	136 (19)
Mean EMG erector spinae (%RVE)	242 (147)	207 (75)	197 (101)	183 (82)
Peak EMG erector spinae (%RVE)	486 (337)	369 (145)	423 (272)	346 (204)

between method and velocity, $F(1,11)=3.66$, $p=0.082$. For the leg lifts a slightly larger trunk angle range was obtained during fast lifts in comparison with slow lifts, shown by the mean values. No such difference was found for the back lifts.

The peak angular velocity in the middle of the box lift phase (Figure 3) was larger during the back lifts than during the leg lifts, $F(1,11)=37.10$, $p<0.0001$. Naturally the trunk angular velocity reached higher values during fast lifts compared with during slow lifts, $F(1,11)=167.57$, $p<0.0001$.

The largest positive peaks of the angular acceleration for the trunk segment occurred in nearly all cases close to lift off (Figure 3). There were no significant differences in peak trunk accelerations between lift methods. As could be expected, the trunk acceleration was of a higher magnitude during the fast lifts than during the slow lifts, $F(1,11)=128.27$, $p<0.0001$.

Peak L5/S1 net moment. The largest peaks of the L5/S1 net moment occurred just after lift off (Figure 3). The ANOVA showed no effect of lift method. However, there was an interaction between lift method and lift velocity, $F(1,11)=6.14$, $p=0.031$. For the fast lifts, there was a small difference between the back and leg lifts with slightly higher moments for the back lifts, significant with a contrast test. For the slow lifts no such difference existed. The moments were higher for the fast lifts than the slow lifts, $F(1,11)=125.54$, $p<0.0001$, and this was true for both lift methods.

Mean and peak EMG amplitude. Neither the mean nor the peak EMG amplitudes from the erector spinae muscle showed any significant differences between the two lift methods, even if there was a tendency to higher amplitudes during back lifts. Both mean and peak EMG amplitudes, were higher during fast lifts than during slow lifts, $F(1,11)=6.92$, $p=0.025$ and $F(1,11)=11.57$, $p=0.0068$ respectively.

Variation between and within subjects. The variation in the studied variables between and within subjects is presented in Table 12. The variation was mostly smaller within subjects than between them.

The variation between subjects varied in magnitude for the different variables. The greatest inter-subject inconsistencies were found in the EMG variables. The size of the variation between repetitions of the same lift type within subjects varied between subjects.

The variations of the kinematic variables between subjects were mostly larger for leg lifts than for back lifts, except for angular velocities and accelerations of the trunk in slow lifts.

Table 12. The coefficient of variation (CV) for each dependent variable and each lift combination for the female subjects. Both the mean intra-individual CV (Intra) and the inter-individual CV (Inter) are presented. The CV expresses the standard deviation as a percentage of the mean.

CV (%)	Back lifts				Leg lifts			
	Fast		Slow		Fast		Slow	
	Intra	Inter	Intra	Inter	Intra	Inter	Intra	Inter
Trunk angle range	2.0	4.9	1.5	4.6	4.0	12.3	4.5	11.8
Peak trunk angular velocity	6.0	12.3	10.3	17.2	8.6	20.7	10.1	12.9
Peak trunk angular acceleration	12.5	19.1	16.0	23.1	12.9	26.4	15.0	23.4
Peak L5/S1 moment	5.2	13.2	6.4	12.0	4.2	14.0	3.9	14.0
Mean EMG erector spinae	15.8	60.8	11.3	37.0	10.9	52.0	8.6	44.7
Peak EMG erector spinae	21.1	69.6	17.2	40.5	24.8	64.9	15.8	59.2

Kinematic, kinetic and EMG patterns. Apart from differences in amplitudes of the trunk angle, kinematic, kinetic and EMG data did not produce any patterns that clearly distinguished between the lift types. The kinematic and kinetic patterns appeared rather consistent both between and within subjects except for the trunk angular acceleration, which showed large variability; larger between subjects, but also within subjects. Several inconsistencies were observed in the EMG patterns between subjects, concerning the number of distinct peaks and the time for the occurrence of EMG peaks in relation to peaks in the L5/S1 moment curve. However, the intra-individual variation was smaller, i.e. the pattern was often repeated from one lift to another for an individual subject. The pattern could be similar even for different lift types.

Gender differences in lifting technique (study II)

Significant differences between men and women were found for measures of time required to reach maximum box height, trunk angular motion, knee joint angular motion and inter-joint coordination between the hip and knee joints. Comparisons across genders for the kinematic variables are summarised in Table 13.

Box motion. The time taken to reach the maximum box height was significantly greater for men, $F(1,20) = 4.37$, $p=0.050$, but there were no significant differences in the peak values of box vertical velocities or accelerations between men and women.

Trunk angular motion. The ranges of trunk angular motion were significantly larger for men, $F(1,20) = 6.48$, $p=0.019$. There were no significant differences in peak angular velocities of the trunk between men and women. The ANOVA

Table 13. Values for the selected kinematic variables for the lift methods, lift velocities and women and men. Mean values and standard deviations (in brackets) are shown.

	Back lifts				Leg lifts			
	Fast		Slow		Fast		Slow	
Variables	Women	Men	Women	Men	Women	Men	Women	Men
Time for max box height (s)	0.86 (0.09)	0.86 (0.10)	1.33 (0.24)	1.49 (0.25)	0.81 (0.06)	0.89 (0.11)	1.33 (0.21)	1.47 (0.26)
Peak vertical velocity of box (m/s)	2.2 (0.2)	2.3 (0.3)	1.4 (0.3)	1.3 (0.2)	2.3 (0.2)	2.2 (0.3)	1.5 (0.3)	1.4 (0.3)
Peak vertical acceleration of box (m/s2)	9.4 (1.9)	10.2 (2.8)	4.2 (1.2)	3.6 (1.0)	9.2 (2.0)	9.8 (2.8)	4.2 (1.4)	3.8 (2.1)
Trunk angle range of motion (deg)	84.6 (4.7)	85.8 (3.4)	83.2 (5.1)	88.0 (5.6)	51.9 (9.8)	59.3 (7.0)	51.4 (7.6)	59.2 (10.0)
Peak trunk angular velocity (rad/s)	3.6 (0.5)	3.5 (0.5)	2.3 (0.4)	2.4 (0.3)	2.8 (0.6)	3.1 (0.5)	1.8 (0.3)	2.0 (0.3)
Peak trunk angular acceleration (rad/s2)	16.5 (3.9)	18.1 (4.6)	7.7 (2.5)	7.4 (1.7)	14.9 (4.5)	21.3 (4.5)	6.5 (1.2)	10.5 (4.8)
Knee angle range of motion (deg)	14.8 (7.1)	14.0 (7.1)	12.2 (7.6)	10.1 (5.0)	90.8 (12.1)	72.5 (17.6)	93.8 (11.8)	75.5 (20.4)
Min relative phase angle (deg)*					-40 (14)	-85 (11)	-27 (7)	-76 (24)

* The phase plane analysis was not performed for back lifts. Only the minimum values of the relative phase angles are shown, as they represent the largest deviations from a perfectly synchronised hip-knee coordination.

revealed a gender effect of peak angular accelerations of the trunk, $F(1,20)=5.89$, $p=0.025$. However, this gender difference applied only for the leg lifts, shown by an interaction between gender and method, $F(1,20)=16.8$, $p=0.0006$. This was confirmed by performing two-way ANOVA for back and leg lifts separately. For leg lifts, the men reached significantly higher trunk accelerations, $F(1,20)=13.7$, $p=0.0014$.

Knee angle range. A difference in knee angle ranges between men and women was revealed by the ANOVA, $F(1,20)=8.15$, $p=0.0098$, together with an interaction between gender and lift method, $F(1,20)=6.51$, $p=0.019$. Two-way

ANOVA for back and leg lifts separately showed that the women had significantly larger knee angle ranges during leg lifts, $F(1,20)=8.58$, $p=0.0083$.

Inter-joint coordination in leg lifts. The angle-angle diagrams illustrated qualitatively how changes in the hip and knee joints were more synchronised for the women than for the men. The plotted lines were in general less curved for the women than for the men. The extension of the knee joint was faster than the extension of the hip joint for the men immediately after lift off. Moreover, the angle-angle diagrams for the women appeared smoother than for the men; some of the graphs for men displayed obvious jerks close to lift off.

The qualitative differences in coordination between men and women that were observed were confirmed quantitatively in terms of the relative phase angle. When plotted as a function of time, the relative phase angle curve showed a negative valley shortly after lift off and a positive peak just before the box placement (Figure 4c), indicating that the knee joint leads the hip joint initially during the box lift phase, and that during the box placement phase the knee joint lags behind the hip joint. The largest deviation from a perfectly synchronised hip-knee coordination was represented by the negative valley, i.e. the minimum value, except for three trials, one of which is exemplified in Figure 4c, where the largest deviations were positive. These positive peaks were disregarded, being atypical for the coordination of the lifts. The deviations from perfectly synchronised hip-knee coordination, represented by the minimum values of the relative phase angle, were significantly larger for men, $F(1,20) = 80.0$, $p<0.0001$ (Table 13), i.e. the inter-joint coordination was more synchronised for women than for men.

3.2 The observation instrument for assessments of work technique in patient transfer tasks (study III)

For most observation items in the constructed instrument, the criterion-related validity and inter- and intra-observer reliability were satisfactory (i.e. kappa values > 0.40), and for some of them the agreements were excellent (i.e. kappa values > 0.75) (Table 14).

Two items of the preparation phase, concerning whether space is created around the transfer and if the height of the bed is corrected, showed poor agreements between observers, and between one observer and the expert group (Table 14). Judgements of the distance between the feet in the starting position agreed poorly between observers. The assessments of the back variables in the actual performance phase also caused problems. The agreements between the expert group and observers, and between observers, were low for the back motion variable. For the item ”back as main motor component” the agreement was low between the expert group and one observer.

For some other items belonging to the actual performance, low kappa values were achieved, although the percentages of full agreement were high, due to low variability of observations between categories (Table 14).

The intraclass correlation coefficients, used to test for agreements regarding the overall scores, were 0.77 and 0.80 for the agreements between the expert group and the two observers respectively, 0.71 for the agreement between observers, and 0.90 for the reproducibility within observer.

Table 14. Criterion-related validity, inter-observer reliability and intra-observer reliability of the items in the observation instrument. The overall proportion of agreement (P_o) in percent and the kappa values (κ) are shown. The criterion-related validity is presented as the agreement between the observations of one observer and the expert group, and values are presented for two observers.

	Criterion-related validity				Inter-observer reliability		Intra-observer reliability	
	Observer 1		Observer 2					
	Po (%)	κ	Po (%)	κ	Po (%)	κ	Po (%)	κ
Preparation phase								
1. Encourages patient to cooperate	94	.88	100	1.00	94	.88	97	.94
2. Creates space	69	.48	60	.17	66	.43	86	.77
3. Corrects positions of objects	83	.68	86	.73	86	.74	91	.84
4. Corrects bed height	80	.70	54	.31	60	.38	91	.86
5. Uses transferring aid	97	.94	94	.89	97	.94	100	1.00
6. Corrects transferring aids	77	.65	77	.66	89	.83	91	.86
7. Transfers alone	97	.94	97	.94	100	1.00	100	1.00
Starting position								
8. Feet distance	66	.48	74	.53	46	.18	74	.61
9. Feet position	86	.58	94	.85	86	.58	97	.89
10. Gait position	97	.87	91	.53	89	.28	94	.77
11. Left knee bending	89	.82	89	.82	83	.72	97	.96
12. Right knee bending	94	.91	88	.82	82	.72	89	.83
13. Back sagittal bending	86	.73	77	.57	74	.56	91	.85
14. Curved back	83	.64	83	.58	71	.41	89	.77
Actual performance								
15. Starts after a starting sign	91	.81	71	.44	74	.50	97	.93
16. Stimulates patient verbally	89	.60	83	.21	89	.30	94	.72
17. Effort direction	83	.59	86	.64	83	.63	89	.74
18. Back motion:								
* sagittal	80	.18	60	.08	63	.19	86	.61
* lateral bending	83	.32	89	.60	89	.44	100	1.00
* twisting	46	.10	49	.13	69	-.04	91	.72
* no angular motion	86	.25	69	.11	71	.28	91	.72
19. Main motor components:								
* arms	89	.30	86	.22	91	-.04	100	1.00
* back	57	.21	77	.47	69	.41	97	.94
* legs	89	.77	94	.89	89	.77	97	.94
20. In what way legs are used:								
* antero-posterior weight transfer	71	.00	94	.00	73	.00	79	.32
* lateral weight transfer	86	.42	94	.85	87	.58	93	.76
* to crouch	93	.76	100	1.00	93	.76	100	1.00
* to rise	79	.46	100	1.00	73	.38	93	.84
21. Moves the feet	86	.74	89	.79	83	.70	97	.95
22. Quality of motion	86	.39	89	.64	80	.15	94	.47
23. Performance of transfer	89	.30	94	.77	89	.30	100	1.00
24. Loss of balance	94	.64	97	.87	91	.53	94	.64

Note: The item texts are abbreviated.

3.3 Work technique in patient transfer tasks (studies IV and V)

The work technique of nurses at the orthopaedic wards is described according to the 24 items in the observation instrument (Table 15). In preparation for the patient transfers, 78% of the nurses during the transfer higher up in bed (HB), and 66% during the transfer from bed to wheelchair (BW), made efforts to encourage the patient to cooperate, for example by informing the patient about what was going to happen. 70% of them created sufficient space for the transfer HB by removing objects that obstructed the performance, while almost half of them missed out this step before the transfer BW. During the transfer BW only 23% of the nurses corrected the position of the wheelchair appropriately. Furthermore, from an ergonomic point of view, nearly one third of them did not correct the bed to an optimal height during the transfer HB. Most of the nurses used transferring aids during the transfers. Also, more than two-thirds asked for the assistance of a second person.

The actual performance of the transfer HB started in most cases with a starting signal, i.e. a clear indication that the transfer was about to start was given by the nurse to the patient and the assisting person, while during the transfer BW such a signal was seldom given (Table 15). Most of the nurses used a combined vertical and horizontal effort direction to transfer the patient; even in the transfer HB, which is a transfer in the horizontal plane. During the transfer HB, back motion occurred in the sagittal plane for 30% of the nurses, 40% used lateral bending and 40% of the nurses did not make any pronounced back movements. During the transfer BW, 90 % moved their backs in the sagittal plane, 39% used lateral bending and 59 % twisted their backs. To generate force to transfer the patient HB most nurses used their arms and more than half of them also used their legs performing weight transfers. To transfer the patient BW the nurses mostly used their backs to generate force, but their arms and legs were also used.

The overall scores of the participants' work technique are presented in Table 20.

Table 15. Observations of the work technique of 102 nurses while transferring a patient higher up in bed (HB) and from bed to wheelchair (BW) according to 24 items in the observation instrument. The observations are given in percentage of the study group.

Items	Categories	HB %	BW %
Preparation phase			
1. Encouraged the patient to cooperate	.	78	66
2. Created space	.	70	51
3. Corrected the positions of objects that the patient was transferred between	.	n.a [a]	23
4. Corrected the bed height	.	70	87
5. Used transferring aid(s)	.	86	70
6. Corrected the position of transferring aid(s)	.	4	3
7. Asked for assistance	.	67	72
Starting position			
8. Feet distance the same as or larger than hip width	.	93	76
9. Feet position at an angle (≥ 45°)	.	74	64
10. Gait position	.	18	47
11. Left knee straight or slightly bent (< 45°) b	.	95	96
12. Right knee straight or slightly bent (< 45°) b	.	99	97
13. Back straight or slightly bent forward (< 45°)	.	71	93
14. No curved back	.	87	91
Actual performance			
15. Started after a starting signal	.	80	34
16. Stimulated the patient verbally	.	4	86
17. Effort direction	vertical	2	6
	horizontal	31	1
	both	67	93
18. Back motion [b]	sagittal	30	90
	lateral bending	40	39
	twisting	14	59
	no angular motion	40	1
19. Main motor components [b]	arms	80	55
	back	33	66
	legs	58	43
20. If legs were the motor component, in what way were they used? [b]	antero-posterior weight transfer	17	28
	lateral weight transfer	83	19
	to crouch	2	49
	to rise	3	40
21. Moved the feet in the direction of the movement	.	5	97
22. Smooth quality of motion	.	98	90
23. Performed the transfer in one sequence	.	92	17
24. No loss of balance	.	100	99

[a]Not applicable, i.e. the item was not applicable for the transfer being observed.

[b]Registration of more than one category was allowed.

Table 16. The work technique score for different categories of the independent variables for *the transfer higher up in bed*. Medians and p-values for the differences among categories are given.

Independent variables	Categories			p-value
Age (years)	18-34 (n=53)	35-44 (n=32)	≥ 45 (n=17)	
	0.82	0.75	0.72	0.001
Sex	Women (n=86)	Men (n=16)		
	0.81	0.79		0.38
Length (m)	1.53 - 1.62 (n=31)	1.63 - 1.70 (n=36)	1.71 - 1.93 (n=35)	
	0.81	0.82	0.75	0.33
BMI (kg/m2)	< 25 (n=75)	≥ 25 (n=25)		
	0.81	0.79		0.70
Occupation	Registered nurses (n=44)	Enrolled nurses (n=58)		
	0.82	0.78		0.021
Number of years performing patient transfer tasks	≤ 1(n=12)	≤ 5 (n=26)	> 5 (n=64)	
	0.84	0.82	0.79	0.77
Amount of training in patient transfer technique	No training (n=10)	A few hours (n=48)	≥ 1 day (n=39)	
	0.78	0.81	0.81	0.93
Number of years since the latest training occasion in transfer technique	0-2 (n=27)	3-6 (n=29)	7-18 (n=29)	
	0.86	0.82	0.79	0.36
Practical training by instructor in the use of transferring aids	No (n=53)	Yes (n=48)		
	0.82	0.81		0.60
Physical exercise during the last three months	No exercise (n=40)	Regular exercise (n=61)		
	0.79	0.82		0.33

Associations between work technique and personal factors (study IV)

The personal factors: age, occupation, physical exercise habits and low back symptoms, were associated with the safety factor of work technique according to univariate analyses (Tables 16-18). The young nurses received higher scores on their work technique than the older nurses in both tasks (Tables 16 and 17). The work technique differed between the two occupational groups in the transfer HB; the work technique of the registered nurses was assessed as safer than the enrolled nurses' (Table 16). The group of participants who had performed physical exercise regularly during the last three months obtained higher work technique scores in the transfer BW than the group who did not do any exercise (Table 17). The work technique of nurses experiencing ongoing low back symptoms, and of nurses who

Table 17. The work technique score for different categories of the independent variables for *the transfer from bed to wheelchair.* Medians and p-values for the differences among categories are given.

Independent variables	Categories			p-value
Age (years)	18-34 (n=53) 0.75	35-44 (n=32) 0.74	≥ 45 (n=17) 0.66	0.048
Sex	Women (n=86) 0.73	Men (n=16) 0.67		0.17
Length (m)	1.53 - 1.62 (n=31) 0.71	1.63 - 1.70 (n=36) 0.75	1.71 - 1.93 (n=35) 0.70	0.44
BMI (kg/m2)	< 25 (n=75) 0.71	≥ 25 (n=25) 0.75		0.24
Occupation	Registered nurses (n=44) 0.73	Enrolled nurses (n=58) 0.72		0.35
Number of years performing patient transfer tasks	≤ 1(n=12) 0.72	≤ 5 (n=26) 0.74	> 5 (n=64) 0.71	0.92
Amount of training in patient transfer technique	No training (n=10) 0.66	A few hours (n=48) 0.73	≥ 1 day (n=39) 0.74	0.51
Number of years since the latest training occasion in transfer technique	0-2 (n=27) 0.73	3-6 (n=29) 0.75	7-18 (n=29) 0.75	0.54
Practical training by instructor in the use of transferring aids	No (n=53) 0.73	Yes (n=48) 0.71		0.77
Physical exercise during the last three months	No exercise (n=40) 0.67	Regular exercise (n=61) 0.76		0.047

had experienced symptoms during the last 30 days, was rated as less safe in the transfer BW than the work technique of nurses without such symptoms (Table 18). The multivariate analyses confirmed the associations between being older as well as suffering from ongoing low back symptoms, and having a poor work technique in both tasks (Table 19). In addition, an effect for male nurses was seen in the analysis of the transfer BW.

Table 18. The work technique score for nurses without and with musculoskeletal symptoms for two different patient transfers. Medians and p-values for the differences among categories are given.

		The transfer higher up in bed			The transfer from bed to wheelchair		
Independent variables	Response scales	No symptoms	Symptoms	p-value	No symptoms	Symptoms	p-value
Ongoing low back symptoms	10-point scale	(n=42) 0.81	(n=58) 0.79	0.19	0.76	0.67	0.001
Low back symptoms during the last 30 days	Dichotomous	(n=41) 0.81	(n=52) 0.80	0.86	0.76	0.67	0.007
Ongoing neck symptoms	10-point scale	(n=66) 0.81	(n=36) 0.80	0.44	0.73	0.74	0.87
Neck symptoms during the last 30 days	Dichotomous	(n=65) 0.81	(n=30) 0.78	0.60	0.73	0.70	0.56
Ongoing shoulder symptoms	10-point scale	(n=48) 0.81	(n=54) 0.81	0.74	0.73	0.74	0.92
Shoulder symptoms during the last 30 days	Dichotomous	(n=48) 0.81	(n=46) 0.81	0.49	0.71	0.75	0.56

Table 19. Odds ratios with 95% confidence intervals (in brackets) from a logistic regression model for having a poor work technique, i.e. a work technique score belonging to the lower quartile of the score distribution among the 102 participants. Separate analyses have been performed for two different patient transfers: a transfer higher up in bed (HB) and a transfer from bed to wheelchair (BW). The number of subjects with a poor work technique was 25 for the transfer HB and 24 for the transfer BW.

Independent variables	HB	BW
Age (10 years older)	2.0 (1.17 - 3.52)	2.3 (1.24 - 4.17)
Sex (men vs. women)	1.8 (0.38 - 8.40)	4.7 (1.04 - 21.34)
BMI (1 unit higher)	0.95 (0.81 - 1.10)	0.83 (0.68 - 1.01)
Occupation (enrolled nurse vs. registered nurse)	3.2 (0.93 - 11.20)	2.0 (0.57 - 6.96)
Regular physical exercise during the last three months	1.4 (0.45 - 4.14)	1.3 (0.42 - 4.25)
Ongoing low back symptoms	3.6 (1.16 - 11.07)	3.7 (1.17 - 11.41)

Associations between work technique and patients' perceptions of safety and comfort (study V)

The patients' ratings of safety and comfort were positively correlated to the work technique score in both transfer tasks (Tables 20 and 21). The patients' ratings of safety in the transfer from bed to wheelchair, and the patients' ratings of comfort in both transfer tasks, were positively correlated to the nurses' assessments of their own work technique (Tables 20 and 21). The patients rated their perceived safety and comfort higher for transfers performed with a safe work technique than for transfers performed with a poor work technique (Table 22).

Table 20. The work technique score and ratings of the patients and the nurses for two different patient transfers. Medians, ranges and the 25th and 75th percentiles (P_{25} ; P_{75}) are given.

	The transfer higher up in bed (n=102)			The transfer from bed to wheelchair (n=102)		
	Median	Range	P_{25} ; P_{75}	Median	Range	P_{25} ; P_{75}
Work technique score[a]	O.81	0.48 - 1.0	0.70 ; 0.92	0.73	0.45 - 0.94	0.64 ; 0.79
Ratings of the patients						
Safety[b]	2	-2 - 4	1 ; 3	1	-3 - 4	-1 ; 2
Comfort[c]	2	-2 - 4	0.75 ; 3	2	-3 - 4	0 ; 2
Ratings of the nurses						
Work technique[d]	2	-3 - 4	1 : 3	1	-3 - 4	0 ; 2

[a] The work technique score assumes a value between 0 and 1, where 1 is postulated to correspond to an ideal work technique.

[b] Patient safety scale: - 4 (very unsafe) to + 4 (very safe)

[c] Patient comfort scale: - 4 (very uncomfortable) to + 4 (very comfortable)

[d] Nurse's assessment of work technique: - 4 (very poor) to + 4 (excellent)

Table 21. Correlation coefficients (r) with p-values for the relation between the work technique variables and the ratings of the patients, for two different patient transfers.

	The transfer higher up in bed (n=102)		The transfer from bed to wheelchair (n=102)	
	r	p-value	r	p-value
Work technique score[a] - patient safety[b]	0.28	0.004	0.27	0.006
Work technique score[a] - patient comfort[c]	0.48	0.000	0.44	0.000
Nurses' assessments of own work technique[d] - patient safety[b]	0.073	0.466	0.23	0.018
Nurses' assessments of own work technique[d] - patient comfort[c]	0.21	0.035	0.23	0.022

[a] The work technique score assumes a value between 0 and 1, where 1 is postulated to correspond to an ideal work technique.

[b] Patient safety scale: - 4 (very unsafe) to + 4 (very safe)

[c] Patient comfort scale: - 4 (very uncomfortable) to + 4 (very comfortable)

[a] Nurse's assessment of work technique: - 4 (very poor) to + 4 (excellent)

Table 22. Patient ratings for transfers performed with a poor work technique (a work technique score belonging to the lower quartile of the score distribution among the 102 participants) and a safe work technique (a score belonging to the two upper quartiles of the score distribution). Separate analyses have been performed for two different patient transfers. Medians (md), the 25th and 75th percentiles (P_{25} ; P_{75}), and p-values for the differences between groups are given.

	The transfer higher up in bed					The transfer from bed to wheelchair				
	Poor work technique n=25		Safe work technique n=49			Poor work technique n=25		Safe work technique n=52		
	md	P_{25} ; P_{75}	md	P_{25} ; P_{75}	p-value	md	P_{25} ; P_{75}	md	P_{25} ; P_{75}	p-value
Safety[a]	1	0 ; 2	2	2 ; 3	0.004	0	-1 ; 1	2	-0.75 ; 3	0.002
Comfort[b]	0	-1 ; 1,5	2	2 ; 3	0.000	0	-2 ; 1.5	2	1 - 3	0.000

[a] Patient safety scale: - 4 (very unsafe) to + 4 (very safe)

[b] Patient comfort scale: - 4 (very uncomfortable) to + 4 (very comfortable)

4. Discussion

This thesis has explored and developed methods for describing, analysing and assessing work technique in manual handling tasks. The emphasis has been on biomechanical methods for laboratory studies and observation methods for use in the field. Furthermore, work technique in lifting and patient transfer tasks has been explored and related to personal factors, as well as to patients' perceptions of safety and comfort.

4.1 Methods for evaluation of work technique

Kinesiological variables for evaluation of lifting technique

In studies I and II the potential of some selected kinesiological variables for detecting variations in lifting technique was explored. The choice of variables was based on assumptions that they are relevant for the description of lift methods and important characteristics of lifting performance, and that they have implications for musculoskeletal load and hazards.

In study I work technique was dealt with as two elements: method and performance. Some variables proved to be better fit to characterise and distinguish between the methods, while others were more closely related to performance. The trunk angle range and trunk angular velocity clearly separated leg lifts from back lifts, while the trunk angular velocity and acceleration, L5/S1 moment and EMG amplitude distinguished between fast and slow lifting performance. The angular velocity thus seemed to be suitable for characterising both elements of the lifting technique. Marras et al. (153; 154) examined three-dimensional trunk motion variables and found that trunk angular velocity was the best single variable for discrimination between low and high risk jobs concerning low back disorders, while trunk angular acceleration was a weaker predictor. The L5/S1 moment was more influenced by the lift velocity, i.e. the choice between fast and slow lifts, than by the lift method, which has also been found by others (19).

Variations in the studied variables within each lift type, both between and within subjects, were obtained, in spite of the fact that the lifting was constrained to specific methods and specific lift velocities. The inter-individual differences were noticed both as quantitative differences in the studied variables and as inconsistencies and variations in the EMG patterns.

Differences in lifting technique between the men and women were found for some variables in study II. Perhaps most apparent were the differences in inter-joint coordination in leg lifts. Movements in the hip and knee joints were more synchronised and in phase for women than for men. The time required to reach maximum box height was greater for the men. The trunk angle ranges were larger for the men in all lift types. In leg lifts the peak trunk accelerations were larger for the men, while the knee angle ranges were larger for women. These gender differences could be thought of as differences related to the performance element of work technique.

Simplifications and assumptions may have made that our biomechanical model failed to capture some more possible, but less obvious differences between stoop and squat lifts, and between men's and women's performances. One simplification was the treatment of the head-neck-trunk as one rigid segment. Spinal curvatures and pelvic tilt could not be detected correctly. The subjects were instructed to keep their back as straight as possible during squat lifts and to bend their back during stoop lifts. However, the trunk can be bent forward with varying degrees of lumbar lordosis or kyphosis, and with varying proportions of motion between the hip and intervertebral joints. The effect of different lumbar curvatures concerning load on various back tissues has been reported (2; 87; 103; 185). Potvin et al. (185) suggested that the risk of injury may be influenced more by the curvature of the spine than the choice of stoop or squat technique; the shear forces in the L4-L5 joint are lower with a lordotic than with a kyphotic curvature. Furthermore, both the location of mass centre and mass moment of inertia of the trunk depend on the shape of the trunk. On the other hand, the technique to calculate joint reaction forces and joint net moments segment by segment causes measurement and approximation errors to accumulate from segment to segment. Therefore, a more complex model, for example dividing the trunk into several segments, may give less accurate results than a simpler model.

The ability of the L5/S1 moment to quantify back load or predict risk of back injury has been questioned, as it indicates the general demand on the low back, but does not give any information concerning the force distribution among individual muscles and passive tissues (158; 226). In study I there were no great differences in the L5/S1 moment between the two lift methods. Other load variables often used in the literature, such as compression and shear forces, require additional input data to the biomechanical model, for example assumptions about the back muscles' moment arms.

Comparisons between different studies, such as the comparisons of data from the male and female experiments in study II, must be performed with caution. Different experimenters and motion capture systems, as well as slight dissimilarities in experimental procedures, may have introduced systematic errors, falsely interpreted as gender differences.

It should be borne in mind that different sets of variables for evaluation of methods and individual performances are probably required for different types of manual handling tasks. We do not know if the selected variables in our lifting studies would also be appropriate for characterisation of work technique in lifting tasks at workplaces, where the lifting performance presumably are more varied, or in other types of manual handling. A method may sometimes be described in great detail and include performance features, e.g. velocity and acceleration. Individuals may vary their performance regarding body postures and ranges of motion (84).

Concerning the use of EMG measurements for work technique evaluation, it would presumably be more useful to collect EMG from more than one location and study coordination patterns between the main muscle groups involved in lifting. The muscular activity patterns are probably related to spinal load and injury risks (79; 169; 205; 227).

The observation instrument to assess work technique in patient transfer tasks
In study III an observation instrument was constructed to meet the need for a simple and practical tool to assess work technique during patient transfer tasks with regard to musculoskeletal health and safety. The main applications are in intervention studies to evaluate programmes aimed at improving nursing personnel's transfer technique; in epidemiological studies to study the relations between work technique and musculoskeletal disorders; and in studies exploring relations between work technique and different work factors, personal factors and outcome measures. Besides, the instrument may be useful not only in scientific research, but also as a pedagogical tool to provide feedback to the participants in training programmes in work technique, and also as a tool for quality assurance of nursing work.

New features of the observation instrument, compared with other available observation instruments for patient transfer tasks, are that it provides more details about work technique than merely adopted postures. As patient transfer tasks are highly dynamic in character, the dynamics of the performance are registered. Not only the motor performance is observed, but also the preparations before the transfer starts. These actions deeply influence the motor performance and subsequent load on the nurse, as well as injury risk. Lack of space, for example, may impede a safe performance of the transfer (49). Situations where the patient does not cooperate, or moves in an unexpected way, have been shown to contribute to back injuries (22; 49; 214). Adjusting the bed height has been shown to improve back postures and reduce the lumbar load (20; 34; 35). The use of transferring aids has been reported to reduce the load on the lumbar spine and the risk of back injuries (51; 75-77; 152; 200; 222; 263).

A method for a quantitative assessment of the observed work technique, by calculating an overall score regarding musculoskeletal hazard and safety, was proposed. The score should be regarded with care for several reasons. Adding the scores of the items to an overall score could be criticised, since the ordinal level of the data does not permit additions (219). Nevertheless, this is a common procedure in the health sciences (212). The relation of a particular score to the level of musculoskeletal safety and hazard is not known; only the rank order of the score in relation to other scores can be interpreted. The higher value the score assumes, the safer is the technique. Thus, the division of the score into a poor technique and a safe technique in studies IV and V was arbitrary and not based on any biological considerations or known risk levels.

The work factors in the transfer situation (Figure 1), such as the patient's weight, functional ability and willingness to cooperate; the design of the patient's room; and the availability of transferring aids and possibility for assistance from co-workers, influence and limit the work technique chosen by the nurse (49) and may accordingly influence the calculated score. Different transfer tasks differ in complexity and degree of difficulty and this also influences the score; in a complicated transfer there are more challenges for the nurse to use a safe work technique, and thus it is more difficult to obtain a high score. This was shown in the study of orthopaedic ward personnel performing two patient transfer tasks (studies IV and V). Slightly higher scores were obtained for the transfer higher up in bed than for the transfer from bed to wheelchair, which is a more complicated transfer to carry out. Therefore, assessments of individual work technique should preferably be made on standardised, or similar, transfer situations. Scores from different transfer tasks should be analysed separately.

It should be pointed out that this instrument is not suitable as a tool to identify overall musculoskeletal hazards. The score merely designates the musculoskeletal hazards due to the individual nurse's work technique, and does not cover risks due to the work factors. Moreover, a shortcoming in connection with making observations of single, and even more of standardised transfer tasks, is that sudden unexpected events during patient transfers, for example when a patient suddenly loses his/her balance, will not be captured.

The reason for choosing video observations was the large number of items in the observation instrument and the dynamic character of patient transfer tasks. For observations of dynamic work, video recording and subsequent analysis have been recommended (33; 137). The video films can be replayed in order to observe the items separately (119; 137); they can also be played in slow motion, and frozen to study postures. One obvious disadvantage of observations from video recordings is increased time for the analyses. Another drawback is the two-dimensional picture of a video camera (115). Direct observations at the workplace may therefore be preferred, since human vision is three-dimensional (119). Also the observer can move around at the workplace and find optimal views. The presence of a video camera might also cause ethical and bias problems in care situations. Consent from the patients and/or their relatives must be obtained.

The criterion-related validity and inter- and intra-observer reliability for the presented observation instrument were mostly satisfactory, both when evaluating the agreements between the observations of each item, and when evaluating the agreements between the overall scores. However, a few items caused problems: creating space for the transfer and correcting the height of the bed in the preparation phase, the distance between the nurse's feet in the starting position, and motions of the back in the actual performance phase. To improve the validity and reliability, some changes in the instrument, the video recording and observation procedures were suggested in study III. These changes were all implemented in studies IV and V. The items of the preparation phase were more exactly defined in order to provide the observers with more consistent criteria concerning what is "enough" space and a "correct" bed height. The transfers were recorded with two cameras to ease the judgements of distance between the feet and back motion. The observers were provided with video recorders with slow motion functions and were advised to complement the viewing at normal speed with slow motion for the items of the actual performance phase. It remains to be investigated whether these changes will improve the validity and reliability of the observations.

The reliability examined in study III refers to the extent to which repeated observations with the instrument of the same videotaped patient transfers yield the same results (219). However, a good agreement between observers, or between repeated observations by one observer, does not guarantee a high validity. Both observers could have used the same erroneous criteria for the assessments, and one observer probably uses the same criteria at repeated observations.

Validity refers to the extent to which the instrument measures the dimension it is supposed to measure (219). In study III the *criterion-related validity* was evaluated by comparing the ratings of observers with the ratings of the expert group, which were considered the true observations, i.e. the "gold standard". This procedure may be questioned, as it examines the ability of the observers to use the instrument correctly rather than the ability of the method to measure the correct dimension. Comparisons between the observation instrument and more objective methods, such as technical measurements, may be more appropriate. However, the items concerning preparations of the surroundings and the interaction with the patient are not objectively measurable, which means that the ratings of qualified observers are the closest it is possible to get to the "true state" (219). The *content validity*, i.e. whether the instrument covers all important aspects of work technique, was to some extent ascertained by choosing the items from the scientific literature, and by having experts in transfer technique involved in constructing the instrument, judging that no important aspect was missed (212).

The *external validity*, i.e. the ability of the instrument to identify work technique features associated with an increased risk of musculoskeletal disorders (119), is still a concern. Most observation items were selected according to their relations to musculoskeletal load, found in the literature. Only a few items were based on epidemiological studies of risk factors. The ability of the work technique score to predict risk of musculoskeletal disorders, should be studied in prospective studies. The relation found between poor work technique and low back symptoms in study IV offers some support for an external validity of the instrument. Moreover, the observation instrument has been used to evaluate training in patient transfer technique (107). Improvements in the scores were obtained as a result of training, which provide further support for an external validity of the instrument.

General discussion about methods for evaluation of work technique

Biomechanical studies have been frequently conducted to explore the mechanisms behind back injuries during manual handling. It is believed that an injury occurs when the applied load exceeds the tolerance of a particular tissue (158; 253). Forces on individual tissues within the body are not easily measured and therefore biomechanical modelling is needed to estimate the loading forces. However, simplifications of the models may conceal important injury mechanisms; thus validity is a concern (40; 158). Also, it is not possible to expose human subjects in the laboratory to forces leading to musculoskeletal injuries. Biomechanical models cannot directly link calculated forces on the low back with low back disorders (103). Therefore, biomechanical analyses should preferably be performed on comparisons of differences and changes in work methods and individual performances. Moreover, to investigate the role of individual variations in movement patterns and muscle activation, e.g. complex coordination patterns, in injury mechanisms, biomechanical laboratory studies are necessary (158; 192). Modern biomechanical laboratory methods are often highly sophisticated and provide quantitative measurements with high precision and accuracy, but are expensive, time-consuming and complicated to use. This may limit the usefulness of the methods and the number of subjects to examine, and make measurements at workplaces difficult. When important work technique features have been identified in the laboratory, simpler field measuring instruments may be used. Simple biomechanical measurements outside the laboratory may also be used in epidemiological studies and to evaluate intervention effects.

In field studies comprising a large number of subjects, long observation periods or a large number of work tasks, simpler and less expensive instruments are needed. Systematic observations by experienced ergonomists offer an alternative for assessments of work technique (119). The disadvantage is a decrease in precision compared to technical, or direct, measurements (139; 235).

Epidemiology constitutes an important complement to the biomechanical studies of manual handling, due to the complications, limitations and validity problems of biomechanical modelling discussed above (40; 103). There is a great need for prospective epidemiological research to establish relationships between specific work technique variables, such as biomechanical and observation measures, and the risk of musculoskeletal disorders.

4.2 Variations in lifting technique

Lifting is of course not a simple process, not even when constrained to specific methods. Even seemingly simple motor tasks can be performed through an infinite number of possible combinations of coordinated movements, i.e. there is a kinematics redundancy whose complexity increases as the number of degrees of freedom increases (182). An example of the kinematics redundancy is the performance of three simple tasks involving unconstrained lumbar flexion studied by Gatton and Pearcy (78). To perform the tasks, a large number of strategies were found between the subjects, regarding the sequencing of movements within the lumbar spine alone. There is also a second level of redundancy concerning muscle recruitment; for most tasks the number of muscles will exceed the number of equilibrium equations. The same kinematic pattern may be obtained by different combinations of active muscles. By imposing restrictions on the movements, the number of degrees of freedom can be reduced. It could be assumed that the variability in performance between subjects would be less for the studied lift methods in study I and II than for freestyle lifts without any directions as to the method. On the other hand, a self-selected technique would presumably reduce the variability within subjects between repetitions of the lifts, in comparison with the constrained stoop or squat method.

The scope of the lifting experiments was to obtain knowledge about how work technique analysis can be performed. Therefore a simple work task with constrained movements, i.e. the stoop and squat lift, and prescribed velocities, was studied, as a first application of the work technique concept (study I). For the purpose of detecting possible differences between two groups, i.e. women and men, it was also considered convenient to apply the design of a previous study on men (study II). No self-selected technique, i.e. freestyle lift, was studied. Nevertheless, variations in the studied variables, both between and within subjects, as well as between men and women were obtained. The work technique was, as expected, more varied between subjects than within subjects over repetitions of a lift task. Also, the subjects did not always keep to the assigned lifting times, as shown by the wide and overlapping ranges of lifting times between the fast and slow lifts. The distinction between the fast and slow lifts was thus not quite clear across all trials.

The kinematics redundancy provides an explanation as to why the inter-subject and inter-group inconsistencies in the kinematic variables were mostly larger for the leg lifts than for the back lifts, a circumstance also noticed by others (31; 83). The stoop lift performed with straight legs would provide an additional constraint compared with the squat lift which allows knee joint motion. In patient transfer tasks, even larger inter-individual variations could be anticipated compared with lifting tasks, as transferring a patient is a much more complex motor task than lifting a box. Also, in authentic lifting tasks at workplaces the variations will presumably be larger than in the constrained experimental lifting tasks studied here.

The even larger variability in EMG measurements, compared to the kinematics, could probably be explained by the redundancy concerning muscle recruitment, but also by biological differences, methodological aspects and variations in the EMG amplitudes due to the dynamic conditions. Larger variations in EMG data than in kinematic and kinetic data have usually been found (for example: (7; 199)).

The size of variation between repetitions of the same lift type within subjects differed between subjects, for both the kinematic, kinetic and EMG variables examined in study I. This indicates different abilities to reproduce the movements. It remains to be investigated whether small or large variations in performance imply a favourable work technique regarding musculoskeletal load. A varied movement pattern may distribute the loads on different parts of the body and thereby prevent musculoskeletal problems (203). Van Dieën et al. (241) showed that high endurance in the erector spinae muscle was related to high variability of the EMG amplitude and alternations between different parts of the muscle. In lifting studies where a considerable number of repetitions of the lifts have been performed by the subjects, large within-subject variations regarding measures of spinal load have been found (70; 239). In the experiments by van Dieën et al.

(239) the variance could be explained to only a minor degree by fatigue. In the experiments by Gagnon et al. (70) on subjects inexperienced in manual handling, no effects of practice or fatigue was found, but the variations in performance during repeated trials seem to have occurred randomly. Granata et al. (80) found larger within-subject variations in spinal load for experienced manual handlers than for inexperienced subjects during lifting. It could be assumed that practice of a task increases the consistency in motion patterns, which is crucial in technique training in sports. However, this notion was not supported by the studies cited above.

The inter-individual differences in lifting technique found in study I imply that work technique may need to be considered on an individual level when exploring mechanisms and risk factors for musculoskeletal disorders. A question to be raised is to what extent work methods can be standardised. Another question is whether averaged subject data should be used at all. The use of subject-specific data when studying motor performance has also been proposed by others (15; 169; 195; 205). For example, Sommerich and Marras (205) suggested individual EMG patterns to be used in biomechanical models of spinal loading during lifting tasks.

4.3 Individual variations in work technique and relations to personal factors

The individual's work technique is determined by work factors and personal factors as described by the work technique model in this thesis (Figure 1) and in section 1.5. Variations in work technique due to personal factors alone have been studied in this thesis. This has been accomplished by standardising the work factors. The lifting task was performed in a laboratory setting where even the lifting methods were standardised (studies I and II), while the two patient transfer tasks were performed in a standardised work situation in the field where the work technique was entirely self-selected (studies IV and V).

Our hypothesis was that the individual performance element of work technique is a function of many factors within the individual. Each human being has his/her own individual movement patterns, which are partly inherited and partly learned through practice and experience (182; 191). They are adapted to the person's physical capacity and characteristics, e.g. muscular strength, joint geometry and anthropometrics. The individual movement patterns are probably the basis for the individual's work technique. When a person begins to work in, for example, the health care sector, he/she has to learn techniques for transferring patients, i.e. he/she has to acquire a new motor skill. Maybe he/she will be trained in a patient transfer technique programme. The learning during such a programme will be dependent on the person's motor and physical capacity and motivation to learn. Also he/she will probably adapt to and learn from the work practices of colleagues (81; 109; 217). Furthermore, experience of movement from sports and other physical activities may be useful. The transfer technique will probably be continuously modified during the years of working, as a consequence of experience and practice (5; 71). The nurse will develop work techniques which are optimal in terms of time expenditure, patient comfort, security and rehabilitation needs, but also that minimise his/her own energy expenditure, mechanical load, exertion, fatigue, pain and discomfort (120). Different nurses will presumably favour different transfer techniques depending on their own priorities and the work situation (4; 217).

In the two patient transfer tasks a variety of strategies were used by the nurses as shown by the registrations of the 24 items of the observation instrument (study IV). Variations in transfer techniques between nurses were also found in a Danish laboratory study of self-selected work technique in nine different transfer tasks (199).

It is important to bear in mind that, in order to standardise the external situation, the work technique of the nurses was not studied in real work situations in the wards, but in a room which was specially arranged to simulate a patient room (studies IV and V). Besides, the patient was not a "real" patient, but a healthy person acting as an orthopaedic patient with a specified diagnosis. It may be questioned whether it is possible for healthy persons to simulate patient characteristics, dysfunctions, pain etc. Furthermore, the work situation arranged was in many ways optimal in terms of, for example, space around the transfer, availability of transferring aids and assistance from a co-worker, and a relatively light and cooperative patient, in order to minimise the risk of injuries during the transfers. This "optimal" work situation may have reduced the variations in work technique, as it is easier to apply a safe technique in a situation with few obstacles for the transfer, in comparison with a more complicated transfer situation. However, the nurses were requested to try to act as if this was a normal work situation in the ward.

Moreover, since the study took place at different orthopaedic wards in different hospitals and since three different persons acted as the patient, the work factors cannot be considered as completely standardised. For example, organisational differences between the wards and/or hospitals, and differences in the acting of the persons who were "patients", may have influenced the results.

At this writing, except for lifting studies, only few studies have been found investigating whether differences in work technique in manual handling exist that can be attributed to specific personal factors.

Gender

Gender differences in work technique were found, both in lifting (study II) and in performing patient transfers (study IV).

Among all investigations reporting on lifting there are relatively few which have reported on female subjects and few that have considered possible gender differences in the performance. Most studies and data in the literature are on male subjects and it is uncertain whether these results can be extrapolated to be valid also for women. Bejjani et al. (9) reported that back and knee shear forces were greater for women, and back compression was larger for men in static analysis of sagittal plane lifting. Gender differences in the performance of an incremental lifting machine test were observed in terms of timing, displacement, velocity, acceleration, force and power (207; 208).

In study II the male subjects required a longer time than the females to lift the box to its maximum height. A reasonable explanation would be that the men were taller and therefore needed more time to perform the lifts . However, correlation analyses were performed to check if the times for maximum box height were related to the subjects' heights, and no correlation was found.

To be able to explain the gender differences in trunk and knee angle ranges during the lifts, the trunk and knee angles at lift off (i.e. in maximum flexion) and in the upright position (i.e. in maximum extension) were analysed, as complements to the selected variables. The men's larger trunk angle range was caused by a deeper forward bending of the trunk at lift off as compared with the women, especially during leg lifts, but also during back lifts. In leg lifts deep trunk bending in the squat position can be expected to be associated with minor knee bending. However, no differences in knee angles between men and women were found in this position. Hence, the deeper forward bending of the trunk in leg lifts is difficult to explain. In back lifts a possible explanation for the men's slightly larger forward bending of the trunk at lift off was that the men flexed their knees somewhat in this position, while the women kept their knees extended. With the knees extended, the hamstrings limit the flexion range of the hip joint, and this may explain why the women, performing a more correct back lift, did not bend forward as deeply as the men did. The women's larger knee angle ranges in leg lifts resulted from larger knee extension in the upright position. As mentioned above, there were no differences between men and women in knee angles in the squat position at lift off; the differences appeared exclusively in upright postures where the men on average had 20 degrees larger knee flexion than the women. It seems that the angular range of motion is an ambiguous measure, and that the maximum and minimum joint angle values would be more useful for the description of the lifting technique.

It can be speculated as to whether the differences in angular motion between men and women, found in study II, arise from gender differences in joint and muscle flexibility. For example, gender differences in lumbar mobility have been reported, indicating that men have a greater maximum flexion angle, whereas the extension angle is greater for women (78; 216). Conceivable differences in lumbar lordosis, with larger lordosis for women, shown by some authors, could have influenced the motion patterns (57; 259). The observed deeper forward bending of the trunk among men may also be related to gender differences in movement patterns reported by others (150; 151; 223). Thomas et al. (223) found two distinctly different movement patterns used by men and women performing reaching tasks in which forward bending of the trunk was necessary. The men flexed nearly equally about the hips, calculated as the change in pelvis tilt, and the lumbar spine, with minimal flexion about the knees. The women used a minimal amount of lumbar spine flexion and flexed mainly about the hips and knees. The authors were not able to explain these differences by gender differences in hamstrings flexibility, also found in the study, or by differences in lumbar ranges of motion. They discussed whether the gender differences in movement patterns may to some extent be the result of sociological or cultural factors, for example avoidance of deep trunk bending among women. Similar differences in lifting kinematics between women and men were found by Marras and co-workers (150; 151). The female subjects flexed their hips more, whereas the male subjects used more trunk motions to perform the lifts. The male subjects in our study might have achieved a deeper forward bending of the trunk by using more lumbar flexion than the women, i.e. by kyphosing the lumbar spine, while the women might have bent the trunk forward with more pelvic tilt, i.e. with a lumbar lordosis. However, since the biomechanical model used treats the entire head-neck-trunk system as one single segment, it was not possible to study the motion of the pelvis and the lumbar spine separately.

The men's larger relative phase angles indicated that the hip joints lagged behind the knee joints in the extension movements to a greater extent than for the women. Qualitatively it was shown that the men extended their knees faster than their hips at the start of the actual lift. Knee extension typically occurs earlier and faster relative to hip extension in lifting (14). With increasing load mass this deviation from perfectly in-phase coordination has been shown to gradually increase (18; 193; 194; 196). As early as 1965 Davis et al. (31) observed that the hips rose faster than the shoulders at lift off in leg lifts when lifting heavier weights, i.e. knee extension initially led trunk extension and resulted in a slight trunk flexion just after lift off. This continued trunk flexion after lift off in leg lifts, especially in fast leg lifts, was observed in study I when the kinematic patterns of the lifts were qualitatively examined. Other studies have also shown that the trunk flexion angle increases at lift off with heavier weights (190; 198). Burgess-Limerick et al. (18) suggested that a distal-to-proximal coordination between knee, hip and lumbar vertebral joints is functional since it takes advantage of the muscles mechanical properties, and thereby reduces the required muscular effort. The use of rapid knee extension at the start of the lift, both lengthens and delays the rapid shortening of the hamstrings and the erector spinae early in the lift, thereby increasing their strength when the acceleration of the box is at its maximum. Moreover, as the hamstrings are biarticular muscles, the knee extension may contribute to hip extension through a tendinous action of the hamstrings. The men lifted a heavier weight and the question might be raised whether it was too heavy to match the assumed greater physical capacity. Also, men's trunks are heavier than women's, which adds to the weight to be lifted. If so, this could explain both their deeper forward bending of the trunk at lift off and their larger phase lags. However, several studies examining acceptable weights for female and male workers to lift, point to the fact that the larger box weight for men in our study was rather too small than proportionate to their physical capacity (117; 204; 215). Still, it could be criticised that the box weights were not adjusted to each subjects' individual strength, as the chosen box weights (12.8 kg for male subjects and 8.7 kg for female subjects) might have been too heavy for some men and too light for some women.

It remains to be investigated whether the differences found in the studied variables solely reflect gender differences in strength and anthropometrics, or if they also arise from differences in motor strategies between men and women. Some precautions were taken in order to avoid influences of strength and anthropometrics dissimilarities, by using different box weights for men and women and by adjusting the table heights in proportion to the subject's length. When studying pushing and pulling tasks, van der Beek et al. (236) found that male postal workers exerted higher forces than female workers did. These differences could not be explained by differences in anthropometrics and maximum physical capacity. They also found indications that men and women used slightly divergent work technique, in terms of a slower work pace for the women.

After the completion of study II, an American research group has presented results from lifting experiments also showing gender differences in lifting performance, as well as in spinal load (150; 151). Marras et al. (150) reported that women experienced generally higher normalised loads during sagittal symmetric freestyle lifts, which was explained by their use of more hip-pelvic motion and an increased coactivity of trunk muscles compared to men. These dissimilarities were interpreted as kinematic compensations by the women due to lower muscle strength. The same authors found similar gender differences in kinematics and muscle coactivity in symmetric and asymmetric freestyle lifts in another study (151). However, it was shown that the gender differences in spinal loads were almost eliminated when the origin height of the lift was adjusted to the individual's anthropometry. It was also discovered that stress and mental demands during lifting affected the kinematics and spinal loads in different ways for men and women (30; 149). This indicates that there may be other sources of differences in motor strategies between men and women than only differences in strength and anthropometrics.

In the study of work technique of nurses in patient transfer tasks (study IV) we found an association between gender and the safety factor of work technique, with lower work technique scores for the male nurses compared with their female colleagues in one of the two studied transfers: the transfer from bed to wheelchair. However, the number of men in our study was too low to obtain reliable statistical estimates of the association. No other studies have been found investigating whether differences in work technique exist between male and female nurses in patient transfer tasks. The biomechanical studies on lifting do not provide any general conclusion as to whether men or women use the safest techniques.

To summarise, there are no obvious explanations for the gender differences in work technique during lifting and patient transfer activities discovered in this thesis. Possible explanations discussed in this section are that they arise from differences in strength, anthropometrics, body weight, box weight, joint and muscle flexibility and motor strategies between men and women. Gender specific motor strategies could also originate from some other unknown factors related to gender.

Low back disorders
In the patient transfer tasks the work technique of nurses with ongoing low back symptoms and of nurses who reported low back symptoms during the last 30 days, was less safe than that of nurses without symptoms (study IV). Due to the cross-sectional design of the study no conclusions can be drawn about any causal relations between low back symptoms and poor work technique. We do not know whether the nurses' poor work technique was a consequence of ongoing, or previous, low back pain, or whether the poor technique existed before the onset of low back pain, and contributed to the development of back pain.

Ongoing symptoms from the low back at the time of the video registrations may have influenced the performance of the patient transfers, through restrictions of movements due to pain avoidance, increased muscle tone and co-contraction, and fear of injury and increased pain. Differences in motor control characteristics seen in low back pain patients in comparison with healthy subjects, can be interpreted both as functional adaptations and as dysfunctional changes (24; 26). For example, reduced movement velocity and range of motion, as well as increased spinal stability, may be interpreted as means of preventing provocation of pain and loading of the damaged tissues (11; 237; 242). In other studies, changes in motor control are seen as dysfunctional, for example a limited ability to stabilise the lumbar spine, causing negative effects on the motor control and potentially causing recurrence of low back disorders (97; 98; 157). McGill et al. (157) found that a history of low back pain was associated with impairments in movement patterns, lifting technique, balance, stabilisation of the spine and numerous other aspects of motor control, no changes that the authors considered advantageous for low back patients. Johansson et al. (106) have suggested a pathophysiological model behind work-related muscle pain syndromes. A vicious circle is created where the musculoskeletal pain causes disturbances in the proprioception, stiffness regulation and motor control. Thus, it seems as if ongoing symptoms may both worsen and improve the motor performance element of work technique.

It may seem strange that the nurses with low back symptoms would use a poor work technique that would increase the load on their back, and possibly also their pain, this is an argument that points to the opposite causal relation. However, as shown in the work technique model (Figure 1), the individual's choice of work technique is determined by several factors, and not only by perceptions of pain. Furthermore, it is not self-evident that individuals with low back pain choose a work technique that saves their backs (157). Nevertheless, an alternative explanation could be that nurses with a poor work technique are more likely to overload the low back and develop low back pain. A few prospective studies have shown that a poor work technique constitutes a risk factor for musculoskeletal disorders (121; 254).

A third alternative might be that the causal relation may exist in both directions in the process of disorder development. A poor work technique may cause symptoms from the low back. These symptoms may lead to changes in motor control which further worsen the work technique.

What is known is that chronic low back pain patients show different movement and coordination patterns in lifting and other trunk motions. For example, it has been shown that patients lift more slowly, with less synchronised hip and knee movements and with more of a leg lift-style (11). In another lifting experiment patients with low back pain reduced their trunk and hip flexion range and flexion velocity during lifting, as compared with healthy subjects (148). However, increased muscle coactivation and higher body weights among the patients resulted in higher spinal loads. Differences in lifting kinematics between women with and without low back pain after pregnancy have been discovered, for example larger peak phase lags between knee and hip joint in the extension movements for the women with back pain (26). Studies of trunk motion have shown that chronic low back pain patients flex and extend the spine at lower velocities through a decreased movement range than healthy subjects do (161; 178; 220). All these studies are cross-sectional laboratory studies; hence the cause and effect regarding the kinematic differences and back disorders have not been identified. The association between low back disorders and a poor work technique in patient transfer tasks, found in study IV, needs to be further investigated in a prospective study, where work technique should be assessed before the onset of back disorders.

Age

Age was associated with the safety factor of work technique in the patient transfer tasks (study IV). The younger nurses adopted safer work techniques than the older nurses. Similar results were obtained in a study of hospital nurses, where an observation instrument with a scoring system were used to assess if the nurses transferred patients in bed in a prescribed manner (232). The younger nurses received higher scores, i.e. they used transfer techniques more in line with the prescribed techniques, than the older nurses did. One explanation could be that the participants' basic nursing education, which usually includes some training in patient transfer technique, was closer in time for younger nurses in comparison with their older colleagues. As the majority of the participants in our study had not been trained regularly at the workplace, the older nurses may have forgotten the transfer technique taught. Also, they may have developed their own techniques, which may not be optimal in terms of musculoskeletal load, and may not follow principles taught in training. An additional explanation could be that training may not have been included in the older nurses' nursing education, or, if training was provided, that it may have been inadequate.

The fact that ageing is normally accompanied with a decline in motor performance as well as in physical capacity (37; 52; 188; 191) could provide a further explanation for the older nurses' poorer work technique. However, many years in the occupation should imply increased work skills, expertise and development of compensatory strategies. The role of experience to compensate for the age-related decline in the job performance is debated in the literature on age and work (188). It may be that ageing nurses change their work methods and techniques in order to cope with the heavy physical work (37). In a Canadian study, differences in work strategies between younger and older trash collectors were identified; the older trash collectors adopted a slower work pace and more often asked for help from co-workers than the younger ones (25). The older workers' work technique seemed to be adapted to a lower physical capacity induced by age. To our knowledge no previous studies have been carried out to examine whether work technique adopted by older or younger workers is the safest from a musculoskeletal point of view. Nygård et al. (172) reported that improvements in work technique achieved by store workers after a training programme in manual material handling were not dependent on age. The prevalence of musculoskeletal disorders in physically demanding occupations increases with age (36). A higher prevalence of low back symptoms among the older nurses in study IV might have explained the differences between the younger and older nurses' work technique. However, no relation between age and low back symptoms was found in our material.

Experience

Contrary to our expectations, we found no association between experience, in terms of number of years performing patient transfer tasks, and the work technique score (study IV). Differences in lifting strategies between experienced and inexperienced manual material handlers have been demonstrated in several studies, as noted in section 1.7 (3; 5; 71; 80; 180; 181; 203). However, the results are inconclusive regarding whether experienced workers' techniques are favourable with respect to musculoskeletal load and safety. The choice of work technique by experienced manual handlers is not determined solely by load effects on muscles and joints, but presumably also by the worker's ambitions, for example, to maintain balance, and to perform the work task rapidly, safely and with high quality (4; 5). In an interview study manual handlers in transport companies, considered as experts in handling, were asked about which factors determine whether a handling method is good (4). One of the most important factors, almost as important as reducing the back effort, turned out to be "controlling the load", meaning that the method provides a good grip and prevents the handler from dropping the load.

Training in work technique

In the study of work technique in patient transfer tasks (study IV) no association was found between training in patient transfer technique and the work technique score. Neither the amount of training the individual nurse had received, nor how close in time the latest training occasion had occurred, influenced the safety factor of the work technique. Possible explanations could be that the training was deficient and/or not long enough, or that the observation instrument is not a valid method to assess work technique with regard to musculoskeletal safety.

Training programmes in lifting and patient transfer technique, are common approaches to prevent back disorders. In Sweden, the Swedish Work Environment Authority has stated that the employer is obliged to provide training in work technique for the employees and to see to it that the technique instructions are followed (218).

The programmes have mainly been evaluated regarding effects on the participants' work technique and musculoskeletal load, as intermediate effects, and on musculoskeletal disorders, as an endpoint effect. Improvements in work technique with regard to musculoskeletal safety, assessed with observation methods, have been presented (48; 55; 88; 107; 172; 230; 254). Reductions in mechanical load on the low back have been demonstrated in biomechanical laboratory studies (32; 68; 170; 189). However, the effects on back disorders are inconclusive (28; 90; 91; 94; 126; 132; 202; 258).

It is doubtful whether the learning of a new work technique will cure already established musculoskeletal disorders (113; 118; 125; 131). A safe work technique will rather prevent the development of new disorders and the exacerbation of existing symptoms. Due to the latency period for the development and recovery of musculoskeletal disorders, follow-ups of the programmes have to be performed for a long time, which is seldom done in intervention studies. Therefore, changes in work technique, as an intermediate effect, can be used as an early indicator of intervention effects (118; 125; 252).

Many programmes are probably not sufficiently extensive in time. Also, if the learned transfer skill is to be maintained, repetitions of the training on a regular basis are presumably necessary. In study IV the majority of the participating nurses had received a total of less than one day of training during their career (Table 16). Only nine out of 97 nurses, who answered this particular question, had participated in training for one week or more. The vast majority had not received any follow-up training and none of the studied wards had routines for regular training of staff in transfer technique, as reported by the participants and head nurses in interviews. The low contrast in training times may explain the lack of association with transfer skill.

Lack of results may also be explained by deficiencies in the handling methods taught, and in the pedagogical and implementation approaches. It has been argued that no universal "correct" lifting technique exists, but that the work technique has to be adapted for each individual worker and each specific work situation (4; 14; 67; 68; 126; 130; 179; 192; 197; 213). As an example, Gagnon et al. (68) found promising results regarding low back loading as a result of training based on observations of expert manual handlers' strategies. The teaching methods in training programmes may also be discussed; for example, theory versus practical training, training in classrooms versus in real workplaces, participative approaches and time aspects (e.g. (145)). Furthermore, training programmes presumably have to be incorporated in larger organisational-level interventions to have any effect

(74; 91; 94; 132; 163; 252). It is difficult for the individual nurse to change his/her behaviour when the prerequisites for applying the learned techniques are not met in the ward, for example regarding the availability of transferring aids, assistance from co-workers and time. Intervention programmes combining training with provision of transferring aids, and training in their use, have shown better effects on the nursing personnel's well-being, as well as on compliance with the content of the programme, compared with only training in work technique; reductions in the number of back and shoulder injuries related to patient handling tasks have also been shown (32; 177; 258). In a cross-sectional study it was found that availability of transferring aids and training in workstation adjustments were related to lower prevalence of musculoskeletal disorders, whereas training in safe work postures was not (229). Moreover, support from the management, as well as direct involvement of the workers in so-called participatory ergonomics programmes, seem to be promising approaches (53; 184). For instance, Evanoff et al. (53) were able to show substantial reductions of musculoskeletal disorders and work injuries as a result of the formation of a participatory ergonomics team among hospital orderlies. The team developed policies for patient transfers, for example which transfer methods and transferring aids should be used, for training in these standardised procedures, and for the maintenance of the transferring aids.

4.3 Work technique and patient's perceptions during patient transfers

The findings of study V support our hypothesis of an association between the transfer skill of the nursing personnel, in terms of musculoskeletal safety for the nursing personnel, and quality of care, in terms of safety and comfort for the patient being transferred. A positive correlation was shown between the work technique score, based on observations of nurses performing two patient transfer tasks, and ratings of safety and comfort of the patients. Also, during transfers performed with a safe work technique, according to the score, the patients felt safer and more comfortable, than during transfers performed with a poor technique. It can be presumed that the various performance aspects of patient transfers that characterise a safe work technique for the nurse, and which are all registered by the instrument and contribute to the calculated score, will make the transfer safe and comfortable for the patient. Examples of such performance aspects are actions taken by the nurse to support and allow the patient to take an active part in the transfer. A further example is the removal of objects that impede and jeopardise the transfer, e.g. the footrest of a wheelchair. The use of transferring aids, such as a walking belt or a draw sheet, makes hard and painful grips in the patient's arm or under the axilla unnecessary (262). A smooth and coordinated movement pattern and the fact that the nurse keeps her balance also contributes to the patient's safety and comfort, as well as the synchronised efforts of the nurses, if more than one nurse is assisting the patient.

The patients' ratings of safety in one of the transfer tasks, and the patients' ratings of comfort in both tasks, were positively correlated to the nurses' assessments of their own work technique. We do not know which factors the nurses took into consideration when judging their own work technique. Besides, this may have varied between nurses. The only instruction given to the nurses was that they were to assess their work technique on a scale from very poor to excellent. Factors that may have influenced their assessments are the perceived musculoskeletal load, discomfort and pain caused by the transfer, the time taken and the believed effects of the transfer on the patient. A possible interpretation of the positive correlations between the nurses' assessments and the patients' ratings is that to some extent the nurses have included quality aspects for the patient in their skill assessments. In an exploratory study on nurses' perceptions of patient handling, it was found that nurses perceived the way in which the patient transfers were carried out to be influenced by the following factors: the maintenance of quality of care, for example regarding privacy, dignity and demands from the patients and their relatives; the patient's physical ability; and the physical safety of the patient (96). Other factors were related to the organisation, the workplace and the nurse. This implies that the nurse not only considers her own interests when deciding how to perform the transfer, but also takes into account the needs and interests of the patient. It may be presumed that such patient factors also influenced the nurses' assessments of their own work technique.

However, the correlation coefficients between the different assessments of the work technique and the patient perceptions were rather low. The strongest correlation coefficients were for the relations between the work technique score and the patients' ratings of comfort. An alternative interpretation would thus be that the nurses were not very competent in judging the outcome for the patient. It has been found that the beliefs of nursing personnel concerning how patients perceive the transfers are not always accurate. When interviewing patients concerning their attitudes towards hoists, McGuire et al. (160) found that nurses' beliefs that patients experienced discomfort and fear during transfers with hoists can be questioned. Most patients considered the use of hoists to be comfortable and had no objections to being transferred with them. Dixon et al. (41) and Knibbe (124) also experienced that patients prefer the hoist to being transferred manually. This indicates the importance of gathering the opinions of patients, as it has been shown in several studies that one reason for the personnel's reluctance to use transferring aids is that they think that the patients dislike them (12; 124; 162).

Other factors than the work technique of the nurses also presumably influenced the perceived safety and well-being of patients during transfers: for example the strength and body size of the nurse. Furthermore, in some transfer situations there may be a conflict between safety aspects for the nursing personnel, and the needs and wishes of the patients. The transfers are often part of a rehabilitation process. The patient's wish to execute the transfer as independently as possible and the personnel's wish to use transferring aids to reduce their physical load may be at odds with each other. In fact, one basic principle of safe handling practices is to encourage the patients to assist as much as possible in moving themselves (12; 189). However, allowing patients to perform the movements themselves without the help of any transferring aids, may in some situations increase the load on the personnel. Another example is the use of mechanical hoists to transfer non-weight-bearing patients. These devices certainly reduce the musculoskeletal load imposed on the personnel, but can be perceived as insecure and uncomfortable by patients (262; 263). The seemingly contradictory findings presented above regarding patients' opinions on hoists may be explained by different study contexts: a laboratory study with healthy persons acting as patients (262) and field studies including interviews with patients (41; 124; 160). Thus, a work technique which is safe for the nurses does not guarantee that the patients perceive the transfer as comfortable and safe. However, if the nurses use a poor technique, this will probably always jeopardise the safety and comfort of the patients.

Whether or not the ratings of healthy persons acting as patients really reflect the ratings of "real" patients may be discussed. These persons were health professionals; two of them were physiotherapists and one was a registered nurse, which may have influenced their ratings. They may have had other frames of reference for what is safe and what is comfortable during a transfer than a "real" patient, as they usually have another role in transfer situations: that of the caregiver. Moreover, physiotherapists are considered by other health professionals to be experts on transfer technique and often have the role of instructor. It could have been that their perceptions when they were being transferred were "coloured" by assessments of the work technique according to their expert view. However, they were all instructed to try to disregard their professional assessments, and focus on their bodily sensations. Getting healthy persons to act as patients is a common procedure in experimental studies of patient transfer tasks. Only two Danish studies have been found where a "real" patient, a patient with a stroke, was transferred (189; 199).

From interviews with nurses and physiotherapists about the meaning of patient transfers from their respective perspectives, it appeared that the patient was affected by the extent to which the caregiver had confidence in the transfer situation, implying that the transfers were easier to execute if the caregiver was confident of his or her own transfer skill (21). It can be assumed that a patient who feels comfortable and secure when being transferred will be relaxed and cooperative, while a patient who perceives the transfer as frightening might offer resistance. Patient comfort and safety during transfers may therefore contribute to increased safety for the nursing personnel. From analyses of reported accidents of nurses during patient transfers leading to back injuries, it is known that they often involve a patient-related problem, for example that the patient resisted or moved in an unexpected way (49; 214).

Similarly, the well-being of the nursing personnel will presumably affect their behaviour towards the patients in the transfer situation. Thomsen (224) has suggested that there is a relationship between the nursing personnel's work environment and the quality of care they provide to patients. She proposes that this relationship is mediated by effects of the work environment on the nursing personnel, for example on personnel satisfaction. The satisfaction of the personnel will in turn affect their attitudes towards and way of treating the patients. She detected positive correlations between the personnel's perception of their workload and, on the one hand, the patients' ratings of the personnel's work environment, and on the other, the quality of care they received. Thomsen suggests further that improvements to the personnel's work environment may not always influence the patient's well-being. What may be an optimal work environment for health care staff may not always be in the best interest of patients (225). However, improvements in quality of care will not be successful without the well-being of the personnel. With reference to patient transfer work, training in work technique may have the effect of increasing the nursing personnel's well-being, satisfaction, motivation, self-esteem and confidence in transfer situations. This may in turn positively affect their work technique and their way of treating the patients when assisting them during transfers.

On the whole, little is known about how patients perceive the transfers. Attention to the patients' perceptions is probably essential when developing equipment, methods and policies for patient transfer work, and when developing and evaluating intervention programmes aiming at improving the conditions of these work tasks (12; 159; 160). Until now, the focus has merely been on preventing musculoskeletal disorders and injuries among the nursing personnel (12). Positive outcomes of the transfers on the part of the patients will presumably also have positive effects on safety for the personnel; on the one hand, nurses who see positive patient outcomes will be encouraged to apply safe handling practices, and on the other, positive outcomes will make the patients cooperative. Lack of focus on patients may partly explain the often reported absence of positive effects of measures taken to improve the conditions of patient transfer work (90; 132). To sum-up, it seems as if good quality for the patient during a transfer is associated with a safe work technique on the part of the nursing personnel.

4.5 Implications for training programmes

In training programmes in work technique aiming at preventing musculoskeletal disorders among workers due to manual handling work, some strategies can be recommended. Some of the following issues are supported by the findings in this thesis; some others have appeared from the literature reviewed during the work on this thesis.

- General principles of lifting and transferring patients, rather than standard work methods, should be taught. Examples of such principles can be found in section 1.7 and 1.8.
- The participants in training programmes should be trained in adapting the work technique to the specific work conditions, i.e. to the work task, workplace design and work organisation, as well as to his/her own capacity.
- Training in work technique should be given on an individual level, or for homogenous groups of participants in terms of, for example, age, gender and low back disorders. Our findings indicate that special attention should be given to older persons, persons with low back disorders, and possibly also

men. The training should help the participant to discover his/her own optimal individual movement patterns.

- The patient perspective should be integrated in training of transfer technique, i.e. attention should be given to the needs and perceptions of the patients being transferred. Training in transfer technique, and also other measures to improve the safety of nurses during patient transfer work, such as provision of transferring aids, should be regarded as means of improving both safety for the nurses and safety and comfort for the patients.
- The work technique model (Figure 1) outlined in this thesis can be used by educators in the development of training programmes.

5. Conclusions

- Separate kinesiological variables should be used for descriptions of work methods and task performances. Simple kinematic descriptions of joint configurations in specific phases of the movement cycle, e.g. maximum and minimum joint angle values, seem to be appropriate for characterising a method. To distinguish between individual performances, descriptions of motion in terms of displacement derivatives (e.g. angular velocities and accelerations) and load variables (e.g. net joint moments) seem to be more useful.
- The observation instrument developed has been shown to be a valid, reliable and useful method for assessments of nurses' work technique in patient transfer tasks. The proposed calculations of a work technique score would be of value, e.g. for evaluations of intervention programmes in transfer technique.
- Inter-individual variations regarding work technique in lifting and patient transfer tasks suggest that evaluations of work technique may need to be carried out on an individual level.
- Special attention should be given to possible differences between women and men, younger and older persons, and persons with and without low back symptoms, when evaluating work technique in lifting and patient transfer tasks.
- Being older, suffering from low back symptoms and being male were associated with a poor work technique in patient transfer tasks, according to the work technique score.
- The transfer skill of nurses could also be regarded as a matter of quality of care, since it was associated with safety and comfort for the patients during transfers.

6. Summary

Kjellberg K. *Work technique in lifting and patient transfer tasks*. Arbete och Hälsa 2003:12.

The overall aim of this thesis was to explore and develop methods for describing, analysing and assessing work technique in lifting and patient transfer tasks, and to study how the work technique is related to personal factors and aspects of patient quality and safety. The focus was on work technique features with implications for musculoskeletal load and for the development of musculoskeletal disorders. Work technique was viewed in two basic elements: method and individual performance. The thesis is based on biomechanical model studies in the laboratory and observational studies in the field.

Results from lifting experiments implied that separate variables should be used for descriptions of work methods and task performances. The work technique varied between the subjects to a greater extent than the individual variability over repetitions of a lift task. Differences between men and women in lifting kinematics were found, e.g. in trunk motion, knee angle ranges and hip-knee inter-joint coordination.

An observation instrument for description and a quantitative assessment of work technique in videotaped patient transfer tasks was developed, and an overall score with regard to musculoskeletal hazard and safety was calculated. The validity and reliability of the instrument were mostly satisfactory, both when evaluating the agreements between the observations of each item and when evaluating the agreements between the overall scores.

Observations of nurses at orthopaedic wards revealed that a variety of strategies were used to perform two patient transfer tasks. Being older, suffering from low back symptoms and being male were associated with a poor work technique. Patients' perceptions of safety and comfort when being transferred were related to the work technique of nurses, both regarding the work technique score, and the nurses' own subjective assessments of their work technique.

In conclusion, inter-individual variations regarding work technique in lifting and patient transfers tasks suggest that evaluations of work technique may need to be carried out on an individual level. Evaluations should also consider possible differences in work technique between women and men, younger and older persons, and persons with and without low back symptoms. Finally, the transfer skill of nurses could also be regarded as a matter of quality of care.

Keywords: age, biomechanics, gender, lifting, low back disorders, methods, observations, nurses, patient comfort, patient handling, patient safety, work technique

7. Sammanfattning (summary in Swedish)

Kjellberg K. *Arbetsteknik vid lyft och patientförflyttningar.* Arbete och Hälsa 2003:12.

Det övergripande syftet med denna avhandling var att utveckla och pröva metoder för att beskriva, analysera och bedöma arbetsteknik vid lyft och patient-förflyttningar, och att studera samband mellan arbetsteknik och faktorer hos individen, samt mellan arbetsteknik och patientens säkerhet och komfort. Fokus har varit på aspekter av arbetsteknik som har betydelse den mekaniska belastningen på muskler och leder och för utveckling av besvär i rörelseorganen. Begreppet arbetsteknik delades upp i två beståndsdelar: metod och individuellt utförande. Avhandlingen är baserad på biomekaniska modellstudier i laboratorium och observationsstudier i fält.

Resultaten från experiment på lyft visade att olika variabler bör användas för att för beskriva metoden och för att beskriva utförandet av en arbetsuppgift. Variationer i arbetsteknik mellan försökspersonerna var större än variationer inom individerna under upprepningar av lyften. Resultaten visade också skillnader i mäns och kvinnors rörelsemönster vid lyft, t ex i bål- och knäledsrörelser samt i koordinationen mellan höft- och knäledsrörelser.

Ett observationsinstrument utvecklades för beskrivning och kvantitativ bedömning av vårdpersonals arbetsteknik vid videofilmade patientförflyttningar, och ett ”arbetsteknikpoäng”, som indikerar risk och säkerhet för rörelseorganen, beräknades. Validiteten och reliabiliteten var i de flesta fall tillfredsställande, både överensstämmelsen mellan observationer av varje enskild bedömningspunkt, och överensstämmelsen mellan de beräknade arbetsteknikpoängen.

Observationer av vårdpersonal på ortopedavdelningar vid två olika patientförflyttningar visade att en mängd olika tekniker används för att förflytta patienter. Att vara äldre, ha ländryggsbesvär och att vara man hade samband med att använda en dålig arbetsteknik. Patienternas upplevelser av säkerhet och komfort under förflyttningarna hade samband med vårdpersonalens arbetsteknik, både beträffande arbetsteknikpoängen och sköterskornas egna subjektiva bedömningar av sin arbetsteknik.

Sammanfattningsvis kan variationerna i arbetsteknik mellan individer tolkas som att arbetsteknik bör utvärderas på individnivå. Man bör då också beakta möjliga skillnader i arbetsteknik mellan kvinnor och män, yngre och äldre, och personer med och utan ländryggsbesvär. Slutligen, att vårdpersonalen använder en säker arbetsteknik vid förflyttningar, kan också betraktas som en aspekt av vårdkvalitet.

Nyckelord: arbetsteknik, biomekanik, lyft, metodutveckling, kön, ländryggsbesvär, observationer, patientförflyttning, patientkomfort, patientsäkerhet, vårdpersonal, ålder

8. Acknowledgements

I wish to express my sincere gratitude to everyone who has contributed to the work presented here, and has supported me during my years as a doctoral student. In particular I would like to thank:

Mats Hagberg, Department of Occupational Medicine at the Sahlgrenska Academy at Göteborg University - my supervisor and co-writer, for introducing me to this field of research, for providing sources for my research, for always being supportive and enthusiastic, and believing that I was capable of completing this thesis venture.

Monica Lagerström, Department of Nursing at Karolinska Institutet - my supervisor and co-writer, for her encouragement and support, for always taking the time to answer my questions and discuss things, and for helping me with all kinds of problems, even the small practical ones, such as during data collection at the hospitals.

Lars Lindbeck, Department for Work and Health at the National Institute for Working Life - my co-writer, co-worker and former supervisor, for sharing his deep knowledge in biomechanics with me, and for being prepared to listen to all my scientific thoughts and questions at any time, thereby helping me sorting out my confusion. Special thanks for reading the manuscript of the thesis so carefully and giving a lot of constructive comments and suggestions.

Elisabeth Olsson, Division of Physiotherapy, Neurotec Department at Karolinska Institutet - my co-writer and former supervisor, for encouragement and support during the first phase of the work on this thesis.

Christina Johnsson, Department of Nursing at Karolinska Institutet - my co-writer, for all our discussions about patient transfer technique and observations, and for sharing with me her knowledge and long experience in teaching patient transfer technique.

Karin Proper, TNO Work and Employment in Hoofddorp, the Netherlands - my co-writer, for nice cooperation during the development of the observation instrument.

Ewa Wigaeus Tornqvist - Head of the Department for Work and Health at the National Institute for Working Life - for providing me with work facilities and resources to carry out my research projects, and for her encouragement and support.

Åsa Kilbom – for inspiring discussions about work technique and valuable ideas during the planning of the last field study.

Anders Kjellberg and Anna Ekman - for valuable advice and discussions regarding statistical methods.

Anita Isaksson - for assistance during experiments.

Helene Callert Jakobsson and Ruth Carlsson - for valuable contributions to the development of the observation instrument, and for making observations from the video recordings.

Gunnel Almqvist, Karin Olsson and Cristina Rudäng - for valuable contributions to the development of the observation instrument.

Sofia Tor and Jenny Sterner - for making observations from the video recordings.

Helena Åkerman Tillegård and Ewa Gustafsson - for indispensable help with the data collection at the orthopaedic wards.

Annika Thorsson, Gustav Jansson and Lena Jensen - for being my contacts and helping me with practical matters at the orthopaedic wards.

Monica Mortimer and Allan Toomingas - for reading the manuscript of the thesis and giving a lot of constructive suggestions for the writing at the chaotic end.

All my co-workers at the Ergonomics group at the National Institute for Working Life in Stockholm - for all support, research discussions, valuable criticism of my work, for sharing their knowledge with me, and for all their encouragement and care for me at the hectic end of this thesis writing.

Hilary Hocking - for checking and improving the language of my papers and the thesis so carefully and creatively, and for a smooth and nice cooperation.

The library staff at the National Institute for Working Life - for helping me to find articles so quickly.

All the participating nursing personnel at the hospital wards - for taking time to participate and for their positive attitudes towards the project.

The studies were partly supported by the Swedish Council for Work Life Research.

9. References

1. Alavosius MP & Sulzer-Azaroff B (1985) An on-the-job method to evaluate patient lifting technique. *Applied Ergonomics,* 16(4), 307-311.

2. Anderson CK & Chaffin DB (1986) A biomechanical evaluation of five lifting techniques. *Applied Ergonomics,* 17(1), 2-8.

3. Authier M, Gagnon M & Lortie M (1995) Handling techniques: the influence of weight and height for experts and novices. *International journal of occupational safety and ergonomics,* 1(3), 262-275.

4. Authier M & Lortie M (1993) Assessment of factors considered to be important in handling tasks by expert handlers. *International Journal of Industrial Ergonomics,* 11, 331-340.

5. Authier M, Lortie M & Gagnon M (1996) Manual handling techniques: comparing novices and experts. *International Journal of Industrial Ergonomics,* 17, 419-429.

6. Axelsson J (2000) *Quality and ergonomics: Towards successful integration.* Doctoral thesis, Linköpings universitet. Linköping: Quality and human-systems engineering. Department of mechanical engineering.

7. Balogh I, Hansson GA, Ohlsson K, Stromberg U & Skerfving S (1999) Interindividual variation of physical load in a work task. *Scandinavial Journal of Work, Environment and Health,* 25(1), 57-66.

8. Baril-Gingras G & Lortie M (1995) The handling of objects other than boxes: univariate analysis of handling techniques in a large transport company. *Ergonomics,* 38(5), 905-925.

9. Bejjani FJ, Gross CM & Pugh JW (1984) Model for static lifting: relationship of loads on the spine and the knee. *Journal of Biomechanics,* 17(4), 281-286.

10. Bonato P, Ebenbichler GR, Roy SH, Lehr S, Posch M, Kollmitzer J & Della Croce U (2003) Muscle fatigue and fatigue-related biomechanical changes during a cyclic lifting task. *Spine,* 28(16), 1810-1820.

11. Boston JR, Rudy TE, Lieber SJ & Stacey BR (1995) Measuring treatment effects on repetitive lifting for patients with chronic low back pain: speed, style, and coordination. *Journal of Spinal Disorders,* 8(5), 342-51.

12. Brown Wilson C (2001) Safer handling practice for nurses: a review of the literature. *British Journal of Nursing,* 10(2), 108-14.

13. Burdorf A & Sorock G (1997) Positive and negative evidence of risk factors for back disorders. *Scandinavian Journal of Work, Environment & Health,* 23, 243-256.

14. Burgess-Limerick R (2003) Squat, stoop, or something in between? *International Journal of Industrial Ergonomics,* 31(3), 143-148.

15. Burgess-Limerick R & Abernethy B (1997) Qualitatively different modes of manual lifting. *International Journal of Industrial Ergonomics,* 19, 413-417.

16. Burgess-Limerick R & Abernethy B (1997) Toward a quantitative definition of manual lifting postures. *Human factors,* 39(1), 141-148.

17. Burgess-Limerick R, Abernethy B & Neal RJ (1993) Relative phase quantifies interjoint coordination. *Journal of Biomechanics,* 26(1), 91-94.

18. Burgess-Limerick R, Abernethy B, Neal RJ & Kippers V (1995) Self-selected manual lifting technique: functional consequences of the interjoint coordination. *Human Factors,* 37(2), 395-411.

19. Bush-Joseph C, Schipplein O, Andersson GBJ & Andriacchi TP (1988) Influence of dynamic factors on the lumbar spine moment in lifting. *Ergonomics,* 31(2), 211-216.

20. Caboor DE, Verlinden MO, Zinzen E, Van Roy P, Van Riel MP & Clarys JP (2000) Implications of an adjustable bed height during standard nursing tasks on spinal motion, perceived exertion and muscular activity. *Ergonomics,* 43(10), 1771-80.

21. Carlsson R, Ekman S-L & Lagerström M (2002) The meaning of patient transfers, in the narratives of physiotherapists and nurses. *Vård i Norden (Abstract in English),* 22, 37-41.

22. Cato C, Olson DK & Studer M (1989) Incidence, prevalence and variables associated with low back pain in staff nurses. *American Association of Health Nurses Journal,* 37(8), 321-327.

23. Chaffin DB, Gallay LS, Wooley CB & Kuciemba SR (1986) An evaluation of the effect of a training program on worker lifting postures. *International Journal of Industrial Ergonomics,* 1, 127-136.

24. Cholewicki J, van Dieen JH & Arsenault AB (2003) Muscle function and dysfunction in the spine. *Journal of Electromyography and Kinesiology,* 13(4), 303-4.

25. Cloutier E (1994) The effect of age on safety and work practices among domestic trash collectors in Québec. *Safety Science,* 17, 291-308.

26. Commissaris DA, Nilsson-Wikmar LB, Van Dieen JH & Hirschfeld H (2002) Joint coordination during whole-body lifting in women with low back pain after pregnancy. *Archives of Physical Medicine and Rehabilitation,* 83(9), 1279-89.

27. Commissaris DACM & Toussaint HM (1997) Load knowledge affects low-back loading and control of balance in lifting tasks. *Ergonomics,* 40(5), 559-575.

28. Daltroy LH, Iversen MD, Larson MG, Lew R, Wright E, Ryan J, Zwerling C, Fossel AH & Liang MH (1997) A controlled trial of an educational program to prevent low back injuries. *The New England Journal of Medicine,* 337(5), 322-8.

29. Dapena J (1997) The influence of muscle physiology and mechanics on sports technique. XVIth Congress of the International Society of Biomechanics, Tokyo, Japan.

30. Davis KG, Marras WS, Heaney CA, Waters TR & Gupta P (2002) The impact of mental processing and pacing on spine loading: 2002 Volvo Award in biomechanics. *Spine,* 27(23), 2645-53.

31. Davis PR, Troup JDG & Burnard JH (1965) Movements of the thoracic and lumbar spine when lifting: a chrono-cyclophotographic study. *Journal of Anatomy,* 99, 13-26.

32. Daynard D, Yassi A, Cooper JE, Tate R, Norman R & Wells R (2001) Biomechanical analysis of peak and cumulative spinal loads during simulated patient-handling activities: a substudy of a randomized controlled trial to prevent lift and transfer injury of health care workers. *Applied Ergonomics,* 32(3), 199-214.

33. De Looze MP, Tuossaint HM, Ensink J, Mangnus C & van der Beek AJ (1994) The validity of visual observation to assess posture in a laboratory-simulated, manual material handling task. *Ergonomics,* 37(8), 1335-1343.

34. de Looze MP, Zinzen E, Caboor D, Heyblom P, van Bree E, van Roy P, Toussaint HM & Clarijs JP (1994) Effect of individually chosen bed-height adjustments on the low-back stress of nurses. *Scandinavian Journal of Work, Environment & Health,* 20, 427-434.

35. de Looze MP, Zinzen E, Caboor D, van Roy P & Clarijs JP (1998) Muscle strength, task performance and low back load in nurses. *Ergonomics,* 41(8), 1095-1104.

36. de Zwart BCH, Broersen JPJ, Frings-Dresen MHW & van Dijk FJH (1997) Musculoskeletal complaints in The Netherlands in relation to age, gender and physically demanding work. *International Archives of Occupational and Environmental Health,* 70(5), 352-60.

37. de Zwart BCH, Frings-Dresen MHW & van Dijk FJH (1995) Physical workload and the ageing worker: a review of the literature. *International Archives of Occupational and Environmental Health,* 68(1), 1-12.

38. Delisle A, Gagnon M & Desjardins P (1998) Knee flexion and base of support in asymmetrical handling: Effects on the worker's dynamic stability and the moments of the L5/S1 and knee joints. *Clinical Biomechanics,* 13(7), 506-514.

39. Delisle A, Gagnon M & Desjardins P (1999) Kinematic analysis of footstep strategies in asymmetrical lifting and lowering tasks. *International Journal of Industrial Ergonomics,* 23, 451-460.

40. Dempsey PG (1998) A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. *Ergonomics,* 41(1), 73-88.

41. Dixon R, Lloyd B & Coleman S (1996) Defining and implementing a 'no lifting' standard. *Nursing Standard,* 10(44), 33-6.

42. Dolan P & Adams MA (1998) Repetitive lifting tasks fatigue the back muscles and increase the bending moment acting on the lumbar spine. *Journal of Biomechanics,* 31(8), 713-21.

43. Dolan P, Earley M & Adams MA (1994) Bending and compressive stresses acting on the lumbar spine during lifting activities. *Journal of Biomechanics,* 27(10), 1237-1248.

44. Donbaek Jensen L & Schibye B (2000) Assessment of exposure in intervention studies in the health care sector. In: Wickström G ed. *Intervention studies in the health care work environment.* Arbete och hälsa 2000:10. Pp 81-89, Stockholm: National Institute for Working Life.

45. Elford W & Leon Straker GS (2000) Patient handling with and without slings: an analysis of the risk of injury to the lumbar spine. *Applied Ergonomics,* 31(2), 185-200.

46. Engels JA, Brandsma B & van der Gulden JWJ (1997) Evaluation of the effects of an ergonomic-educational programme. The assessment of "ergonomic errors" made during the performance of nursing tasks. *International Archives of Occupational Environment Health,* 69, 475-481.

47. Engels JA, van der Gulden JWJ, Senden TF, Hertog CAWM, Kolk JJ & Binkhorst RA (1994) Physical work load and its assessment among the nursing staff in nursing homes. *Journal of Occupational Medicine,* 36(3), 338-345.

48. Engels JA, van der Gulden JWJ, Senden TF, Kolk JJ & Binkhorst RA (1998) The effects of an ergonomic-educational course. Postural load, perceived physical exertion, and biomechanical errors in nursing. *International Archives of Occupational Environment Health,* 71, 336-342.

49. Engkvist I-L, Hagberg M, Wigaeus Hjelm E, Menckel E, Ekenvall L & PROSA study group (1998) The accident process preceding overexertion back injuries in nursing personnel. *Scandinavian Journal of Work, Environment & Health,* 24(5), 367-375.

50. Engkvist I-L, Kjellberg A, Wigaeus Hjelm E, Hagberg M, Menckel E & Ekenvall L (2001) Back injuries among nursing personnel - identification of work conditions with cluster analysis. *Safey science,* 37, 1-18.

51. Engkvist I-L, Wigaeus Hjelm E, Hagberg M, Menckel E & Ekenvall L (2000) Risk indicators for reported over-exertion back injuries among female nursing personnel. *Epidemiology,* 11(5), 519-22.

52. Enoka RM (1994) *Neuromechanical basis of kinesiology.* (2nd ed.). Champaign: Human Kinetics.

53. Evanoff BA, Bohr PC & Wolf LD (1999) Effects of a participatory ergonomics team among hospital orderlies. *American Journal of Industrial Medicine,* 35(4), 358-65.

54. Fathallah FA, Marras WS & Parnianpour M (1998) The role of complex, simultaneous trunk motions in the risk of occupation-related low back disorders. *Spine,* 23(9), 1035-1042.

55. Feldstein A, Valanis B, Vollmer W, Stevens N & Overton C (1993) The back injury prevention project pilot study. Assessing the effectiveness of back attack, an injury prevention program among nurses, aides, and orderlies. *Journal of Occupational Medicine,* 35(2), 114-120.

56. Feldstein A, Vollmer W & Valanis B (1990) Evaluating the patient-handling tasks of nurses. *Journal of Occupational Medicine,* 32(10), 1009-1013.

57. Fernand R & Fox DE (1985) Evaluation of lumbar lordosis. A prospective and retrospective study. *Spine,* 10(9), 799-803.

58. Feuerstein M (1996) Workstyle: Definition, empirical support, and implications for prevention, evaluation, and rehabilitation of occupational upper-extremity disorders. In: Moon SD & Sauter SL eds. *Beyond biomechanics. Psychosocial aspects of musculoskeletal disorders in office work.* Pp 177-206, London: Taylor & Francis.

59. Feuerstein M, Armstrong T, Hickey P & Lincoln A (1997) Computer keyboard force and upper extremity symptoms. *Journal of Occupational and Environmental Medicine,* 39(12), 1144-53.

60. Feuerstein M & Fitzgerald TE (1992) Biomechanical factors affecting upper extremity cumulative trauma disorders in sign language interpreters. *Journal of Occupational Medicine,* 34(3), 257-264.

61. Fleiss JL (1981) *Statistical methods for rates and proportions.* (2:nd ed.). New York: John Wiley & Sons.

62. Fleiss JL (1986) *The design and analysis of clinical experiments.* New York: John Wiley & Sons.

63. Fogleman M & Smith JL (1995) The use of biomechanical measures in the investigation of changes in lifting strategies over extended periods. *International Journal of Industrial Ergonomics,* 16, 57-71.

64. Folkerts JK (1994) *Transfervaardigheden geobserveerd. De ontwikkeling van een observatie-intsrument voor transfervaardigheden van verpleegkundigen.* (In Dutch): University of Groningen, Department of Human Movement Science.

65. Fransson-Hall C, Gloria R, Winkel J & Kilbom Å (1995) A portable ergonomic observation method (PEO) for computerized on-line recording of postures and manual handling. *Applied Ergonomics,* 26(2), 93-100.

66. Freivalds A, Chaffin DB, Garg A & Lee KS (1984) A dynamic biomechanical evaluation of lifting maximum acceptable loads. *Journal of Biomechanics,* 17(4), 251-262.

67. Gagnon M (1997) Box tilt and knee motions in manual lifting: two differential factors in expert and novice workers. *Clinical Biomechanics,* 12(7/8), 419-428.

68. Gagnon M (2003) The efficacy of training for three manual handling strategies based on the observation of expert and novice workers. *Clinical Biomechanics,* 18(7), 601-11.

69. Gagnon M, Chehade A, Kemp F & Lortie M (1987) Lumbo-sacral loads and selected muscle activity while turning patients in bed. *Ergonomics,* 30(7), 1013-1032.

70. Gagnon M, Delisle A & Desjardins P (2002) Biomechanical differences between best and worst performances in repeated free asymmetrical lifts. *International Journal of Industrial Ergonomics,* 29(2), 73-83.

71. Gagnon M, Plamondon A, Gravel D & Lortie M (1996) Knee movement strategies differentiate expert from novice workers in asymmetrical manual materials handling. *Journal of Biomechanics,* 29(11), 1445-1453.

72. Gagnon M, Roy D, Lortie M & Roy R (1988) Examination of biomechanical principles in a patient handling task. *International Journal of Industrial Ergonomics,* 3, 29-40.

73. Gagnon M, Sicard C & Sirois J-P (1986) Evaluation of forces on the lumbo-sacral joint and assessment of work and energy transfers in nursing aides lifting patients. *Ergonomics,* 29(3), 407-421.

74. Garg A & Owen B (1992) Reducing back stress to nursing personnel: an ergonomic intervention in a nursing home. *Ergonomics,* 35(11), 1353-1375.

75. Garg A & Owen B (1994) Prevention of back injuries in healthcare workers. *International Journal of Industrial Ergonomics,* 14, 315-331.

76. Garg A, Owen B, Beller D & Banaag J (1991) A biomechanical and ergonomic evaluation of patient transferring tasks: bed to wheelchair and wheelchair to bed. *Ergonomics,* 34(3), 289-312.

77. Garg A, Owen B, Beller D & Banaag J (1991) A biomechanical and ergonomic evaluation of patient transferring tasks: wheelchair to shower chair and shower chair to wheelchair. *Ergonomics,* 34(4), 407-419.

78. Gatton ML & Pearcy MJ (1999) Kinematics and movement sequencing during flexion of the lumbar spine. *Clinical Biomechanics,* 14(6), 376-83.

79. Granata KP & Marras WS (1995) The influence of trunk muscle coactivity on dynamic spinal loads. *Spine,* 20(8), 913-919.

80. Granata KP, Marras WS & Davis KG (1999) Variation in spinal load and trunk dynamics during repeated lifting exertions. *Clinical Biomechanics,* 14(6), 367-75.

81. Green C (1996) Study of moving and handling practices on two medical wards. *British Journal of Nursing,* 5(5), 303-4, 306-8, 310-1.

82. Hagen KB & Harms-Ringdahl K (1994) Ratings of perceived thigh and back exertion in forest workers during repetitive lifting using squat and stoop techniques. *Spine,* 19(22), 2511-2517.

83. Hagen KB, Sørhagen O & Harms-Ringdahl K (1995) Influence of weight and frequency on thigh and lower-trunk motion during repetitive lifting employing stoop and squat techniques. *Clinical Biomechanics,* 10(3), 122-127.

84. Hagner I-M & Hagberg M (1989) Evaluation of two floor-mopping work methods by measurement of load. *Ergonomics,* 32(4), 401-408.

85. Hammarskjöld E, Ekholm J & Harms-Ringdahl K (1989) Reproducibility of work movements with carpenters' hand tools. *Ergonomics,* 32(8), 1005-1018.

86. Hansson T (2001) Ländryggsbesvär och arbete. In: Hansson T & Westerholm P eds. *Arbete och besvär i rörelseorganen. En vetenskaplig värdering av frågor om samband.* Vol. 12. Pp 19-69, Stockholm: National Institute for Working Life.

87. Hart DL, Stobbe TJ & Jaraiedi M (1987) Effect of lumbar posture on lifting. *Spine,* 12(2), 138-145.

88. Hellsing A-L, Linton SJ, Andershed B, Bergman C & Liew M (1993) Egonomic education for nursing students. *International Journal of Nursing Studies,* 30(6), 499-510.

89. Hignett S (1996) Postural analysis of nursing work. *Applied Ergonomics,* 27(3), 171-176.

90. Hignett S (1996) Work-related back pain in nurses. *Journal of Advanced Nursing,* 23, 1238-1246.

91. Hignett S (2003) Intervention strategies to reduce musculoskeletal injuries associated with handling patients: a systematic review. *Occupational and Environmental Medicine,* 60(9), E6.

92. Hignett S (2003) Systematic review of patient handling activities starting in lying, sitting and standing positions. *Journal of Advanced Nursing,* 41(6), 545-552.

93. Hignett S, Crumpton E, Ruszala S, Alexander P, Fray M & Fletcher B (2003) Evidence-based patient handling: systematic review. *Nursing Standard,* 17(33), 33-6.

94. Hignett S, Crumpton E, Ruszala S, Alexander P, Fray M & Fletcher B (2003) *Evidence-based patient handling: Tasks, equipment and interventions.* London: Routledge.

95. Hignett S & McAtamney L (2000) Rapid Entire Body Assessment (REBA). *Applied Ergonomics,* 31(2), 201-205.

96. Hignett S & Richardson B (1995) Manual handling human loads in a hospital: an exploratary study to identify nurses' perceptions. *Applied Ergonomics,* 26(3), 221-226.

97. Hodges PW & Moseley GL (2003) Pain and motor control of the lumbopelvic region: effect and possible mechanisms. *Journal of Electromyography and Kinesiology,* 13(4), 361-70.

98. Hodges PW & Richardson CA (1996) Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine,* 21(22), 2640-50.

99. Holzman P (1982) ARBAN - a new method for analysis of ergonomic effort. *Applied Ergonomics,* 13, 82-86.

100. Hoogendoorn WE, Bongers PM, de Vet HC, Douwes M, Koes BW, Miedema MC, Ariens GA & Bouter LM (2000) Flexion and rotation of the trunk and lifting at work are risk factors for low back pain: results of a prospective cohort study. *Spine,* 25(23), 3087-92.

101. Hoogendoorn WE, van Poppel MNM, Bongers PM, Koes BW & Bouter LM (1999) Physical load during work and leisure time as risk factors for back pain. *Scandinavian Journal of Work, Environment & Health,* 25(5), 387-403.

102. Hoozemans MJ, van der Beek AJ, Frings-Dresen MH, van Dijk FJ & van der Woude LH (1998) Pushing and pulling in relation to musculoskeletal disorders: a review of risk factors. *Ergonomics,* 41(6), 757-81.

103. Hsiang SM, Brogmus GE & Courtney TK (1997) Low back pain (LBP) and lifting technique - A review. *International Journal of Industrial Ergonomics,* 19, 59-74.

104. Hsiang SM & McGorry RW (1997) Three different lifting strategies for controlling the motion patterns of the external load. *Ergonomics,* 40(9), 928-939.

105. Jensen RC (1990) Back injuries among nursing personnel related to exposure. *Applied Occupational and Environmental Hygiene,* 5(1), 38-45.

106. Johansson H, Sjölander P, Djupsjöbacka M, Bergenheim M & Pedersen J (1999) Pathophysiological mechanisms behind work-related muscle pain syndromes. *American Journal of Industrial Medicine,* Suppl 1, 104-6.

107. Johnsson C, Carlsson R & Lagerström M (2002) Evaluation of training in patient handling and moving skills among hospital and home care personnel. *Ergonomics,* 45(12), 850-865.

108. Juul-Kristensen B, Fallentin N & Ekdahl C (1997) Criteria for classification of posture in repetitive work by observation methods: A review. *International Journal of Industrial Ergonomics,* 19, 397-411.

109. Kane M & Parahoo K (1994) Lifting: why nurses follow bad practice. *Nursing Standard,* 8(25), 34-8.

110. Karhu O, Kansi P & Kuorinka I (1977) Correcting working postures in industry: a practical method for analysis. *Applied Ergonomics,* 8, 199-201.

111. Kelsey JL, Githens PB, White III AA, Holford TR, Walter SD, O'Connor R, Ostfeld AM, Weil U, Southwick WO & Calogero JA (1984) An epidemiologic study of lifting and twisting on the job and risk for acute prolapsed lumbar intervertebral disc. *Journal of Orthopaedic Surgery,* 2, 61-66.

112. Kemmlert K (1995) A method assigned for the identification of ergonomic hazards - PLIBEL. *Applied Ergonomics,* 26(3), 199-211.

113. Kemmlert K, Örelius-Dallner M, Kilbom Å & Gamberale F (1993) A three-year follow-up of 195 reported occupational over-exertion injuries. *Scandinavian Journal of Rehabilitation Medicine,* 25, 16-24.

114. Kerr MS, Frank JW, Shannon HS, Norman RW, Wells RP, Neumann WP & Bombardier C (2001) Biomechanical and psychosocial risk factors for low back pain at work. *American journal of public health,* 91(7), 1069-75.

115. Keyserling WM (1986) Postural analysis of the trunk and shoulders in simulated real time. *Ergonomics,* 29, 569-583.

116. Keyserling WM, Brouwer M & Silverstein BA (1992) A checklist for evaluating ergonomic risk factors resulting from awkward postures of the leg, trunk and neck. *International Journal of Industrial Ergonomics,* 9, 283-301.

117. Khalil TM, Waly SM, Genaidy AM & Asfour SS (1987) Determination of lifting abilities: A comparative study of four techniques. *American Industrial Hygiene Association Journal,* 48(12), 951-956.

118. Kilbom Å (1988) Intervention programmes for work-related neck and upper limb disorders: strategies and evaluation. *Ergonomics,* 31(5), 735-747.

119. Kilbom Å (1994) Assessment of physical exposure in relation to work-related musculoskeletal disorders - what information can be obtained from systematic observations? *Scandinavian Journal of Work, Environment & Health,* 20(special issue), 30-45.

120. Kilbom Å (1997) Work technique - scientific and practical issues, definitions, and relation to musculoskeletal injuries. IEA´97 Proceedings of the 13th Triennial Congress of the International Ergonomics Association, Tampere.

121. Kilbom Å & Persson J (1987) Work technique and its consequences for musculoskeletal disorders. *Ergonomics,* 30(2), 273-279.

122. Kilbom Å, Persson J & Jonsson BG (1986) Disorders of the cervicobrachial region among female workers in the electronics industry. *International Journal of Industrial Ergonomics,* 1, 37-47.

123. Kjellberg K, Lindbeck L & Hagberg M (1998) Method and performance: two elements of work technique. *Ergonomics,* 41(6), 798-816.

124. Knibbe H (1992) Overcoming resistance. *Nursing Times,* 88(52), 46-7.

125. Kristensen T (2000) The choice of endpoint variables in intervention studies in the health care sector. In: Wickström G ed. *Intervention studies in the health care work environment.* Arbete och hälsa 2000:10. Pp 49-61, Stockholm: National Institute for Working Life.

126. Kroemer KHE (1992) Personnel training for safer material handling. *Ergonomics,* 35(9), 1119-1134.

127. Kuiper JI, Burdorf A, Verbeek JHAM, Frings-Dresen MHW, van der Beek AJ & Viikari-Juntura ERA (1999) Epidemiologic evidence on manual materials handling as a risk factor for back disorders: a systematic review. *International Journal of Industrial Ergonomics,* 24(4), 389-404.

128. Kumar S (1990) Cumulative load as a risk factor for back pain. *Spine,* 15, 1311-1316.

129. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering Sørensen F, Andersson G & Jørgensen K (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics,* 18(3), 233-237.

130. Kuorinka I, Lortie M & Gautreau M (1994) Manual handling in warehouses: the illusion of correct working postures. *Ergonomics,* 37(4), 655-661.

131. Lagerström M & Hagberg M (1997) Evaluation of a 3 year education and training program for nursing personnel at a Swedish hospital. *American Association of Health Nurses Journal,* 45(2), 83-92.

132. Lagerström M, Hansson T & Hagberg M (1998) Work-related low-back problems in nursing. *Scandinavian Journal of Work, Environment & Health,* 24(6), 449-464.

133. Lavender SA, Andersson GBJ, Schipplein OD & Fuentes HJ (2003) The effects of initial lifting height, load magnitude, and lifting speed on the peak dynamic L5/S1 moments. *International Journal of Industrial Ergonomics,* 31(1), 51-59.

134. Lee Y-H & Chiou W-K (1995) Ergonomic analysis of working posture in nursing personnel: Example of modified Ovako Working Analysis System application. *Research in Nursing & Health,* 18, 67-75.

135. Lees A (1980) An optimised film analysis method based on finite difference techniques. *Journal of Human Movement Studies,* 6, 165-180.

136. Lees A (2002) Technique analysis in sports: a critical review. *Journal of Sports Sciences,* 20(10), 813-28.

137. Leskinen T, Hall C, Rauas S, Ulin S, Tönnes M, Viikari-Juntura E & Takala E-P (1997) Validation of Portable Ergonomic Observation (PEO) method using optoelectronic and video recordings. *Applied Ergonomics,* 28(2), 75-83.

138. Leskinen TPJ (1985) Comparison of static and dynamic biomechanical models. *Ergonomics,* 28(1), 285-291.

139. Li G & Buckle P (1999) Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. *Ergonomics,* 42(5), 674-695.

140. Lindbeck L & Arborelius UP (1991) Inertial effects from single body segments in dynamic analysis of lifting. *Ergonomics,* 34(4), 421-433.

141. Lindbeck L & Engkvist I-L (1993) Biomechanical analysis of two patient handling tasks. *International Journal of Industrial Ergonomics,* 12, 117-125.

142. Lindegård A, Wahlström J, Hagberg M, Hansson GA, Jonsson P & Wigaeus Tornqvist E (2003) The impact of working technique on physical loads - an exposure profile among newspaper editors. *Ergonomics,* 46(6), 589-615.

143. Ljungberg A-S, Kilbom Å & Hägg GM (1989) Occupational lifting by nursing aides and warehouse workers. *Ergonomics,* 32(1), 59-78.

144. Lortie M & Baril-Gingras G (1998) Box handling in the loading and unloading of vans. *International journal of occupational safety and ergonomics,* 4(1), 3-18.

145. Luopajarvi T (1987) Workers´ education. *Ergonomics,* 30(2), 305-311.

146. Marras WS (1992) Toward an understanding of dynamic variables in ergonomics. *Occupational Medicine,* 7(4), 655-677.

147. Marras WS, Allread WG, Burr DL & Fathallah FA (2000) Prospective validation of a low-back disorder risk model and assessment of ergonomic interventions associated with manual materials handling tasks. *Ergonomics,* 43(11), 1866-86.

148. Marras WS, Davis KG, Ferguson SA, Lucas BR & Gupta P (2001) Spine loading characteristics of patients with low back pain compared with asymptomatic individuals. *Spine,* 26(23), 2566-74.

149. Marras WS, Davis KG, Heaney CA, Maronitis AB & Allread WG (2000) The influence of psychosocial stress, gender, and personality on mechanical loading of the lumbar spine. *Spine,* 25(23), 3045-54.

150. Marras WS, Davis KG & Jorgensen M (2002) Spine loading as a function of gender. *Spine,* 27(22), 2514-20.

151. Marras WS, Davis KG & Jorgensen M (2003) Gender influence on spine loads during complex lifting. *The spine journal,* 3, 93-99.

152. Marras WS, Davis KG, Kirking BC & Bertsche PK (1999) A comprehensive analysis of low-back disorder risk and spinal loading during the transferring and repositioning of patients using different techniques. *Ergonomics,* 42(7), 904-926.

153. Marras WS, Lavender SA, Leurgans SE, Fathallah FA, Ferguson SA, Allread WG & Rajulu SL (1995) Biomechanical risk factors for occupationally related low back disorders. *Ergonomics,* 38, 377-410.

154. Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Allread WG, Fathallah FA & Ferguson SA (1993) The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. *Spine,* 18(5), 617-628.

155. Mathiassen SE, Moller T & Forsman M (2003) Variability in mechanical exposure within and between individuals performing a highly constrained industrial work task. *Ergonomics,* 46(8), 800-24.

156. Mathiassen SE, Winkel J & Hägg GM (1995) Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies - a review. *Journal of Electromyography and Kinesiology,* 5(4), 197-226.

157. McGill S, Grenier S, Bluhm M, Preuss R, Brown S & Russell C (2003) Previous history of LBP with work loss is related to lingering deficits in biomechanical, physiological, personal, psychosocial and motor control characteristics. *Ergonomics,* 46(7), 731-46.

158. McGill SM (1997) The biomechanics of low back injury: implications on current practice in industry and the clinic. *Journal of biomechanics,* 30(5), 465-475.

159. McGuire T, Moody J & Hanson M (1996) An evaluation of mechanical aids used within the NHS. *Nursing Standard,* 11(6), 33-8.

160. McGuire T, Moody J, Hanson M & Tigar F (1996) A study into clients' attitudes towards mechanical aids. *Nursing Standard,* 11(5), 35-8.

161. McIntyre DR, Glover LH, Conino MC, Seeds RH & Levene JA (1991) A comparison of the characteristics of preferred low-back motion of normal subjects and low-back-pain patients. *Journal of Spinal Disorders,* 4(1), 90-5.

162. Moody J, McGuire T, Hanson M & Tigar F (1996) A study of nurses' attitudes towards mechanical aids. *Nursing Standard,* 11(4), 37-42.

163. Mykletun R (2000) Interventions for better health in health care workplaces: Individual or organisational level? In: Wickström G ed. *Intervention studies in the health care work environment.* Arbete och hälsa 2000:10. Pp 21-35, Stockholm: National Institute for Working Life.

164. Nelson A, Lloyd JD, Menzel N & Gross C (2003) Preventing nursing back injuries: redesigning patient handling tasks. *American Association of Health Nurses Journal,* 51(3), 126-34.

165. Neumann WP, Wells RP, Norman RW, Frank J, Shannon H, Kerr MS & Oubps Working G (2001) A Posture and Load Sampling Approach to Determining Low-Back Pain Risk in Occupational Settings. *International Journal of Industrial Ergonomics,* 27(2), 65-77.

166. Neumann WP, Wells RP, Norman RW, Kerr MS, Frank J, Shannon HS & Oubps Working G (2001) Trunk Posture: Reliability, Accuracy, and Risk Estimates for Low Back Pain from a Video Based Assessment Method. *International Journal of Industrial Ergonomics,* 28(6), 355-365.

167. NIOSH (1981) *Work practices guide for manual lifting.* Technical Report No 81-122, Cincinnati, Ohio: National Institute for Occupational Safety and Health.

168. Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M & Ontario Universities Back Pain Study Group (1998) A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clinical Biomechanics,* 13, 561-573.

169. Nussbaum MA & Chaffin DB (1997) Pattern classification reveals intersubject group differences in lumbar muscle recruitment during static loading. *Clinical Biomechanics,* 12(2), 97-106.

170. Nussbaum MA & Torres N (2001) Effects of training in modifying working methods during common patient-handling activities. *International Journal of Industrial Ergonomics,* 27, 33-41.

171. Nuwayhid IA, Stewart W & Johnson JV (1993) Work activities and the onset of first-time low back pain among New York City fire fighters. *American Journal of Epidemiology,* 137(5), 539-48.

172. Nygård C-H, Merisalo T, Arola H, Manka M-L & Huhtala H (1998) Effects of work changes and training in lifting technique on physical strain: a pilot study among female workers of different ages. *International Journal of Industrial Ergonomics,* 21(1), 91-98.

173. Owen BD & Fragala G (1999) Reducing perceived physical stress while transferring residents. An ergonomic approach. *American Association of Health Nurses Journal,* 47(7), 316-23.

174. Owen BD & Garg A (1991) Reducing risk for back pain in nursing personnel. *American Association of Health Nurses Journal,* 39, 24-33.

175. Owen BD & Garg A (1994) Reducing back stress through an ergonomic approach: weighing a patient. *International Journal of Nursing Studies,* 31(6), 511-9.

176. Owen BD & Hasler-Hanson CR (1999) A study comparing three methods of repositioning "patients" up in bed. *Journal of Healthcare Safety, Compliance & Infection Control,* 3(8), 362-367.

177. Owen BD, Keene K & Olson S (2002) An ergonomic approach to reducing back/shoulder stress in hospital nursing personnel: a five year follow up. *International Journal of Nursing Studies,* 39(3), 295-302.

178. Paquet N, Malouin F & Richards CL (1994) Hip-spine movement interaction and muscle activation patterns during sagittal trunk movements in low back pain patients. *Spine,* 19(5), 596-603.

179. Parnianpour M, Bejjani F & Pavlidis L (1987) Worker training: The fallacy of a single, correct lifting technique. *Ergonomics,* 30, 331-334.

180. Patterson P, Congleton J, Koppa R & Huchingson RD (1987) The effects of load knowledge on stresses at the lower back during lifting. *Ergonomics,* 30(3), 539-549.

181. Patterson PE, Koppa R, Congleton J & Huchingson RD (1986) Low back stress, muscle usage, and the appearance of transient load movement during manual lifting. *International Journal of Industrial Ergonomics,* 1, 137-143.

182. Pedotti A & Crenna P (1990) Individual strategies of muscle recruitment in complex natural movements. In: Winters JM & Woo SL-Y eds. *Multiple Muscle Systems - Biomechanics and Movement Organization.* Pp 542-549, New York: Springer-Verlag.

183. Pheasant S (1986) *Bodyspace: Anthropometry, Ergonomics and Design.* London and Philadelphia: Taylor and Francis.

184. Pohjonen T, Punakallio A & Louhevaara V (1998) Participatory ergonomics for reducing load and strain in home care work. *International journal of industrial ergonomics.,* 21(5), 345.

185. Potvin JR, McGill SM & Norman RW (1991) Trunk muscle and lumbar ligament contributions to dynamic lifts with varying degrees of trunk flexion. *Spine,* 16, 1099-1107.

186. Punnett L, Fine L, Keyserling WM, Herrin GD & Chaffin DB (1991) Back disorders and nonneutral trunk postures of automobile workers. *Scandinavial Journal of Work, Environment and Health,* 17, 337-346.

187. Riihimäki H (1991) Low-back pain, its origin and risk indicators. *Scandinavian Journal of Work, Environment & Health,* 17, 81-90.

188. Robertson A & Tracy CS (1998) Health and productivity of older workers. *Scandinavian Journal of Work, Environment & Health,* 24(2), 85-97.

189. Schibye B, Faber Hansen A, Hye-Knudsen CT, Essendrop M, Böcher M & Skotte J (2003) Biomechanical analysis of the effect of changing patient-handling technique. *Applied Ergonomics,* 34, 115-123.

190. Schipplein OD, Trafimow JH, Andersson GBJ & Andriacchi TP (1990) Relationship between moments at the L5/S1 level, hip and knee joint when lifting. *Journal of Biomechanics,* 23, 907-912.

191. Schmidt RA & Lee TD (1999) *Motor control and learning : a behavioral emphasis.* (3rd ed.). Champaign: Human Kinetics.

192. Scholz JP (1992) Low back injury and manual lifting: Review and new perspective. *Physical Therapy Practise,* 1(3), 20-31.

193. Scholz JP (1993) The effect of load scaling on the coordination of manual squat lifting. *Human Movement Science,* 12, 427-459.

194. Scholz JP (1993) Organizational principles for the coordination of lifting. *Human Movement Science,* 12, 537-576.

195. Scholz JP & McMillan AG (1995) Neuromuscular coordination of squat lifting, II: Individual differences. *Physical Therapy,* 75(2), 133-144.

196. Scholz JP, Millford JP & McMillan AG (1995) Neuromuscular coordination of squat lifting, I: Effect of load magnitud. *Physical Therapy,* 75(2), 119-132.

197. Sedgwick A & Gormley J (1998) Training for lifting; an unresolved ergonomic issue? *Applied Ergonomics,* 29(5), 395-398.

198. Shim J & Carlton LG (1997) Perception of kinematic characteristics in the motion of lifted weight. *Journal of Motor Behavior,* 29(2), 131-146.

199. Skotte JH, Essendrop M, Hansen AF & Schibye B (2002) A dynamic 3D biomechanical evaluation of the load on the low back during different patient-handling tasks. *Journal of Biomechanics,* 35(10), 1357-1366.

200. Smedley J, Egger P, Cooper C & Coggon D (1995) Manual handling activities and risk of low back pain in nurses. *Occupational and Environmental Medicine,* 52, 160-163.

201. Smedley J, Egger P, Cooper C & Coggon D (1997) Prospective cohort study of predictors of incident low back pain in nurses. *British Medical Journal,* 314(7089), 1225-8.

202. Smedley J, Trevelyan F, Inship H, Buckle P, Cooper C & Coggon D (2003) Impact of ergonomic intervention on back pain among nurses. *Scandinavian Journal of Work, Environment & Health,* 29(2), 117-123.

203. Smith JL, Smith LA & McLaughlin TM (1982) A biomechanical analysis of industrial manual materials handlers. *Ergonomics,* 25(4), 299-308.

204. Snook SH & Ciriello VM (1991) The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics,* 34(9), 1197-1213.

205. Sommerich CM & Marras WS (1992) Temporal patterns of trunk muscle activity throughout a dynamic, asymmetric lifting motion. *Human Factors,* 34, 215-230.

206. Sparto PJ, Parnianpour M, Reinsel TE & Simon S (1997) The effect of fatigue on multijoint kinematics and load sharing during a repetitive lifting test. *Spine,* 22(22), 2647-54.

207. Stevenson JM, Bryant JT, French SL, Greenhorn DR, Andrew GM & Thomson JM (1990) Dynamic analysis of isoinertial lifting technique. *Ergonomics,* 33(2), 161-172.

208. Stevenson JM, Greenhorn DR, Bryant JT, Deakin JM & Smith JT (1996) Gender differences in performance of a selection test using the incremental lifting machine. *Applied Ergonomics,* 27(1), 45-52.

209. Stobbe TJ, Plummer RW, Jensen RC & Attfield MD (1988) Incidence of low back injuries among nursing personnel as a function of patient lifting frequency. *Journal of Safety Research,* 19, 21-28.

210. Straker L (2003) Evidence to support using squat, semi-squat and stoop techniques to lift low-lying objects. *International Journal of Industrial Ergonomics,* 31(3), 149-160.

211. Straker LM (2003) A review of research on techniques for lifting low-lying objects: 2. Evidence for a correct technique. *Work,* 20(2), 83-96.

212. Streiner DL & Norman GR (1995) *Health measurement scales. A practical guide to their development and use.* (2:nd ed.). Oxford: Oxford university press.

213. St-Vincent M, Tellier C & Lortie M (1989) Training in handling: an evaluative study. *Ergonomics,* 32(2), 191-210.

214. St-Vincent M, Tellier C & Petitjean-Roget T (1999) Accidents that occurred in three hospitals. *Safety Science,* 31, 197-212.

215. Stålhammar HR, Troup JDG & Leskinen T (1989) Rating of acceptable loads: lifting with and without handles. *International Journal of Industrial Ergonomics,* 3, 229-234.

216. Sullivan MS, Dickinson CE & Troup JDG (1994) The influence of age and gender on lumbar spine sagittal plane range of motion. *Spine,* 19(6), 682-686.

217. Swain J, Pufahl E & G RW (2003) Do they practise what we teach? A survey of manual handling practice amongst student nurses. *Journal of Clinical Nursing,* 12(2), 297-306.

218. Swedish National Board of Occupational Safety and Health (1998) *Ergonomics for the prevention of musculoskeletal disorders.* AFS 1998:1. Stockholm.

219. Svensson E (1993) *Analysis of systematic and random differences between paired ordinal categorical data.* Doctoral thesis, University of Göteborg. Göteborg: Department of statistics.

220. Szpalski M, Michel F & Hayez JP (1996) Determination of trunk motion patterns associated with permanent or transient stenosis of the lumbar spine. *European spine journal,* 5(5), 332-7.

221. Søgaard K, Fallentin N & Nielsen J (1996) Work load during floor cleaning. The effect of cleaning methods and work technique. *European Journal of Applied Physiology,* 73, 73-81.

222. Takala E-P & Kukkonen R (1987) The handling of patients on geriatric wards. *Applied Ergonomics,* 18(1), 17-22.

223. Thomas JS, Corcos DM & Hasan Z (1998) The influence of gender on spine, hip, knee, and ankle motions during a reaching task. *Journal of Motor Behavior,* 30(2), 98-103.

224. Thomsen S (2000) *Stress, satisfaction and quality: Studies of organizational and individual well-being in health care.* Doctoral thesis, Karolinska institutet. Stockholm.

225. Thomsen S, Arnetz JE & Arnetz BB (2000) Patient and personnel perspectives in intervention studies of the health care work environment. In: Wickström G ed. *Intervention studies in the health care work environment.* Arbete och hälsa 2000:10. Pp 36-48, Stockholm: National Institute for Working Life.

226. Toussaint HM, de Winter AF, de Haas Y, de Looze MP, van Dieën JH & Kingma I (1995) Flexion relaxation during lifting: Implications for torque production by muscle activity and tissue strain at the lumbo-sacral joint. *Journal of Biomechanics,* 28, 199-210.

227. Toussaint HM, van Baar CE, van Langen PP, de Looze MP & van Dieën JH (1992) Coordination of the leg muscles in backlift and leglift. *Journal of Biomechanics,* 25(11), 1279-1289.

228. Trafimow JH, Schipplein OD, Novak GJ & Andersson GB (1993) The effects of quadriceps fatigue on the technique of lifting. *Spine,* 18(3), 364-367.

229. Trinkoff AM, Brady B & Nielsen K (2003) Workplace prevention and musculoskeletal injuries in nurses. *JONA,* 33(3), 153-158.

230. Troup JDG & Rauhala HH (1987) Ergonomics and training. *International Journal of Nursing Studies,* 24, 325-330.

231. Ulin SS, Chaffin DB, Patellos CL, Blitz SG, Emerick CA, Lundy F & Misher L (1997) A biomechanical analysis of methods used for transferring totally dependent patients. *Sci Nursing,* 14(1), 19-27.

232. Wachs JE & Parker-Conrad JE (1989) Predictors of registered nurses' lifting behavior. *American Association of Health Nurses Journal,* 37(4), 131-40.

233. Wahlstrom J, Lindegard A, Ahlborg G, Jr., Ekman A & Hagberg M (2003) Perceived muscular tension, emotional stress, psychological demands and physical load during VDU work. *International Archives of Occupational and Environmental Health,* DOI: 10.1007/s00420-003-0454-5.

234. Wahlstrom J, Svensson J, Hagberg M & Johnson PW (2000) Differences between work methods and gender in computer mouse use. *Scandinavial Journal of Work, Environment and Health,* 26(5), 390-7.

235. van der Beek AJ & Frings-Dresen MH (1998) Assessment of mechanical exposure in ergonomic epidemiology. *Occupational and Environmental Medicine,* 55(5), 291-9.

236. van der Beek AJ, Kluver BDR, Frings-Dresen MHW & Hoozemans MJM (2000) Gender differences in exerted forces and physiological load during pushing and pulling of wheeled cages by postal workers. *Ergonomics,* 43(2), 269-281.

237. van Dieën JH, Cholewicki J & Radebold A (2003) Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. *Spine,* 28(8), 834-41.

238. van Dieën JH, Creemers M, Draisma I, Toussaint HM & Kingma I (1994) Repetitive lifting and spinal shrinkage, effects of age and lifting technique. *Clinical Biomechanics,* 9(6), 367-374.

239. van Dieën JH, Dekkers JJ, Groen V, Toussaint HM & Meijer OG (2001) Within-subject variability in low back load in a repetitively performed, mildly constrained lifting task. *Spine,* 26(16), 1799-804.

240. van Dieën JH, Hoozemans MJM & Toussaint HM (1999) Stoop or squat: a review of biomechanical studies on lifting technique. *Clinical Biomechanics,* 14(10), 685-96.

241. van Dieën JH, Oude Vrielink HHE & Toussaint HM (1993) An investigation into the relevance of the pattern of temporal activation with respect to erector spinae muscle endurance. *European Journal of Applied Physiology,* 66, 70-75.

242. van Dieën JH, Selen LP & Cholewicki J (2003) Trunk muscle activation in low-back pain patients, an analysis of the literature. *Journal of Electromyography and Kinesiology,* 13(4), 333-351.

243. van Dieën JH, Toussaint HM, Maurice C & Mientjes M (1996) Fatigue-related changes in the coordination of lifting and their effect on low back load. *Journal of Motor Behavior,* 28(4), 304-314.

244. van Dieën JH, van der Burg P, Raaijmakers TAJ & Toussaint HM (1998) Effects of repetitive lifting on kinematics: inadequate anticipatory control or adaptive changes? *Journal of Motor Behavior,* 30(1), 20-32.

245. Wanklyn P, Forster A & Young J (1996) Hemiplegic shoulder pain (HSP): natural history and investigation of associated features. *Disability and Rehabilitation,* 18(10), 497-501.

246. Varcin-Coad L & Barrett R (1998) Repositioning a slumped person in a wheelchair. A biomechanical analysis of three transfer techniques. *American Association of Health Nurses Journal,* 46(11), 530-6.

247. Waters TR, Putz-Anderson V, Garg A & Fine LJ (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics,* 36(7), 749-776.

248. Veiersted KB, Westgaard RH & Andersen P (1990) Pattern of muscle activity during stereotyped work and its relation to muscle pain. *International Archives of Occupational Environment Health,* 62, 31-41.

249. Veiersted KB, Westgaard RH & Andersen P (1993) Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. *Scandinavial Journal of Work, Environment and Health,* 19(4), 284-290.

250. Venning PJ, Walter SD & Stitt LW (1987) Personal and job-related factors as determinants of incidence of back injuries among nursing personnel. *Journal of Occupational Medicine,* 29(10), 820-25.

251. Westgaard RH & Winkel J (1996) Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. *Applied Ergonomics,* 27(2), 79-88.

252. Westgaard RH & Winkel J (1997) Ergonomic intervention research for improved musculoskeletal health: A critical review. *International Journal of Industrial Ergonomics,* 20(2), 463-500.

253. Whiting W & Zernicke R (1998) *Biomechanics of musculoskeletal injury.* Champaign: Human Kinetics.

254. Videman T, Rauhala H, Asp S, Lindström K, Cedercreutz G, Kämppi M, Tola S & Troup JDG (1989) Patient-handling skill, back injuries, and back pain. An intervention study in nursing. *Spine,* 14(2), 148-156.

255. Vingård E & Nachemson A (2000) Work-related influences on neck and low back pain. In: Nachemson A & Jonsson E eds. *Neck and back pain. The scientific evidence of causes, diagnosis and treatment.* Pp 97-126, Philadelphia: Lippincott Williams & Wilkins.

256. Winkelmolen GHM, Landeweerd JA & Drost MR (1994) An evaluation of patient lifting techniques. *Ergonomics,* 37(5), 921-932.

257. Winter DA (1990) *Biomechanics and motor control of human movement.* (2:nd ed.). New York: Wiley-Interscience.

258. Yassi A, Cooper JE, Tate RB, Gerlach S, Muir M, Trottier J & Massey K (2001) A randomized controlled trial to prevent patient lift and transfer injuries of health care workers. *Spine,* 26(16), 1739-1746.

259. Youdas JW, Garrett TR, Harmsen S, Suman VJ & Carey JR (1996) Lumbar lordosis and pelvic inclination of asymptomatic adults. *Physical Therapy,* 76(10), 1066-1081.

260. Zhang X & Buhr T (2002) Are back and leg muscle strengths determinants of lifting motion strategy? Insight from studying the effects of simulated leg muscle weakness. *International Journal of Industrial Ergonomics,* 29(3), 161-169.

261. Zhang X, Nussbaum MA & Chaffin DB (2000) Back lift versus leg lift: an index and visualization of dynamic lifting strategies. *Journal of Biomechanics,* 33(6), 777-782.

262. Zhuang Z, Stobbe TJ, Collins JW, Hsiao H & Hobbs GR (2000) Psychophysical assessment of assistive devices for transferring patients/residents. *Applied Ergonomics,* 31(1), 35-44.

263. Zhuang Z, Stobbe TJ, Hsiao H, Collins JW & Hobbs GR (1999) Biomechanical evaluation of assistive devices for transferring residents. *Applied Ergonomics,* 30(4), 285-294.