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Methods for description, analysis and assessment of work technique in manual handling tasks

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List of papers

This licentiate thesis is based on the following three 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. (Submitted)

III Kjellberg K, Johnsson C, Proper K, Olsson E, Hagberg M. An observation instrument for assessment of work technique in patient transfer tasks. (Submitted)

List of abbreviations

%RVE	Percentage of Reference Voluntary Electrical activation
ANOVA	Analysis of variance
CV	Coefficient of variation
EMG	Electromyography
FB	Fast Back lift
FL	Fast Leg lift
κ	Kappa coefficient
L4	Fourth lumbar vertebra
L5	Fifth lumbar vertebra
OWAS	Ovako Working Posture Analysing System
P_o	Overall proportion of agreement
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

In this thesis a work technique concept is addressed. The emphasis is on methods that describe, analyse and assess human movements in work, primarily manual handling tasks. Laboratory methods for motion analysis, based on registrations of movements, forces and muscle activity, and observations in work places have mainly been explored. Furthermore, the focus is on work technique features as preventive or risk factors for the development of musculoskeletal disorders, and in particular of low back disorders. 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 achieve general knowledge about how to perform work technique analyses of manual handling tasks. To meet the need for a practical tool for evaluation of patient transfer technique training, an observation instrument was constructed.

1.2 Background

Manual handling of heavy loads in working life implies high physical loads on the musculoskeletal system of the worker. In spite of extensive mechanisation and automation in industry, heavy manual handling is still required. In nursing and rescue work, lifting and assisting persons during transfers will probably never be entirely substituted with mechanical aids. 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 (133). Workers with these work tasks, for example nursing personnel and industrial workers, are more liable to back injuries than other occupational groups (11, 27, 66, 69, 105, 147). There is a clear association between manual handling tasks and back disorders (10, 12, 60, 65, 84, 114, 149, 153). However, the exact mechanisms behind these back disorders are not known (26, 60, 63, 65, 101). Successful prevention of work-related musculoskeletal disorders requires a better understanding of the injury mechanisms. In spite of a tremendous number of studies on lifting and patient transfer work, the role of work technique as a preventive or risk factor has not been determined (60, 63, 117). The measuring methods used may not have captured all essential features of work technique. Most studies have focused on work postures and the loads imposed upon joints due to these postures. As manual handling tasks are highly dynamic in nature, the influence of dynamic motion on the musculoskeletal load has to be considered (96, 98).

In epidemiological studies of work-related musculoskeletal disorders crude measures of physical exposure are often used, for instance the frequency of lifting or of specific work postures. It has been stated that the concept of physical work load is often poorly defined and that insufficient methods are used, which may explain the lack of quantitative data on relationships between physical exposure and musculoskeletal disorders (150). Presumably a worker's individual work technique during a work task will modify the physical exposure. Kinematic aspects such as movement velocity, acceleration and coordination, might also influence the musculoskeletal load and risk of injury, but have seldom been studied in epidemiological studies (67, 75, 96).

1.3 Work technique

Work technique and related terms such as work methods, postures, work strategies, handling procedures, lifting pattern, work style, movement coordination, performance and skill, etc., are often used in ergonomic contexts (7, 15, 33, 34, 41, 45, 53, 55, 56, 63, 64, 77, 78, 82, 107, 109, 117, 127, 135, 148). The relation between work technique and musculoskeletal disorders has been discussed by several authors. However, there is no common definition of the concept and there are no common measuring methods.

It is a well-known fact that with apparently similar physical exposure regarding work tasks and work settings, some workers develop musculoskeletal disorders, while others remain healthy. Inter-individual differences in work technique may partly explain this phenomenon. Individual variations among workers in the performance of a work task have been observed (55, 56, 135). Associations between these variations and musculoskeletal load and disorders have been shown (1, 34, 41, 78, 79, 106, 145, 148). Also, differences between the performance of experienced and inexperienced workers have been observed (7, 45, 109). However, within individuals the performances are usually highly reproducible (56).

A model for the development of work-related musculoskeletal disorders has been presented where sets of cascading exposure, dose, capacity and response variables interact (Figure 1) (4). *Exposure* refers to external factors in the work environment, or work requirements, for example, the given work task, the work place design and the weight of the object to be handled. Only mechanical exposure will be addressed here, referring to external factors that may give rise to forces acting on the musculoskeletal system of the worker (146). The exposure may give rise to an internal *dose*, referring to factors that disturb the internal state of the worker, for example forces acting on the musculoskeletal system and metabolic demands. *Response* refers to the deformations and changes that occur in the body as a consequence of the dose, for example tissue deformations and changes in metabolic levels. One response may become a new dose, which then produces a new response. Responses also produce new responses in the process of disorder development. *Capacity* refers to the ability of the individual to resist the dose in producing deformations. Responses can increase or decrease the capacity to resist doses (Figure 1) (4).

A modification of the model is suggested here with the addition of a work technique variable (Figure 1). Work technique refers to the modifications by the individual worker of the external exposure, in producing the internal dose (146). The exposure may be modified by adjustments of the work task and work environment, for example, adjusting the work height, using a lifting aid and activating the patient. Also the motor performance of the task is a means to

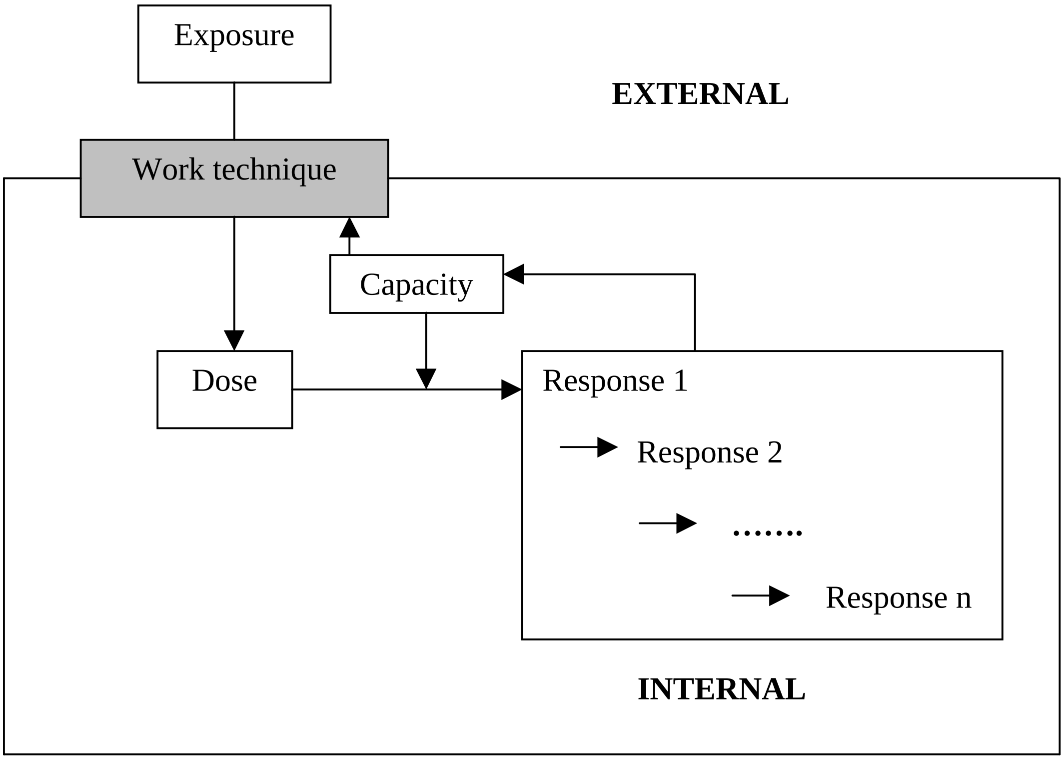

Figure 1. A model for the development of work-related musculoskeletal disorders where sets of cascading exposure, dose, capacity and response variables interact, modified from Armstrong et al. (4). A work technique variable is added.

modify the exposure. The motor performance may be characterised by, for instance, joint positions, the velocity, coordination and smoothness of movements, muscle force, which muscles are active, and lengths of lever arms. External factors are not always modifiable, for example a limited space to move in, a non-adjustable hospital bed and time pressure, and hence will provide limits for the selection of work technique. Different work place designs, work situations and work organisations, will allow a different number of degrees of freedom in the worker's choice of work technique.

The individual's choice of work technique is not only limited by external factors but is also determined by individual factors, e.g. motor and physical capacity, training background, work experience, anthropometrics, motivation and problem-solving skill. Hence, the individual's performance of a work task has a certain number of degrees of freedom, regarding what is possible for the individual in the actual work situation. Within these limitations the choice of work technique will be a trade-off between task demands and costs, as suggested by Kilbom (77). The demands, and ambition of the worker, to perform the work task rapidly, safely, with high quality and precision are balanced against costs in terms of energy expenditure, exertion, fatigue, pain and discomfort (5, 7, 77, 82).

In sports, the performance of athletes is affected by their physical capacity and their technique (20). 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. The work technique concept may be compared with the technique concept in sports. In sports the reduction of musculoskeletal load is not always a primary aim. Besides, it is not clear whether a small variation in work technique is favourable regarding musculoskeletal load. A varied movement pattern may distribute the loads on different parts of the body and thereby prevent musculoskeletal problems. There is also a difference in time perspective between sports and working life. Professional work extends over a large part of life, while competitive sport is often carried on during a more limited period. 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.

When addressing work technique in this thesis, movement characteristics, with importance for the prevention or development of musculoskeletal disorders, will be focused. Time aspects, such as the pace of the work, pause patterns and cumulative exposure will not be considered. Physiological features (e.g. oxygen consumption, heart rate, muscle fatigue), and psychophysical features (e.g. subjective perceptions of exertion, fatigue and discomfort), will be looked upon as effects of certain work techniques and will not be included. Furthermore, muscle mechanics, neurophysiology and neuromotor control mechanisms will not be covered, except for measurements of electromyography (EMG) amplitudes.

In the present study 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. 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. Variables and proper procedures are needed to describe and differentiate between different methods and performances.

1.4 Training in work technique

Training programmes in lifting and patient transfer technique, are a common approach to prevent back disorders and injuries. In Sweden, The National Board of Occupational Safety and Health has recently proclaimed 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 (133). In the literature both successful and unsuccessful examples of training programmes can be found; successful in the meaning of leading to changes in work technique that will prevent the development of musculoskeletal disorders (18, 58, 60, 76, 80, 84, 85, 104, 140, 148). Lack of results may be explained by deficiencies in the handling methods taught, in the pedagogical and implementation approaches, in the study design or in the evaluation methods.

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 (5, 6, 41, 80, 82, 108, 117, 129). The teaching methods in training programmes may also be discussed; for example theory versus practical training, training in classrooms versus in real work places, participative approaches and time aspects (e.g. (95)). Also, whether or not a training programme is supported by the management and combined with organisational changes, e.g. modifications of the work environment, has been shown to be important for the outcome of the programme (50, 84). These aspects are outside the scope of this thesis, however. Furthermore, the evaluation methods have often been rough and lacking in detail. Often the prevalence of musculoskeletal disorders has been used as a measure of effect, but it is doubtful whether the learning of a new work technique will cure already established musculoskeletal disorders (71, 76, 83). A safe work technique will rather prevent the development of new disorders and the exacerbation of existing symptoms. Besides, there is a latency for the development of musculoskeletal disorders, and therefore changes in work technique, as a first effect, should also be assessed (76, 146). The work technique should be assessed regarding musculoskeletal safety, according to what is known about relations between work technique aspects and risk for the development of musculoskeletal disorders. Besides, the safety of the *individual* technique should be assessed, rather than if the worker has assimilated specific methods.

1.5 Methods for evaluation of work technique

Methods for detailed registrations of individual work technique during manual handling are needed; in epidemiological studies, to further explore the relation to musculoskeletal health risks, in biomechanical studies, to further investigate the role of motion patterns in injury mechanisms, and in ergonomic intervention studies, to evaluate the effects of programmes aimed at improving work technique. In the present thesis the literature review of existing methods focused on laboratory motion analyses methods and observation methods, and was restricted to manual handling work. Other work tasks as well as weight lifting in sports were excluded.

Biomechanical methodology

Biomechanics has been defined as *the application of the principles of mechanics to the study of biological systems* (28). Biomechanics of human movement describes, analyses and assesses human movements and may involve kinematics, kinetics and EMG (152). Kinematics is the study of movements without respect to the forces associated with the movements. Kinetics is the study of the forces that cause, or result from, 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, gives 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 this study a limited number of variables were selected which were considered relevant for the description of work technique and for the prediction of low back disorder risk.

Numerous biomechanical experiments on lifting have been reported. Hsiang et al. (63) reviewed advantages and disadvantages of various mechanical aspects of lifting technique and concluded that there is little scientific evidence of a relationship between low back pain and lifting technique. However, what has usually been analysed is standardised lift methods imposed on the subjects, rather than individual lifting performances. A majority of the studies deal with the squat lift, performed with bent knees and erect trunk, and the stoop lift, performed with straight legs and the trunk bent forward. The two lift methods have usually been compared regarding low back load, in order to find out which lift method is least likely to cause injury to the lifter. The results have been quite contradictory; some studies show higher load during the stoop lift, others higher load during the squat lift, and some show no difference at all (3, 16, 24, 53, 89, 91, 139). Different experimental designs, biomechanical models and dependent variables, may explain some of the contradictions. In addition, large variations in the individual performance between workers using the same lift method have been noted (119). 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 (15, 64, 116, 117).

Individual work technique may 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 (54, 115-117). Phase plane analyses, 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 or by fatigue (14, 15, 118-120, 142, 143).

Kinematic variables (e.g. displacement, velocity and acceleration), kinetic variables (e.g. compressive forces, net joint moments and ground reaction forces), mechanical work and energy variables, and amplitudes of muscular activity, have been used to examine work technique during different work conditions and for different subject categories. For example, changes in movement patterns due to long periods of lifting (37, 54) and different pacing (90), differences in work strategies between experienced and inexperienced manual handlers

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* 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 muscle 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, measured forces and moments are integrated to calculate the related kinematics, i.e. information about the segmental movements caused by the measured or known forces.

(41, 45, 93, 109, 110, 123), differences in lifting technique between men and women (9, 90, 126, 127), differences between different lift or transfer methods for the execution of specific tasks (42-44, 46-49, 51, 92, 151), effects of ergonomic interventions (50), and effects of knowledge of load weight (19, 109, 110) have been studied. Sommerich and Marras (125) 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 (64, 110).

Attempts have been made to utilise other biomechanical measures than body postures in epidemiological studies of risk factors (29, 81, 97, 98). Marras et al. and Fathallah et al. showed that three-dimensional trunk kinematic variables could discriminate between low and high risk manual material handling jobs concerning low back disorders (29, 97, 98).

Observation methods

Observation methods offer simpler and more 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 (39, 75), in ergonomic evaluations of work places to identify musculoskeletal hazards (61, 62, 68, 70, 73, 100), and for evaluation of ergonomic interventions (2, 18, 30, 58, 104, 129, 146). Also, a few instruments have been found in the literature which register manual handling techniques developed by individual workers (7, 8).

In studies of nursing work, different types of observation instruments have been applied. General observation methods for quantitative assessments of physical load, e.g. OWAS, have been used (25, 59, 86, 94). Observations are performed over time to obtain measurements of duration and frequency of certain postures and activities. One risk assessment tool, REBA, has been found, developed and validated for use in the health care sector together with the electricity industry, which takes the dynamics of the performance into consideration (61). 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 (58). 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 (2, 30, 31). These checklists only cover the features of the methods, and are not capable of assessing individual variations in work technique. Work technique features, referring to both the method and performance element of a transfer task, were found in two instruments (38, 129), which were used as a basis for the instrument developed in the present study. Subjective overall assessment of patient transfer skill by an observer on a rating scale has been used to evaluate a new training programme within the nursing education (140, 148). Furthermore, the effect of transfer skill on back disorders was prospectively studied (148). In addition, a few work technique items were used in an instrument to investigate transfer technique habits in hosptal wards in relation to training, use of transferring aids and low back disorders (136).

These specific instruments for patient transfer tasks do not provide any assessment of the work technique with regard to the level of musculoskeletal hazard and safety. Furthermore they have not usually been tested for validity, and the descriptions of work technique have not been very detailed.

1.6 Inter-joint coordination and musculoskeletal load

The relation between variation in work technique and load on the locomotor system needs to be investigated. A hypothesis is that lifting coordination may influence the musculoskeletal load. A systematic change in the relative phasing between joint movements has been observed as the lifted weight was increased (15, 118, 120) and it has been suggested that a decreased inter-joint coordination might in some cases decrease the required muscular effort (15). The question might be raised as to whether it would be possible to reduce the lower back moment, also when the weight to lift is unchanged, by appropriately modifying the inter-joint coordination.

1.7 Gender differences in work technique

Among all investigations reported on lifting there are relatively few 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, for instance because of different anthropometric and strength characteristics. 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 (126, 127). Thomas et al. found differences in the kinematics of men and women performing reaching tasks in which forward bending of the trunk was necessary (137). If gender differences in work technique exist, this might for example imply that simple geometric scaling of dimensions would not be a sufficient strategy to adapt a male work place to women. Different work techniques may also affect the contents of work technique training programmes and the design and choice of assisting devices.

1.8 Aim

The overall aim of this licentiate thesis was to explore and develop methods for describing, analysing and assessing work technique in manual handling tasks.

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 examine whether hip-knee coordination, as a work technique variable, was related to the load on the lower back (Study II)
- to construct an observation instrument for description and assessment of nursing personnel's work technique in patient transfer tasks in relation to musculoskeletal health and safety, and to evaluate the validity and reliability of the instrument (Study III).

2. Material and methods

In study I and II lifting technique was studied by kinesiological variables. 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 (91). Study III concerns the construction and evaluation of an observation instrument for patient transfer tasks and was performed as a field study.

2.1 Lifting experiments

Subjects

Twelve women volunteered to participate in the experiments presented in study 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 subject data is given in Table 1.

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 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

Table 1. Means, ranges and standard deviations (SD) of some basic subject data.

	Women (n=12)			Men (n=10)		
	Mean	Range	SD	Mean	Range	SD
Age (years)	39.0	22-60	12.1	37.0	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

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 (91). The subsequent experiments on women were designed to make the data on men and women comparable.

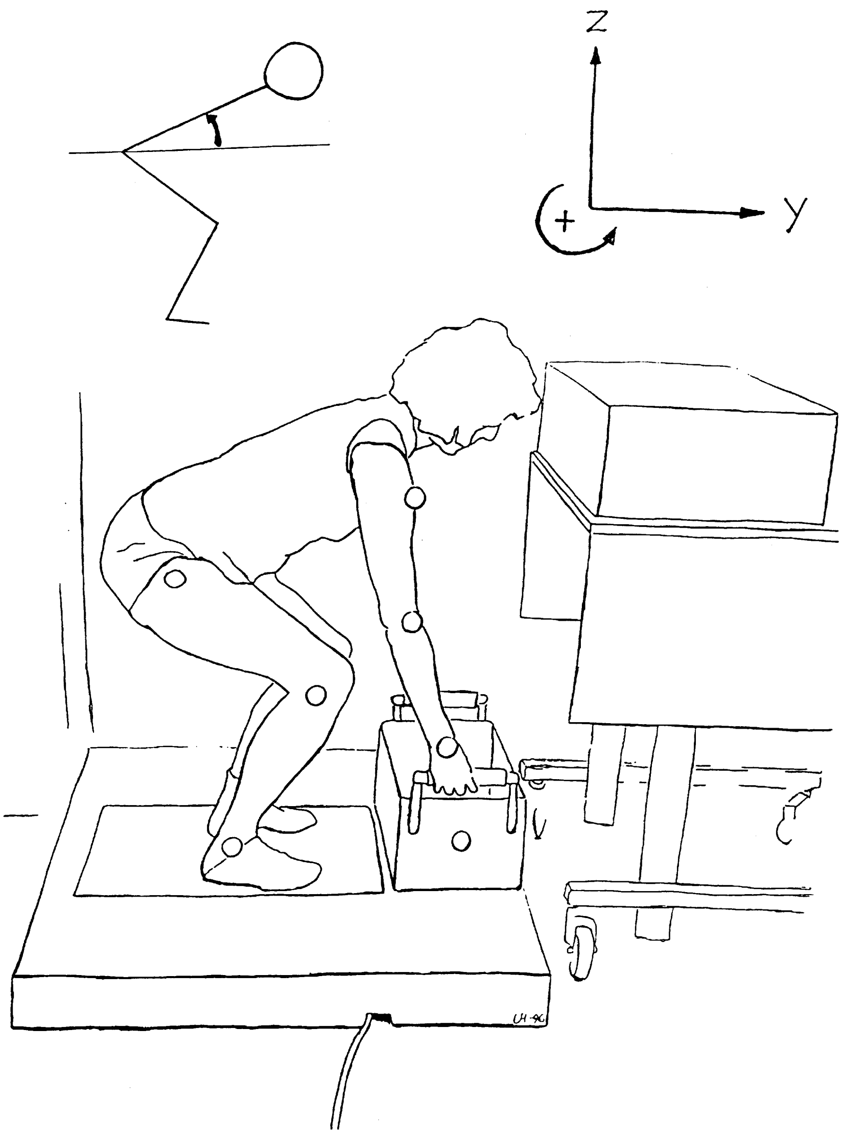

Figure 2. The experimental set-up from the experiments on female subjects showing a leg lift. The location of the markers on the subject and on the box is indicated. The angular orientation of the body segments is measured with respect to a horizontal reference line. Definitions of movement directions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

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 (91), 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 (112). To calculate net moments at L5/S1, assumptions from Freivalds et al. (40) 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.

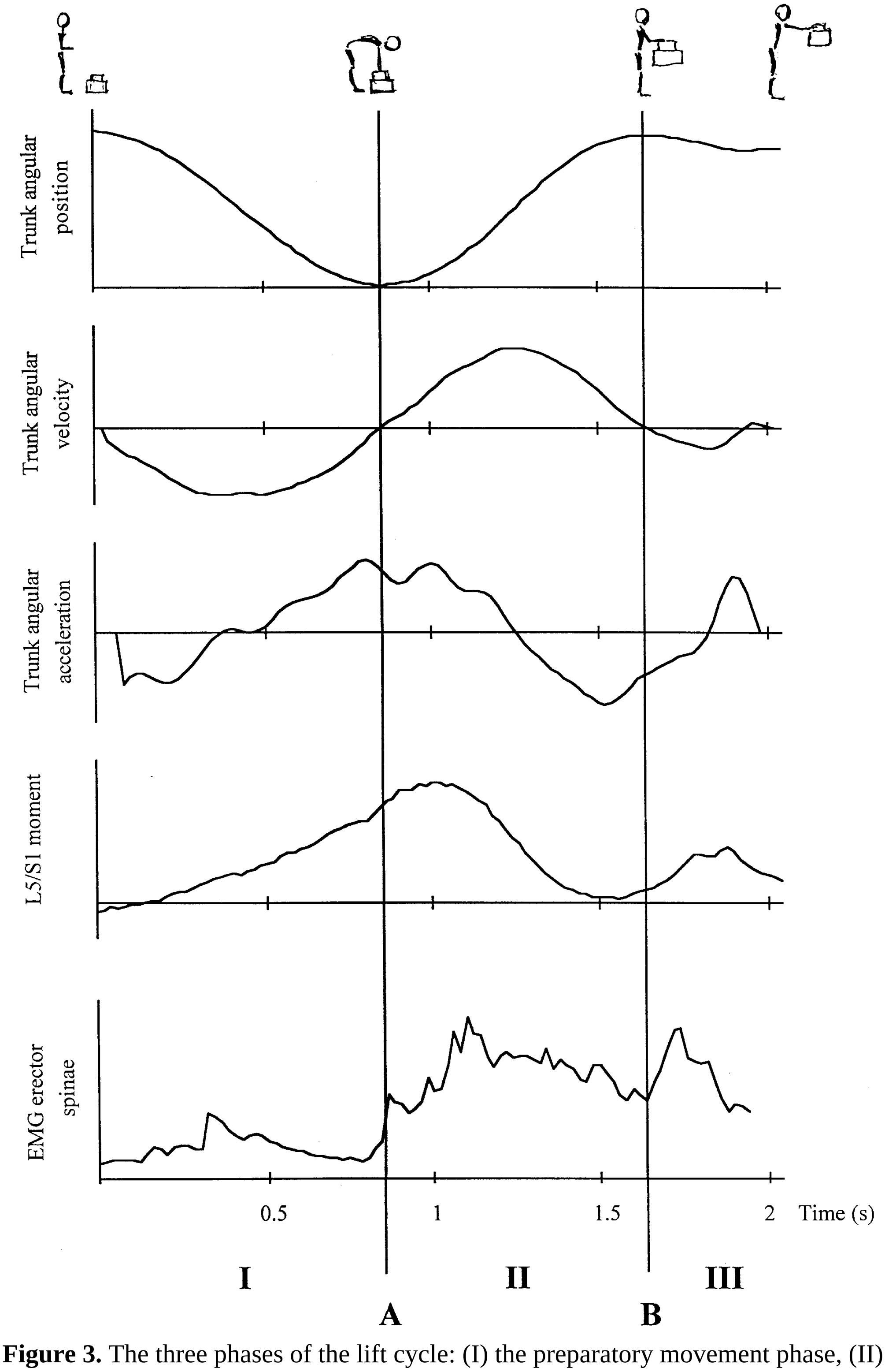

Figure 3. The three phases of the lift cycle: (I) the preparatory movement phase, (II) the box lift phase and (III) the box placement phase. The phases are separated by (A) lift off and (B) the transition from positive to negative angular velocity. An example of the qualitative appearance of five dependent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

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 (152). Velocities and accelerations were calculated from the filtered position data using Lanczos' forms as described by Lees (87).

All EMG values were expressed as a percentage of the reference contraction, %RVE (percentage of Reference Voluntary Electrical activation) (99) (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 and co-workers (14, 15). 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.

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.

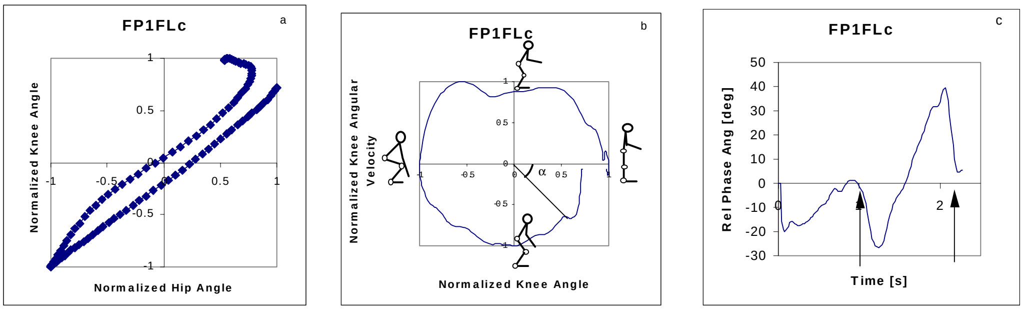

Figure 4. Angle-angle diagram (a), phase plane plot including the phase angle α (b) and relative phase angle (c) for an example of a full lifting cycle. The preparatory movement phase is included (even if not included in the presented analyses) in order to give a notion of the point of time of a full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

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.

The lift off and the box placement event in this example are indicated by arrows in (c).

Dependent variables

From the measurements and the analyses some selected kinematic, kinetic and EMG variables were determined (Table 2). The variables were chosen to cover different aspects of work technique such as movement patterns, coordination, load on the locomotor system and muscle activity.

Table 2. 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	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.

Statistical analyses

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 selected kinematic variables. Two-way ANOVA were used to test for gender differences in the relative phase angles during leg lifts.

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

The relation between hip-knee coordination, represented by the largest relative phase angles, and the peak moments at the L5/S1 joint was examined by simple linear correlation analysis (study II).

2.2 Development of an observation instrument for patient transfers

To meet the above-mentioned needs for a specific method for detailed registrations of individual work technique during patient transfers in work places, as a tool for evaluation of interventions, an observation instrument was developed. The instrument registers the work technique of a nurse during one patient transfer or during one sequence of the transfer, referred to as one operation. Observations are made from video recordings. An attempt was made to quantify the assessments, by calculating an overall score of the work technique with regard to the level of musculoskeletal hazard and safety.

Definitions

The term *nurse* was used for nursing personnel assisting the patients during transfers and included three work categories: registered nurses, state registered nurses and auxiliary nurses. *Patient transfers* were defined as work tasks where nurses assist or lift a patient during transfers from one location to another (e.g. transfer from bed to wheel-chair) or from one position to another (e.g. turning from supine to side-lying in bed). Assistance during locomotion, i.e. during walking and wheel-chair propulsion etc, was not included in the concept. One transfer might consist of several transfer *operations*. As an example, a transfer of a patient from lying in bed to sitting in a wheel-chair can be divided into the following operations: raising to sit on the edge of the bed, standing up, turning and sitting down in the wheel-chair.

Material

The material in study III consisted of a large number of video-recorded patient transfer tasks. Various types of transfer tasks performed by 23 nurses in authentic work situations in four wards in two geriatric hospitals were recorded. This material was used during the construction of the observation instrument and for validity and reliability testing. The recordings were made with one camera, mainly capturing a sagittal view and the whole body of the nurse when possible.

Development of the observation instrument

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:

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

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 3, Table 9). 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 belonging to 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 3). Most of the starting position items were

Table 3. Principal aspects of the observation instrument.

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

assessed on an ordinal scale with categories representing angular sectors.

Quantification of the assessments

To calculate an overall score, 17 items from the instrument were used. The categories of each of these items were scored by the expert group: 1 for a safe technique and 0 for a hazardous technique 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. 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 magnitude rating procedure with one item 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 neglected. The overall score was “normalised” by dividing the sum by the maximum possible scores, 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 provides a crude summary measure of the performance of a particular transfer with regard to musculoskeletal hazard and safety. A “normalised” score equal to 1 would correspond to an ideal work technique.

Validity and reliability evaluation of the observation instrument

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 selected patient transfers, mostly transfers in bed, were observed by the instrument. 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.

Statistical analyses

For evaluation of validity and reliability, the overall proportion of agreement (P_o) and the kappa coefficient (κ) were calculated for the observations of each item separately (36). 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 (36). For kappa values above 0.40 the reliability and validity was considered satisfactory.

The intraclass correlation coefficient was used for evaluation of validity and reliability of the quantitative assessments of the 35 transfers by the calculated overall scores. The intraclass correlation coefficient was computed using one-way analysis of variance with repeated measures and a “raters random” model (35).

3. Results

3.1 Kinesiological variables to detect differences in lifting technique (study 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 4).

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 5.

Table 4. 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 5. 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)

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 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 6. 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, both between and within subjects, were mostly larger for leg lifts than for back lifts.

Table 6. 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.

	Back lifts				Leg lifts			
CV (%)	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 and kinetic data did not produce any patterns that clearly distinguished between the lift types. In addition, the 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. The intra-individual variation was smaller, however, 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 7.

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 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

Table 7. 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/s^2)	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/s^2)	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 min relative phase angles are shown, as they represent the largest deviations from a perfectly synchronised hip-knee coordination.

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, $F(1,20)=8.58$, $p=0.0083$.

Table 8. Correlation coefficients (r) for the relation between the maximum deviation from a perfectly synchronised hip-knee coordination and calculated maximum net moments at the L5/S1 joint during leg lifts. Mean values and standard deviations (in brackets) for moments and relative phase angles are also presented.

	Leg lifts			
	Women		Men	
	Fast	Slow	Fast	Slow
L5/S1 moment (Nm)	160 (24)	132 (15)	333 (59)	247 (55)
Min relative phase angle (deg)	-40 (14)	-27 (7)	-85 (11)	-76 (24)
r	-0.129	0.301	-0.241	0.243

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 event (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 min 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 inter-joint coordination was better synchronised for women than for men, shown by smaller relative phase angles of the women (Table 8). The deviations from perfectly synchronised hip-knee coordination, represented by the minimum values of the relative phase angle, were significantly larger for men, $F(1,20) = 80.0$, $p<0.0001$.

Hip-knee coordination versus lower back moment (study II)

No relation was found, either for women or for men, between the maximum deviation from a perfectly synchronised hip-knee coordination and calculated maximum net moments in the lower back (Table 8).

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 was satisfactory (i.e. kappa values > 0.40), and for some of them the agreements were excellent (i.e. kappa values > 0.75) (Table 9).

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. Judgements of the feet distance 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.

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 9. 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. The item texts are abbreviated.

	Criterion-related validity				Inter-observer reliability		Intra-observer reliability	
	Observer 1		Observer 2					
	P_o (%)	κ	P_o (%)	κ	P_o (%)	κ	P_o (%)	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

4. Discussion

This licentiate thesis has explored and developed methods for describing, analysing and assessing work technique in manual handling tasks. The emphasis has been on laboratory methods for motion analysis and observation methods.

4.1 Kinesiological variables for work technique evaluation

In study I and II the capability 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 the musculoskeletal load.

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, and the trunk angular velocity and acceleration, L5/S1 moment and EMG amplitude were related to the lift velocity. The angular velocity thus seemed to be suitable for characterising both elements of the lifting technique. Marras et al. (97, 98) 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.

Variations in the studied variables, 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 and inter-joint coordination patterns.

Despite both inter- and intra-individual variations, differences in lifting technique between the two studied groups, i.e. 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 were greater for the men, probably a consequence of similar peak box velocities and accelerations for men and women in combination with the taller men's greater lifting height. 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.

It has to be considered that different sets of variables are probably required for different types of manual handling tasks. Lifting tasks at work places provide larger variations in the lifting performance than the constrained stoop and squat method. We do not know if the selected variables in our lifting studies would also be appropriate for characterisation of work technique in other types of manual handling. Furthermore, the separation of variables either for method or performance evaluation, as suggested here, may not be appropriate for other work tasks. 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.

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 main muscle groups involved in lifting. The muscular activity patterns are probably related to spinal load and injury risks (52, 103, 125, 139).

4.2 Gender differences in lifting technique

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 a deep trunk bending in the squat position can be expected to be associated with a minor knee bending. However, no differences in knee angles between men and women were found in this position. Hence, the larger trunk angle in leg lifts is difficult to explain. In back lifts a possible explanation for the men's slightly larger trunk angle 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 probably explains why the women, performing a more correct back lift, did not bend forward as deeply as the men. The women's larger knee angle ranges in leg lifts resulted from larger knee extension in the upright position. 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. On the other hand, discrepancies may occur in specific joint angle values obtained from different experiments due to presumably slight dissimilarities in marker placements by different experimenters. The angle range would be less marred by such measurement errors.

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 (132). Conceivable differences in lumbar lordisis and pelvic tilt in standing, with larger lordosis and pelvic tilts for women, shown by some authors, could have influenced the motion patterns (32, 154). The observed deeper trunk forward bending among men may also be related to gender differences in movement patterns reported by Thomas et al. (137). They 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, calculated as the change in angle of the lumbar segment, 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 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, the biomechanical model used in the present study treats the entire head-neck-trunk system as one single segment, so 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. There are no obvious explanations for this gender difference in coordination between joints. No relation between inter-joint coordination and load on the lower back was found, either for women or for men. Accordingly, no conclusion can be drawn as to whether the men or the women used the safest technique.

It has been reported that increasing load mass increases the deviation from perfectly in-phase coordination (15, 116, 118, 120). It has also been shown that the trunk flexion angle increases at lift off with heavier weights (21, 115, 121). Burgess-Limerick et al. (15) suggested that a distal-to-proximal coordination between knee, hip and lumbar vertebral joints has the effect of reducing the required muscular effort. The use of rapid knee extension at the start of the lift, delays the shortening of the hamstrings and trunk extensor muscles and reduces their shortening velocity, thereby increasing their strength. 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, it could explain both their larger trunk angles at lift off and 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, and can probably not explain the larger relative phase values for the male subjects (74, 124, 131).

Existing gender differences in strength and anthropometrics may explain differences in the studied variables, even if some precautions were taken to avoid such influences, for example by using different box weights and by adjusting the table heights in proportion to the subject's length. There is a possibility that the differences in lifting technique solely reflect variations due to such characteristics, i.e. the lifting technique is determined by levels of strength and body measures, and not by gender per se. The subjects' strength and segment lengths were not measured in the lifting experiments, so this was not possible to study. However, the differences imply that men and women may need to be considered separately in experimental research design, in work place design, and when developing and evaluating training programmes in work technique.

4.3 Individual variations in work technique and their relation to low back load

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 (111). 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 than for freestyle lifts without any directions as to the method. However, the intra-individual variability would presumably be larger for a subject using the stoop or squat method, than when using his/her own personal technique. Hence, a more detailed description of the lift method to be used would decrease the variability between subjects, but possibly to some extent have the opposite effect on the intra-individual variability.

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, was studied, as a first application of the work technique concept. For the purpose of detecting possible differences between two groups, i.e. women and men, it was also considered reasonable to study the constrained squat and stoop lift. No self-selected technique, i.e. freestyle lift, was studied. Nevertheless, variations in the studied variables, both between and within subjects, were obtained.

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 (21, 54). 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. This has not been studied in the present thesis, however.

The even larger variability in EMG measurements, compared to the kinematics and kinetics, could probably be explained by the redundancy concerning muscle recruitment, but also by biological differences and measurement faults due to the dynamic conditions.

The degree of variation within subjects differed between subjects, indicating different abilities to reproduce a movement. 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 (123). As an example, van Dieën (141) 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. On the other hand, it could be assumed that practice of a task increases the consistency in motion patterns.

For a specific work task with a fixed number of degrees of freedom for the performance, the sources of variation in work technique between individuals are not fully recognised. As pointed out in section 1.3, the choice of work technique is influenced by individual characteristics. Some of these characteristics may be related to gender. Different movement patterns entail different biomechanical costs and benefits. A particular work technique, e.g. a particular posture adopted at lift-off or a particular pattern of inter-joint coordination in lifting, may be advantageous for one subject, but not for another, as is also discussed by Burgess-Limerick and Abernethy (13). It can be questioned whether individual patterns are more important for the musculoskeletal load, than the choice of lift methods? This suggestion was supported by the finding in study I that the choice between the stoop and squat lift methods did not considerably influence the peak L5/S1 joint moment, whereas the lift velocity did, a finding that has been confirmed by others (16). Furthermore, a particular movement pattern may be advantageous in terms of, e.g., energy expenditure, but not, or even unfavourable, in other respects, e.g. musculoskeletal load.

The relations between certain features of work technique and musculoskeletal load have not been fully explored. In the present study an hypothesis was tested that lifting coordination influences low back load. If muscular effort could be reduced by altering inter-joint coordination (15), effects on the net joint moments in the lower back joints might be expected. Proper modification of the motion pattern might then be a way to protect the back when the weight of the load increases. Also, when the external load is unchanged, the load on the back might be affected by the inter-joint coordination. However, no relationship between the peak L5/S1 joint moment and the largest relative phase angle during leg lifts could be shown. Hypotheses that the coordination of the lifter’s movement may be important for the lower back load have been tested by other researchers. Hsiang and McGorry (64) showed that the compressive force on the L5/S1 joint could be reduced by manipulation of the motion patterns of the external load. The smoother the motion pattern of the external load, the lower the peak compressive force on the L5/S1 joint.

Existing inter-individual and gender differences imply that work technique may need to be considered on an individual level, or for groups of subjects with common properties in terms of for example sex, age, anthropometry, when exploring mechanisms and risk factors for musculoskeletal disorders, as well as in work technique training and work place design. A number of questions could be raised: to what extent work methods can be standardised, if averaged subject data should be used at all, and if work technique has to be studied and trained on a purely individual level or for homogenous groups of subjects. The use of subject-specific data when studying motor performance has also been proposed by others (13, 103, 119, 125). For example, Sommerich and Marras (125) suggested individual EMG patterns to be used in biomechanical models of spinal loading during lifting tasks.

4.4 Validity and reliability of the observation instrument

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 work with regard to musculoskeletal health and safety. The main application would be in evaluation of intervention programmes aimed at improving nursing personnel's transfer technique. The observation items were selected according to the literature on associations between work technique features and musculoskeletal health. The instrument registers both the motor performance of the nurse, i.e. descriptions of movements and exerted forces, and actions taken by the nurse to facilitate the performance, such as adjusting the bed height, using a transferring aid and activating the patient. Furthermore, a method for a quantitative assessment of the observed work technique, by calculating an overall score regarding musculoskeletal hazard and safety, was proposed.

The criterion-related validity and inter- and intra-observer reliability for the presented observation instrument was mostly satisfactory, both when evaluating the agreements between the observations of each item, and when evaluating the agreements between the overall scores.

To improve the validity and reliability of the observation instrument, some changes of the instrument, the video recording and observation procedures are suggested. Two video cameras or direct observations, as complements to the video recordings, would be beneficial for judgements of the feet distance and back motions. The benefit of viewing the actual performance phase of the transfer in slow motion should be used. More exact definitions in the instrument and longer training periods for the observers would provide them with more accurate criteria for their judgements and enhance the agreements between them.

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 (134). 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 (134). 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. 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 (128). However, the findings in the literature concerning the relation between a certain work technique characteristic, represented by an observation item, and risk for musculoskeletal disorders were not always consistent, for example the use of legs and weight transfers (i.e. shifting the body weight from one leg to another) (41, 45, 129). The selection of items may therefore need further consideration, especially after examining the usefulness of the instrument as an evaluation tool in future training studies.

As the transfer tasks and work techniques in the video recordings were not controlled or arranged, some categories of the items were rarely observed, for example verbal stimulation, antero-posterior weight transfer and jerky quality of motion. Due to its mathematical construction, the kappa value depends on the distribution of observations between categories within an item, i.e. a frequently occurring category makes it difficult to obtain a high kappa value (128). When most of the observations fall into the same category, the overall proportion of agreement *may* be high by chance. As the kappa coefficient is corrected for the agreement expected by chance, this value may be low for the same item. The skewed distributions of observations for some items, mainly actual performance items, in this study gave rise to low kappa values, despite high percentages of agreement.

4.5 Methodologies for evaluation of work technique

The use of biomechanics, observation methods, and epidemiology, to explore work technique in manual handling work and its relation to musculoskeletal disorders, will be discussed in this section. Physiological methods and self-assessments of work technique are also feasible methods to evaluate work technique, but will not be attended to.

Biomechanical studies have been widely 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 (101). 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 (23, 101). Also, it is not possible to expose human subjects in the laboratory to forces leading to musculoskeletal injuries. There is no direct causal link between calculated forces and disorder development (63). Therefore, biomechanical analyses should preferably be performed on comparisons of differences and changes in work methods and individual performances, as was reviewed in section 1.5.

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 work places difficult. However, to investigate the role of individual work technique features, e.g. complex coordination patterns, in musculoskeletal injury mechanisms, biomechanical laboratory studies are necessary (63). 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 addition, biomechanics is used to roughly assess injury risks by determining the size of forces acting on the body during manual handling tasks. Guidelines for work place use have been developed which assess manual handling tasks and provide recommendations for weight limits (102, 144).

Simplifications and assumptions in our biomechanical model may have hidden possible differences between stoop and squat lift, and between men's and women's performances. One simplification was the treatment of the head-neck-trunk as one rigid segment. As already discussed, spinal curvatures and pelvic tilt could not be discovered 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 in the hip and intervertebral joints. The effect of different lumbar curvatures concerning load on various back tissues has been reported (3, 57, 63, 113). Potvin et al. (113) 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 compared 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. However, 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 information of the load of individual muscles and passive tissue (101, 138). In the present study neither the choice of lift method, nor the degree of inter-joint coordination, seemed to be related to the L5/S1 moment. 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.

The biomechanical measures should hence be used with care in work technique assessments, and in the first place to register differences and changes. Comparisons between different studies, for example the comparisons of data from the male and female experiments in study II, must be performed with caution. For example, different experimenters and motion capture systems, as well as slight dissimilarities in experimental procedures, may have introduced systematic errors falsely interpreted as gender differences.

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 observation by experienced ergonomists offers an alternative for assessments of work technique in epidemiological and intervention studies (75). The choice of observation items may be based on biomechanical considerations and laboratory measurements may be used as the "gold standard" when evaluating the observation methods. In addition, the observer can subjectively judge work technique aspects that can not be easily measured, e.g. preparations for a patient transfer. Observation instruments have to be tested for their reliability and validity, due to their qualitative character. Although our observation instrument was evaluated to some extent in the present study, the validity is still a concern due to the lacking knowledge regarding the relationship between work technique aspects and musculoskeletal health effects (67, 75, 146).

One new feature of the observation instrument presented in this study, compared with other available observation instruments is the assessment of work technique, rather than physical work load. Furthermore, the observation instrument provides more details about work technique than merely adopted postures. Not only the nurse's performance of the actual transfer is observed, but also the preparations before the transfer starts. Authier and Lortie (6) stated that particular attention should be paid to the preparation phase of manual handling tasks during work technique training. Lack of space, for example, may impede a safe performance of the transfer (26). Situations where the patient does not contribute to the transfer, or moves in an unexpected way, have been shown to contribute to back injuries (17, 26, 130). The use of transferring aids has been reported to reduce the load on the lumbar spine and the risk of back injuries (51, 122, 136, 149).

No other attempts to quantify the work technique assessment have been found in the literature, except for risk assessment tools that indicate the need for ergonomic improvements (61, 68, 73, 100). Quantitative measures would be of great value for evaluations of intervention programmes in transfer technique. However, the scoring of the observations should be treated as a first rough attempt. The application of an overall score is disputable for several reasons; for example, the relation of a particular overall score to the level of musculoskeletal safety and hazard is not known. Furthermore, external factors, such as factors related to the patient (e.g. the patient's weight, functional ability and willingness to cooperate), the design of the work environment (e.g. the lay-out of a patient's room), and organisational factors (e.g. the amount of staff), may influence and make limitations for the work technique chosen by the nurse (26) and may accordingly influence the calculated score. The overall score should therefore be used with caution: only for comparisons within subjects, e.g. to compare work technique before and after training, and preferably on standardised, or similar, transfer situations.

Only observations from video were tested in study III. The reason for choosing video observation was the large number of items and the dynamic character of patient transfer tasks. For observations of dynamic work, video recording and analysing afterwards have been recommended (22, 88). The video films can be replayed in order to observe the items separately (75, 88); also in slow motion, and frozen to study postures. One obvious disadvantage of observations from video recordings is increased time for the observations. Another drawback is the two-dimensional picture of a video camera (72). Direct observations at the workplace may therefore be preferred, since human vision is three-dimensional (75). Also the observer can move around at the work place and find optimal views. The presence of a video camera might also cause ethical and bias problems in care situations.

The role of epidemiology is to establish possible relations between physical exposure and work-related musculoskeletal disorders (23, 75). 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 (23, 63). There is a great need for prospective epidemiological research to establish relationships between specific work technique variables and the probability of disorders. However, methods for work technique assessments in epidemiological studies have not been studied in this thesis.

Few epidemiological studies have included work technique variables, except for crude measures of work postures (67, 75). The studies found, using other biomechanical measures, have often cross-sectional designs, where comparisons are made between injured and non-injured workers (29, 81, 97, 98). Besides, a skill assessment of patient transfer technique has been used in a prospective study to examine the effect of skill on back disorders (148).

4.6 Further research needed

Methods to study work technique by means of appropriate field devices for direct technical measurements of movements should be developed. The variables found useful in this study, e.g. trunk angles, trunk angular velocity and acceleration, may be measured.

For future studies the choice of kinesiological variables and observation items should be extended to include additional parts of the body, and not only the lower back. In addition, other derived measures, e.g. impulses, measures of the centre of gravity, ground reaction forces, mechanical work and energy, should be explored.

Work technique during patient transfer tasks should also be analysed using biomechanical methods. The items in the observation instrument reflecting motor performance features should be validated against such measurements. Moreover, the quantification of the work technique assessment by the calculation of an overall score needs to be further considered.

5. Conclusions

Kinesiological variables and evaluation of work technique

- Separate variables should be used for descriptions of work methods and task performances. Simple geometric 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 and EMG amplitudes) seem to be more useful.

- The peak L5/S1 net moment, as a work technique variable, was more influenced by lift velocity than by the choice of lift method.

- Inter-individual and gender differences in the studied variables suggest that work technique training and evaluation may need to be carried out on an individual level or for groups of subjects that can be expected to have common properties in terms of for example sex, age, anthropometry, etc.

Gender differences in lifting technique

- Differences between men and women in lifting kinematics were found, e.g. in trunk motion and knee angle ranges.

- The hip-knee inter-joint coordination was better synchronised for women than for men, i.e. the extension movements in the hip and knee joints were more synchronised and better in phase during the lifts of the women.

- Men and women may have to be considered separately in experimental research design, in work place design, and when developing and evaluating training programmes in work technique.

Inter-joint coordination versus low back load

- No indication was found, either for women or for men, that the degree of hip-knee coordination influenced the peak load on the lower back.

The observation instrument

- A new observation instrument for detailed descriptions and assessments of work technique in patient transfer tasks, as a tool for evaluation of intervention programmes, has been developed. Most items of the observation instrument showed satisfactory validity and reliability.

- A method for a quantitative assessment of the observed work technique, by calculating an overall score regarding musculoskeletal hazard and safety, is proposed.

6. Summary

Kjellberg K. Methods for description, analysis and assessment of work technique in manual handling tasks. *Arbete och Hälsa* 1998:17.

To explore the role of individual work technique, as a preventive or risk factor for the development of musculoskeletal disorders, methods are needed for detailed registrations of individual work technique. The overall aim of this licentiate thesis was therefore to explore and develop methods for describing, analysing and assessing work technique in manual handling tasks. Laboratory methods for motion analysis, based on registrations of movements, forces and muscle activity, and observations in work places have mainly been explored.

In the first of three studies, the specific aim was to explore the capability of some selected kinesiological variables to distinguish between different lift methods and between different performances in lifting tasks. Twelve women lifted a box with two lift methods, back and leg lifts, and two lift velocities, fast and slow lifts, in a laboratory study. The lifts were registered by means of an optoelectronic three-dimensional motion capture system, a force plate and electromyography, and were analysed by a dynamic biomechanical model. It was suggested that the concept work technique be regarded as two basic elements: method and individual performance. The method refers to general, established work methods, 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. The results implied that separate variables should be used for descriptions of work methods and task performances. Simple geometric descriptions of joint configurations in specific phases of the movement cycle, e.g. maximum and minimum joint angle values, seemed 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 and EMG amplitudes) seemed to be more useful. The choice of lift method was not important for the peak load on the lower back. Large inter-individual differences in the studied variables, in spite of careful instructions in the specific lift methods, suggested that work technique evaluation may need to be carried out on an individual level or for homogenous groups of subjects.

In the second study, data from the first study was compared with data from a previous investigation on ten male subjects. The aim was to investigate whether gender differences in lifting technique could be detected by some kinematic variables, e.g. a measure of coordination between movements in the hip and knee joints. A further aim was to examine whether hip-knee coordination, as a work technique variable, was related to the load on the lower back. Differences between men and women in lifting kinematics were found, e.g. in trunk motion and knee angle ranges. The hip-knee inter-joint coordination was better synchronised for women than for men, i.e. the extension movements in the hip and knee joints were more synchronised and better in phase during the lifts of the women. No indication was found that the degree of coordination influenced the peak net moments in the lower back. It was concluded that men and women may have to be considered separately in experimental research design, in work place design, and when developing and evaluating training programmes in work technique.

In the third study an observation instrument was constructed for description and assessment of nursing personnel's work technique in patient transfer tasks. The main application would be evaluation of intervention effects. The observation items were selected according to the literature on associations between work technique features and musculoskeletal health. The instrument consisted of 24 items arranged in three phases of a transfer: the preparation phase, the starting position and the actual performance. A detailed description of the individual work technique, including actions taken to prepare the transfer, the interaction with the patient and any assistant co-worker, and the motor performance of the nurse, was provided. In addition, a method for a quantitative assessment of the observed work technique, by calculating an overall score regarding musculoskeletal hazard and safety, was proposed. The validity and reliability of the instrument was evaluated on 35 video recorded patient transfers from hospital wards. The validity and reliability was mostly satisfactory, both when evaluating the agreements between the observations of each item (i.e. kappa values > 0.40), and when evaluating the agreements between the overall scores (i.e. intraclass correlation coefficients 0.71 - 0.90). Further improvements to enhance the agreements were suggested.

Keywords: biomechanics, coordination, electromyography, kinematics, kinetics, lifting, manual handling, motion analysis, musculoskeletal load, nurses, observation methods, patient handling, work technique.

7. Sammanfattning (summary in Swedish)

Kjellberg K. Methods for description, analysis and assessment of work technique in manual handling tasks. *Arbete och Hälsa* 1998:17.

För att kunna undersöka betydelsen av individuell arbetsteknik, som preventiv faktor eller riskfaktor för utveckling av muskuloskelettala besvär, behövs metoder för att studera individuell arbetsteknik. Det övergripande syftet med denna licentiatavhandling var därför att utveckla och pröva metoder för att beskriva, analysera och värdera arbetsteknik vid manuellt hanteringsarbete. Laboratoriemetoder för rörelseanalys, baserade på registrering av rörelse, kraft och muskelaktivitet, och observationer på arbetsplatser prövades.

I den första av tre studier, var syftet att undersöka om några utvalda kinesiologiska variabler kunde användas för att skilja mellan olika lyftmetoder och olika utföranden av en lyftuppgift. I ett laboratorieexperiment fick tolv kvinnor lyfta en låda med två lyftmetoder, rygg- och benlyft, och två lyfthastigheter, snabba och långsamma lyft. Under lyften registrerades rörelser, krafter och muskelaktivitet med ett tredimensionellt optoelektroniskt rörelsemätsystem, kraftplatta och elektromyografi. Data analyserades med hjälp av en dynamisk biomekanisk modell. Begreppet arbetsteknik föreslogs delas upp i två underliggande begrepp: metod och individuellt utförande. Metod avser generella, standardiserade metoder, för t ex lyft eller patientförflyttningar, som lärs ut vid utbildning i arbetsteknik. Individuellt utförande avser individens sätt att utföra en specifik arbetsuppgift eller en specifik metod. Resultaten visade att vissa variabler var bättre lämpade att användas för beskrivning av metoden, och andra för att beskriva utförandet av en arbetsuppgift. Enkla geometriska beskrivningar av ledvinklar vid specifika faser under en rörelsecykel, t ex största och minsta vinkelvärdet, verkade vara lämpliga för att karaktärisera en metod, medan mått på angulär förflyttning (t ex vinkelhastigheter och accelerationer) och belastningsvariabler (t ex ledmoment och EMG-amplituder) var mer användbara när det gällde att skilja mellan olika individuella utföranden. Lyftmetoden befanns inte ha någon avgörande betydelse för ländryggsbelastningen. Stora individuella skillnader i lyftteknik uppmättes, trots att försökspersonerna instruerats i att använda specifika lyftmetoder. Detta kan tolkas som att arbetsteknik bör utvärderas på individnivå eller för homogena grupper.

I den andra studien jämfördes data från första studien med data från en tidigare studie på tio män. Syftet var att undersöka om könsskillnader i lyftteknik kunde upptäckas med några utvalda kinematiska variabler, bl a ett mått på koordinationen mellan rörelser i höft- och knäled. Ett ytterligare syfte var att undersöka om höft-knä koordinationen, som ett mått på arbetsteknik, har samband med belastningen på ländryggen. Resultaten visade skillnader i rörelsemönster mellan män och kvinnor vid lyft, t ex i bålrörelser och knävinkelutslag. Koordinationen mellan höft- och knäledsrörelser var bättre synkroniserad för kvinnor jämfört med män; bättre i den meningen att knäled och höftled extenderades mer synkront och i fas med varandra under kvinnornas lyft. Något samband mellan grad av synkronisering och belastning på ländryggen kunde ej påvisas. En slutsats var att män och kvinnor kanske bör beaktas var för sig; i försöksdesigner, vid design av arbetsplatser, och vid uppläggning och utvärdering av träningsprogram i arbetsteknik.

I den tredje studien konstruerades ett observationsinstrument för beskrivning och bedömning av vårdpersonals arbetsteknik vid patientförflyttningar, att användas fr a som ett utvärderingsinstrument i interventionsstudier. Det framtagna instrumentet innehöll 24 bedömningspunkter uppdelade på tre faser av en förflyttning; förberedelsefasen, utgångsställningen och utförandefasen. Bedömningspunkterna valdes ut efter litteraturstudier över samband mellan olika arbetsteknikaspekter och muskuloskelettal hälsa. Instrumentet ger en detaljerad beskrivning av den individuella arbetstekniken och omfattar åtgärder för att förbereda patientförflyttningen, samspelet mellan patient och vårdpersonal, och vårdpersonalens motoriska utförande. Dessutom föreslogs en metod för en kvantitativ värdering av arbetstekniken utifrån instrumentet, genom beräkning av ett totalvärde för muskuloskelettal risk och säkerhet. Instrumentet testades för validitet och reliabilitet på 35 patientförflyttningar, som videofilmats på vårdavdelningar. Validiteten och reliabiliteten var i de flesta fall tillfredsställande, både överensstämmelsen mellan observationer av varje enskild bedömningspunkt (dvs kappavärden > 0,40), och överensstämmelsen mellan de beräknade totalvärdena (dvs intraklass korrelationskoefficienter 0,71 – 0,90). Vissa förändringar av instrument och observationsprocedur för att öka validiteten och reliabiliteten föreslogs.

Nyckelord: arbetsteknik, biomekanik, elektromyografi, kinematik, kinetik, koordination, lyft, manuell hantering, muskuloskelettal belastning, observationsmetoder, patientförflyttning, rörelseanalys, vårdpersonal.

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