INDUSTRIAL SEATING
AND
SPINAL LOADING

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ABSTRACT

Little information is available in the literature concerning an ergonomic systems view of industrial seats. This study has been aimed at expanding knowledge of industrial seat design. For this purpose, a model for evaluating industrial seats has been proposed, listing demands and restrictions from the task and the workplace. It also includes responses and effects on the sitter, and methods of measurement for evaluating industrial work seats.

The appropriateness of work seat design has been assessed in laboratory and field studies, using methods to measure body loads, their effects and responses. These have been body height shrinkage, biomechanical methods, subjective assessment, and posture assessment.

The shrinkage method, including equipment and procedures, has been developed in this project. It assesses the effect of loads on the spine in vivo by using body height changes as a measure of disc creep. The results are well correlated with spinal loads. The method is sensitive enough to differentiate between spinal loads of 100 N difference. The results are also related to the perception of discomfort. Biomechanical methods have been developed for calculating compressive, shear, and momental loads on the spine. Ratings of discomfort, body mapping, interviews, video recordings, and prototype equipment for the recording of head posture have also been used. The methods have been shown to be appropriate for seat evaluation.

Work seats have been evaluated in different tasks, incorporating backrests of different height, width and shape, conventional seat pans and sit-stand seats. It has been shown that advantageous chair features could be referred to each particular task. The tasks evaluated included forward force exertion (high backrests advantageous), vision to the side (low backrests advantageous), work with restricted knee-room (seats allowing increased trunk-thigh angle advantageous), grinding (high, narrow backrests advantageous), punch press work (increased seat height advantageous), and fork lift truck driving (medium height backrest advantageous).

The work task has been shown to be a major influence on seat design, and must therefore always be thoroughly considered.

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LIST OF ARTICLES

This work has led to a number of articles describing results from applications of the methods developed. These have extended beyond the problems of seating. This list is provided to indicate the extent and utility of these applications.

Eklund JAE, Corlett EN, Johnson F. A method for measuring the load imposed on the back of a sitting person. Ergonomics 1983;26(11):1063-1076. (Included as Appendix 1)

Corlett EN, Eklund JAE, Houghton CS, Webb R. A design for a sit-stand stool. Proceedings of the Ergonomics Society's conference. Cambridge, March 1983:157.

Corlett EN, Eklund JAE. The measurment of spinal loads arising from work seats. Proceedings of the Human Factors Society — 27th annual meeting, Santa Monica, 1983:786-789.

Eklund JAE, Corlett EN. A method for evaluation of the effectiveness of a work seat. Proceedings of the Ergonomics Society's conference. Cambridge, March 1983:155.

Corlett EN, Eklund JAE. Changes in stature as a measure of the effectiveness of industrial seating. The 1984 International Conference on Occupational Ergonomics. Canada, 1984:299-300.

Eklund JAE, Corlett EN. Shrinkage as a measure of the effect of load on the spine. Spine 1984;9(2):189-194. (Included as Appendix 3)

Corlett EN, Eklund JAE. How does a backrest work? Applied Ergonomics 1984;15(2):111-114. (Included as Appendix 6)

Eklund JAE, Corlett EN. Changes of stature as a measure of body loads. Seminario internazionale su "Metodi di valutazione delle posture de lavoro". Milano, 19 April 1985.

Eklund JAE, Liew M, Örtengren R. Methods for evaluation of industrial seating. Proceedings. Applications of Biomechanics. Bjärka-Säby, Linköping, Sweden, 13-15 June 1985:111-112.

Troup JDG, Reilly T, Eklund JAE, Leatt P. Changes in stature with spinal loading and their relation to the perception of exertion or discomfort. Stress Medicine 1985;1:303-307.

Eklund JAE, Corlett EN. Experimental and biomechanical analysis of seating. In Wilson JR, Corlett EN and Manenica, I ed. The ergonomics of working postures: Models, methods and cases. London: Taylor and Francis, 1986. (Included as Appendix 5)

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Eklund JAE, Nilsson SE, Odenrick P, Örtengren R. A pilot study of neck flexion and rotation in truck drivers. In Oborne DJ ed. Contemporary Ergonomics. London: Taylor and Francis, 1986:83–87.

Eklund J, Liew M, Örtengren R. Utvärdering av industristolars utformning (Evaluation of industrial seat design). Rapport LiTH-IErg-R-6, Institutionen för industriell ergonomi, Universitetet, Linköping, 1986.

Corlett EN, Eklund JAE, Reilly T, Troup JDG. Assessment of work load from measurements of stature. Accepted for publication in Applied Ergonomics 1986.

Eklund JAE, Örtengren R, Corlett EN. A biomechanical model for evaluation of spinal loads in seated work tasks. Accepted for publication in Jonsson B ed. Biomechanics X-B. Champaign, Illinois: Human Kinetics Publishers Inc., 1987. (Included as Appendix 2)

INTRODUCTION

Stools have been used by man for more than 5,000 years according to excavations in Egypt. The chair is considered to have developed from the stools of 4,500–5,000 years ago. Chairs were then probably used in formal situations. Their design was surprisingly similar to some of the chairs still used today. It has even been found that cushions or padding were sometimes used on these early chairs.

One of the oldest stools found was made of stone and had three legs. There is evidence from Egypt that craftsmen used stools around 2000 B.C., and before that they squatted on the ground. These stools, the first work seats, were often made of timber and they generally could be four legged. Their designs varied, but the height was often low (Killen 1980).

The use of work seats increased in Western countries when hunting, fishing and agricultural work was replaced by manual skills/handiwork. Craftsmen made their own tools, which included work seats if needed. Hence, they were in control of choosing and designing these according to their own preferences, influenced by their perception, feelings and attitudes towards the equipment and seats. It is probably reasonable to assume that the design of work seats was affected both by random influences and by the suitability of the design. However, it is more difficult to see how factors such as long term effects on health could be accounted for in the design. There were also limitations in the manufacturing techniques and materials available.

Industrialization created new types of jobs, many of which were often performed standing. For a long period of time, it was considered that industrial workers should stand during their working time. Sitting was a sign of being impudent and lazy. This can be illustrated by a rule used for dismissing labourers, by the reminiscence of a retired worker talking of his apprenticeship days: "Three times on your ass and you're out" (Seymour 1986). During the last decades, an increasing number of jobs in industry are being performed in a sitting position, which is due both to changed attitudes and the changed structure of industry. New production methods have created new jobs which can be better performed sitting, such as inspection tasks, supervision, console operation and semi-automated assembly. In many countries, work legislation now demands the provision of seats for resting purposes in standing jobs.

The use of chairs in industry has caused chairs to be manufactured as industrial products. Chair design can no longer be directly controlled by users, as the earlier craftsmen could. The consequences are that little or even no feedback reaches the manufacturers, concerning the comfort and the appropriateness of the chairs as perceived by the users in their work tasks. It is not until fairly recently that awareness of the use of ergonomics in chair design has started to spread into industry.

However, the use of chairs, chair design and preferred postures in sitting also differs between cultures. Squatting or sitting cross-legged on a horizontal surface is common in Africa and Asia (Chapanis 1974). These postures have advantages for people accustomed to them and living in suitable cultural and environmental situations. Several of the advantages were pointed out by Sen (1984), such as obtaining support for the back from the thighs when squatting, using the feet to hold the workpiece, and being less exposed to heat in a hot climate when sitting on the ground. These postures would not work at all for people in the industrialized countries, for reasons such as lack of joint mobility in the feet, knees and hips.

There are also several other social and traditional norms connected with sitting and chair design. A throne, an expensive and ornamented piece of art, raised in relation to the surroundings, is a symbol of power, authority and status. Even today in companies and organizations, chairs are symbols of the status of their occupants. It has been claimed that the cost of purchase of work chairs is closely related to the salary of the employee. Also the language of today reveals the historical importance of chairs, for example "chairman" and "to hold a Chair at a University".

The ergonomics of sitting therefore do not lead to absolutely true answers or solutions. The recommendations put forward by ergonomists must be related to the historical, cultural, social and environmental situation (Chapanis 1974).

The structure of tasks in industry is changing, as earlier mentioned. For many years, the number of heavy manual handling tasks has been decreasing, and the number of seated tasks has increased. Supervisory tasks and assembly of products with small, light components, often in large quantities, have become more common. In a recent Swedish study by interview, it was estimated that 43% of the working population sits at least half of the working day (The working environment in figures 1985). About 35% of the Swedish working population is employed in the industrial sector and about 60% in the service sector. It has also been estimated that 65–70% of the people employed in the industrial sector are blue collar workers (The working environment in figures 1985). Hence, a large proportion of the working population is employed in industrial or non-clerical sitting work tasks. It has also often been claimed that people in Western society spend an increasing part of their leisure time sitting (Grieco 1986).

High rates of back, neck and shoulder pain and also discomfort or pain from the lower legs and feet have been shown among people in sitting tasks (Grieco 1986, Andersson 1981, Winkel 1985). In addition to the suffering of the people affected, high economic costs are a result of the above mentioned consequences, and these costs hit not only the individual, but also society and industry, through for example sickness absence, work injuries and premature retirement. Further, it is probable that jobs causing discomfort also lead to productivity losses. Musculoskeletal ailments in industry appear to show an increasing trend (Onishi et al 1976), which is of great concern. It is considered that a substantial part of these ailments can be prevented by redesign of workplaces and tasks, utilizing effective ergonomic design.

Many investigations have been carried out concerning the ergonomics of office chairs, vehicle chairs and school chairs. Industrial seating is, however, a badly neglected field in this respect. Very few investigations and scientific articles have been published in this field. Therefore, the standard of knowledge is relatively low. Also, the standard and ergonomic quality of chairs used in industry and for sale on the market are low. There are other reasons too, for example price competition among manufacturers and the fact that industrial buyers can easily see the cost but cannot analyse or calculate the benefits of improved chairs. Ergonomic design is often connected with luxury and expensive products, which causes low cost products to be designed without considering ergonomics. If a comparison is made between different tasks and occupations, the relation between the costs of the chairs used in these will show large differences. Seats for lorries, buses, fork lift trucks, and also control room operators are often substantially more expensive than seats for assembly workers, machine operators or sewing machine operators, in spite of the fact that the seats may be used just as many hours a day. Another factor increasing the difficulties of improving the ergonomic standard of industrial seating is the enormous variation and complexity of industrial tasks and workplaces, and the lack of methods for systemizing and categorizing the design features of industrial chairs. In particular, little research has been carried out concerning stools and the design features for chairs and sit-stand seats which would be suitable in jobs where the worker would normally stand.

All the factors mentioned emphasize the importance of further studies within the field of ergonomic design for seated workplaces and chairs in industry. Increased knowledge is needed both for the stimulation of more appropriate chair design and for increasing the awareness of choosing optimal chairs for industrial tasks.

LITERATURE REVIEW

The back, neck and shoulders

A brief summary of anatomy

The spine is a subtle and complex structure. It enables movements of the back to take place, and at the same time transfers loads caused by gravity and human activities to the pelvis. The vertebral column consists of 7 cervical, 12 thoracic, and 5 lumbar vertebrae, attached to the sacrum, which is joined to the pelvis at the sacroiliac joints. The spine is S-shaped in the sagittal plane, which is considered to increase its strength and mobility. The size of the vertebrae increase the further down and closer to the pelvis they are situated.

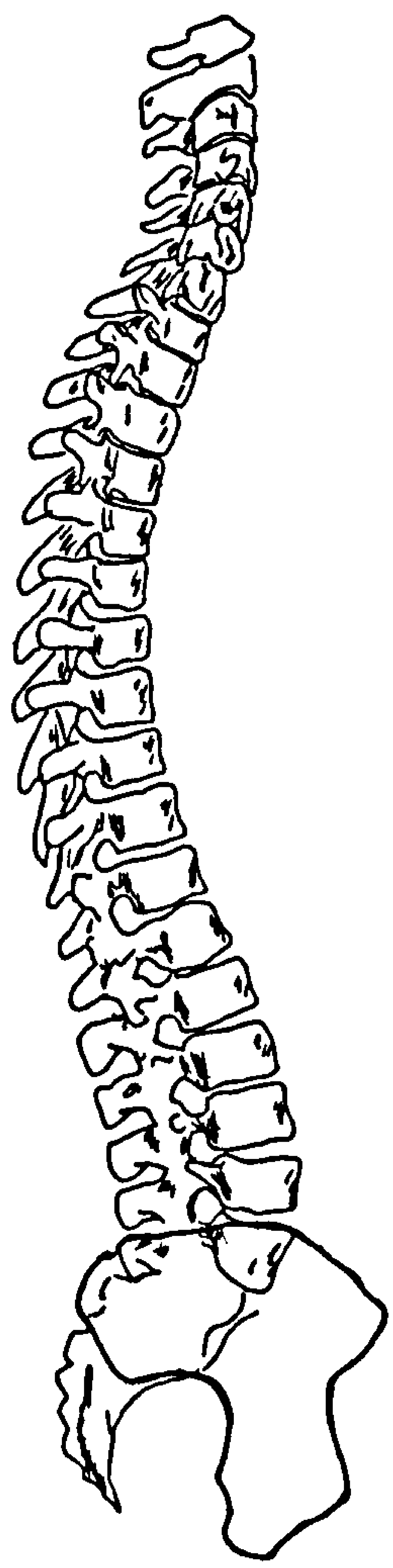


Figure 1. The human spine and the pelvis.

The structure of the vertebra is a shell of cortical bone, which encloses a meshwork of cancellous bone. It consists of a body, cylindrically shaped at the front, the upper and lower surfaces of which are referred to as the end-plates. There are two transverse processes, one spinous process, two vertebral arches and two articular facet joints, all of which form the posterior segment of the vertebra (see Figure 2). The spinal cord is well protected in the vertebral canal, as it is situated between the vertebral arches and the vertebral body. The facet joints limit the motion between the adjacent vertebrae. This is both due to the joint capsule ligaments and the orientation of the facets in the transverse and frontal planes.

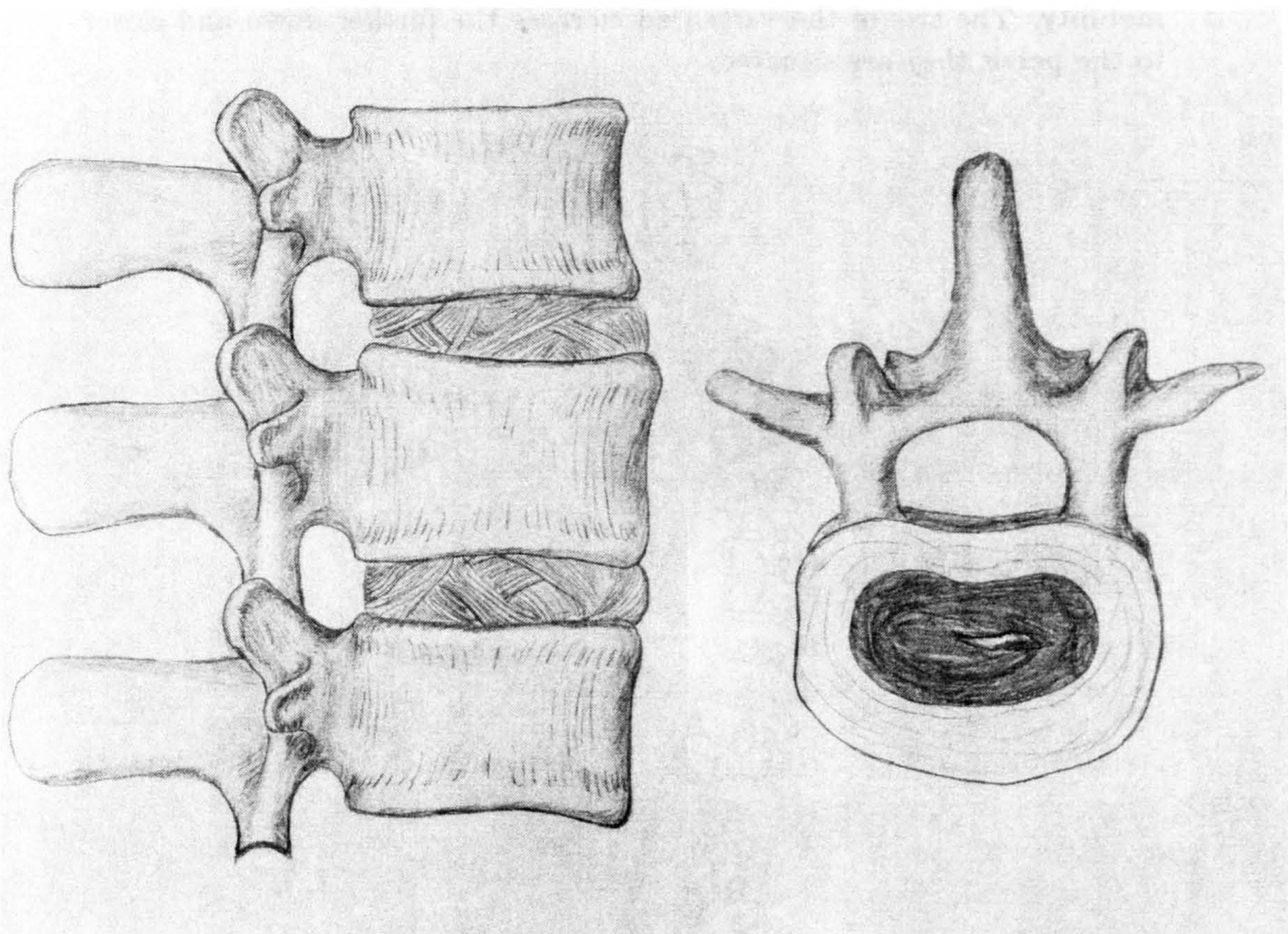


Figure 2. Intervertebral joints, including three vertebrae and two intermediate discs.

An intervertebral disc is positioned between each vertebral body. Both the vertebral bodies and the discs are wedged in the lumbar and cervical regions of the spine. There is a considerable individual variation in this respect, and thus also in the curvatures of the spine. The disc consists of the nucleus pulposus in the centre and the annulus fibrosus surrounding it. It is attached to the vertebral end-plates. It can alter its shape in response to various loadings, and can transmit high compressive loads because of its hydrostatic properties. The annulus fibrosus is composed of concentric layers of collagen fibres, attached diagonally in both directions, which encapsulate the disc. As a result of the structure of the discs, they have properties which make them flexible at the same time as they can withstand high compressive loads. However, the discs degenerate with age, which gradually causes a decreased ability to resist loads.

Vertical loads are primarily transmitted through the vertebral bodies and the discs, but can partly also be transmitted through the facet joints. The more the spine is extended, the greater part of the vertical load is transmitted via the facet joints. Other postures and external loads create different patterns of distribution of the load on the facet joints (Adams and Hutton 1980).

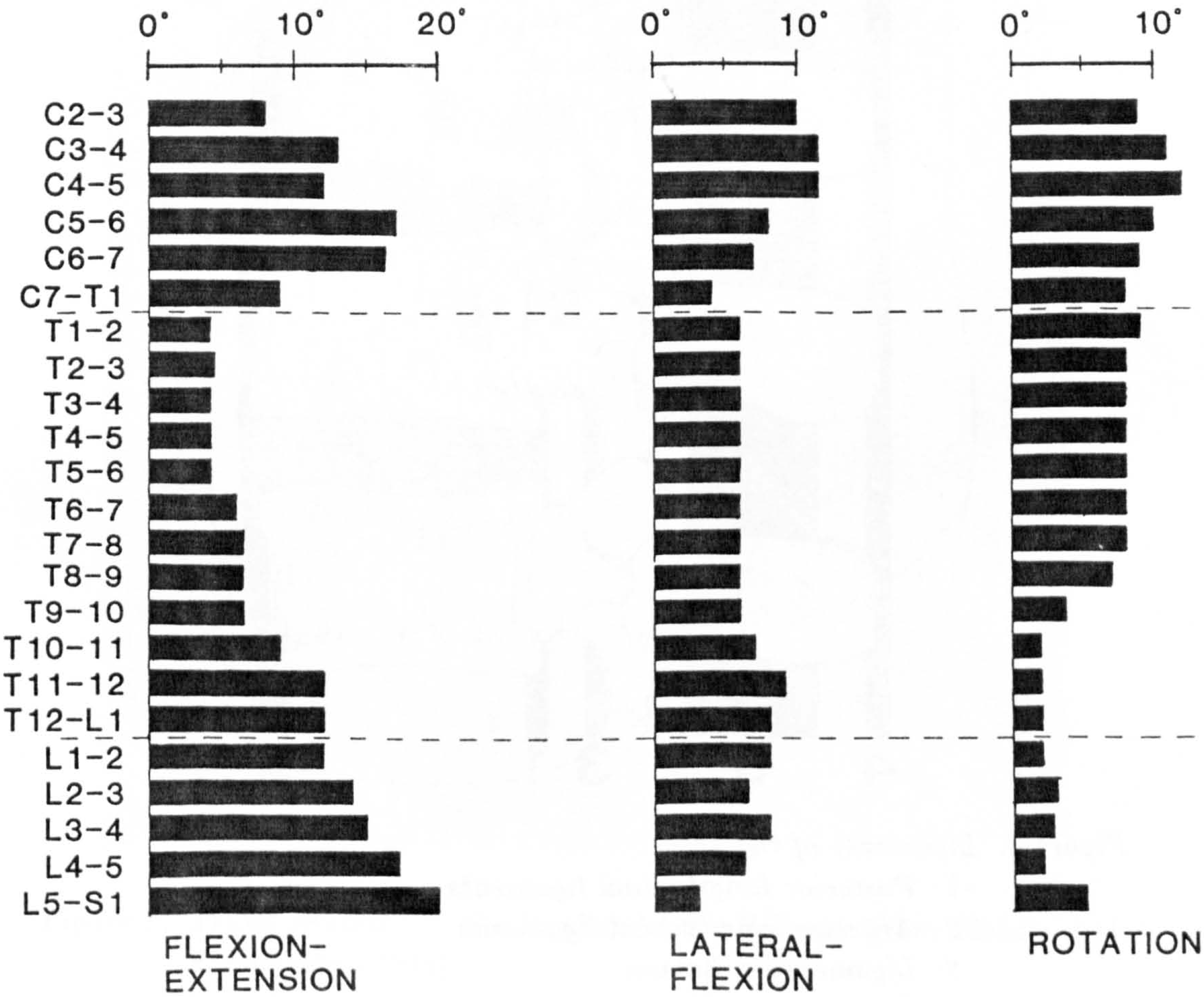


Figure 3. The ranges of motion at different levels of the spine. Redrawn from White and Panjabi (1978).

Ligaments stabilize and increase the resistance to stress of the vertebral column. The ligaments are mainly composed of collagen fibres, and therefore form a passive structure which can resist high traction forces. They are arranged to permit movements between the vertebrae within a certain range, but they restrict larger movements.

Three systems of ligaments of the spine can be separated. They are the long longitudinal system, (the anterior and posterior longitudinal ligaments and the supraspinous ligaments), the segmental longitudinal system, (the interspinous and intertransverse ligaments and the ligamentum flavum) and the capsular system. Important ligaments in the restriction of flexion are the supraspinous and interspinous ligaments and the capsular ligaments of the facet joints (Adams et al 1980).

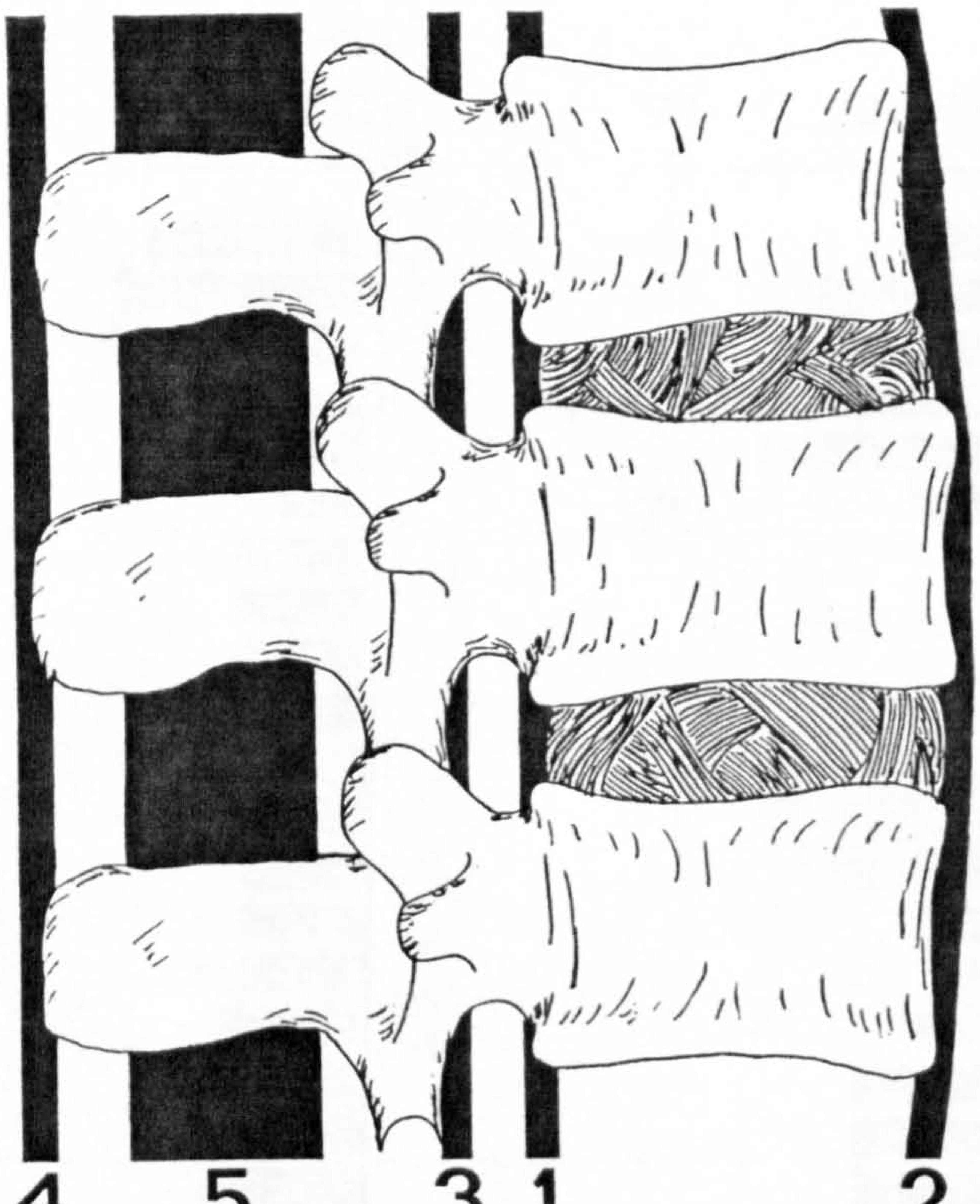


Figure 4. Ligaments of the spine.
-1- Posterior longitudinal ligaments
-2- Anterior longitudinal ligaments
-3- Ligamentum flavum
-4- Supraspinous ligaments
-5- Interspinous ligaments

Two nerve roots leave the spinal cord from each vertebral level. They pass the intervertebral foramina, between the vertebral arches, the disc and the articular facets. The spine itself has also a nerve supply. No nerve endings however occur in the intervertebral discs. The ligaments around the spine and the facet joints have a rich nerve supply, as also have the blood vessles.

There is blood supply for the structures around the spine and in the bone marrow of the vertebrae. The intervertebral discs however have no blood supply, at least not in adults.

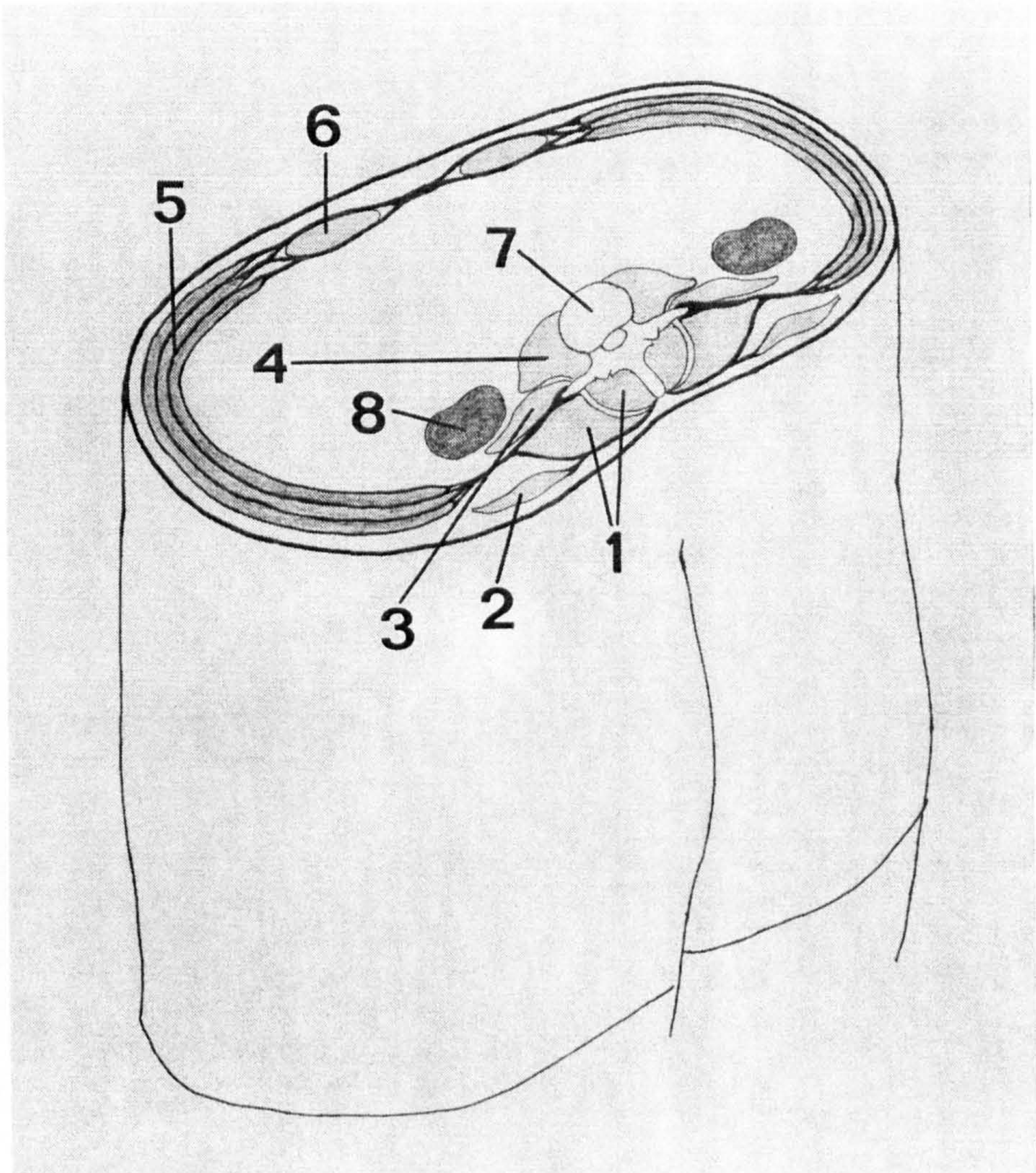


Figure 5. Trunk muscles at the lumbar level. Redrawn from Rohen and Sandström (1979).

- -1- *Erector spinae*
- -2- *Latissimus dorsi*
- -3- *Quadratus lumborum*
- -4- *Psoas*
- -5- *Obliquus abdominis and transversus abdominis*
- -6- *Rectus abdominis*
- -7- *Vertebra*
- -8- *Kidney*

Active muscle control is needed in order to maintain stability and to produce movements of the spine. Controlled muscle activity is also essential in the protection of the spine from sudden forces. The interspinales are deep muscles, running between the vertebrae. The erector spinae in the thoracic and lumbar spines, the iliocosto cervicalis in the cervical spine, together with the longissimus and the spinalis muscles, are the most important muscles for extension. The abdominal muscles are active when initiating flexion. The rotatores, the internal and external oblique muscles produce rotation of the trunk.

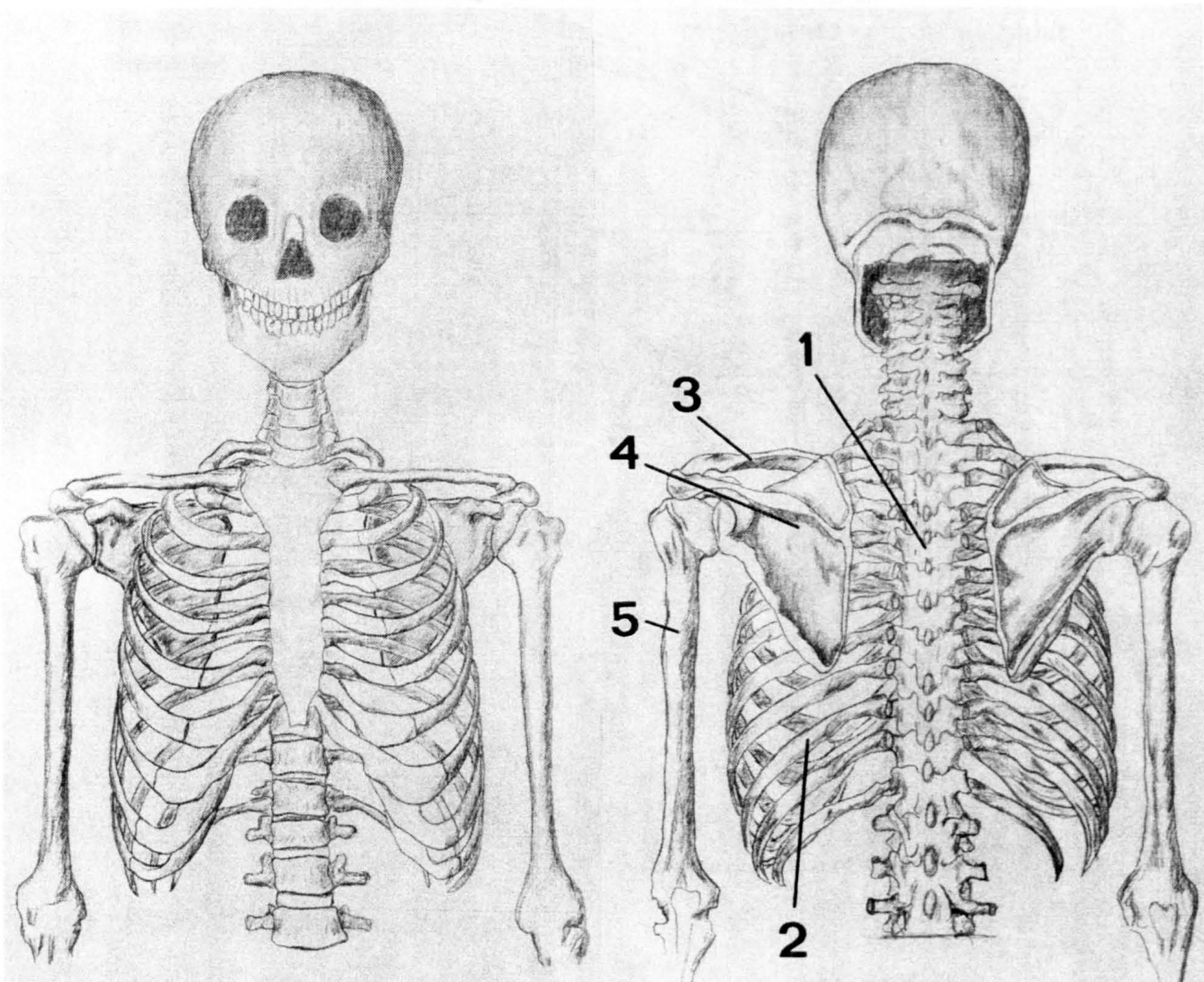


Figure 6. The skeleton of the upper body.

-1- Spine	*-3- Clavicle*	*-5- Humerus*
-2- Ribcage	*-4- Scapula*	

The sternocleido mastoid muscles are the most important muscles for flexion of the neck. The iliocosto cervicalis together with trapezius are the most important for extension of the neck.

The shoulder girdle consists of bones, ligaments and muscles, by which the upper arms are attached. The head of the humerus and glenoid fossa of the scapula form the gleno-humeral joint. Around it, ligaments form the joint capsule. The scapula articulates with the clavicle. It has no other joints and is therefore kept in place by muscles and ligaments. The clavicle articulates with the sternum at the other end. The ribcage consists of twelve pairs of ribs, ten of which are attached to the sternum. All twelve pairs of ribs articulate with the thoracic vertebrae. This structure causes an increased stabilization of the thoracic spine.

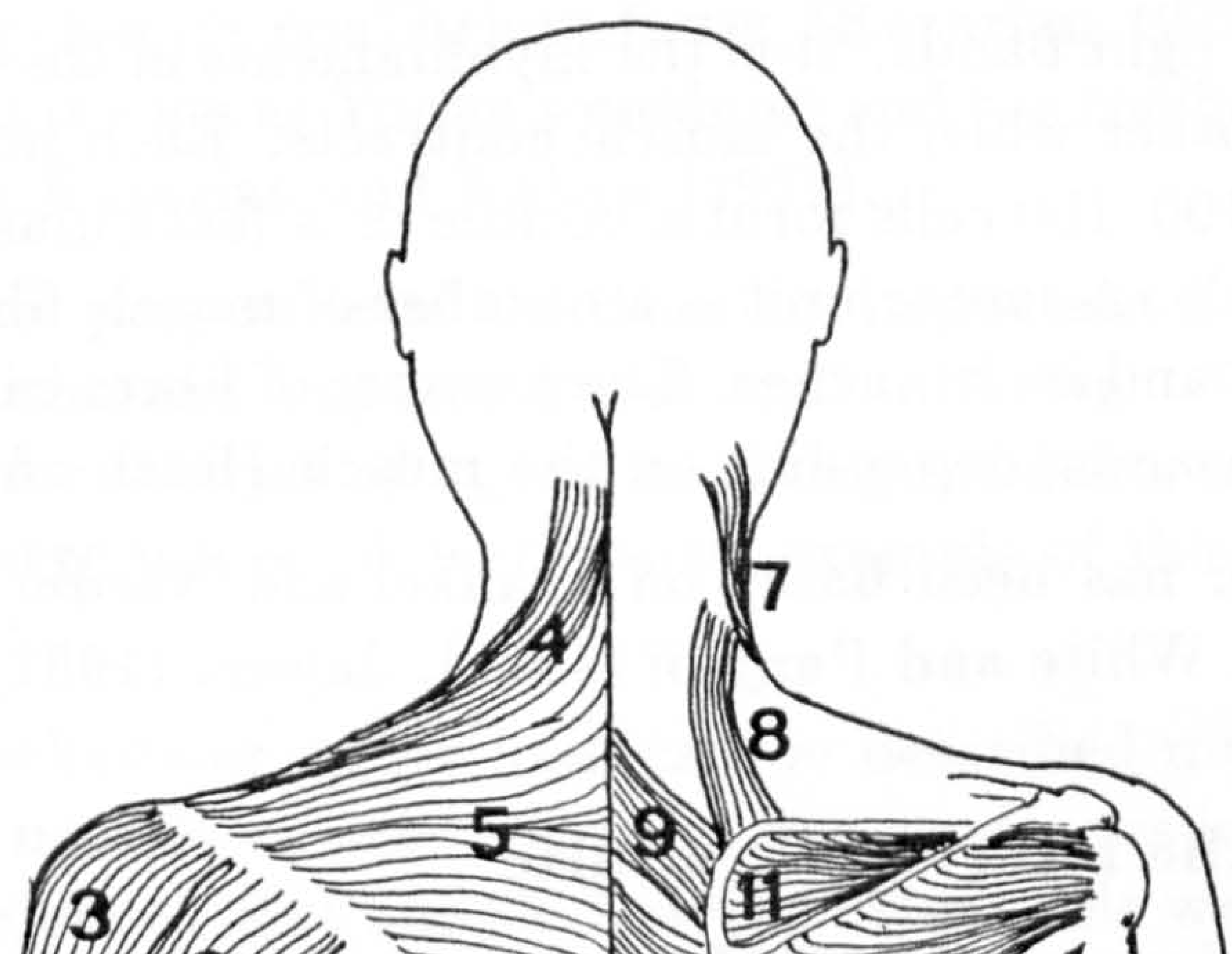


Figure 7. Muscles of the neck and upper back.

-1-	*Latissimus dorsi*	-8-	*Levator scapulae*
-2-	*Deltoideus pars posterior*	-9-	*Rhomboideus minor*
-3-	*Deltoideus pars media*	-10-	*Rhomboideus major*
-4-	*Trapezius pars descendens*	-11-	*Supraspinatus*
-5-	*Trapezius pars media*	-12-	*Infraspinatus*
-6-	*Trapezius pars ascendens*	-13-	*Teres minor*
-7-	*Sternocleido mastoideus*	-14-	*Teres major*

The scapula is dependent on muscles for being kept in position. As a result of this, the scapula has a good range of mobility, which adds increased mobility to the upper arm. The most important muscles for the elevation of the scapula are the trapezius, levator scapulae and to some extent also the rhomboid muscles. The rotator cuff consists of the subscapularis, supraspinatus, infraspinatus and the teres minor and major muscles. Their function is to stabilize the gleno-humeral joint and to rotate the humerus. The deltoid muscle acts by lifting the upper arm.

There are three types of muscles in the human body. Smooth muscles, which are involuntarily controlled, form the walls of for example the bronchi, the blood vessels, and the stomach. Cardiac muscle of the heart has structural resemblance to skeletal muscle and a functional resemblance to smooth muscle. Striated muscles consist of thread-like fibres with alternating dark and light bands. It is the myofilaments in these bands, which slide over each other when the muscle contracts. Each muscle fibre is in fact a cell, and 100–150 cells form a bundle or a fasciculus. Several fasciculi form a muscle. A motor unit is a number of muscle fibres, innervated by one nerve cell and its branches. The number of fibres can vary between a few up to thousands, depending on the muscle (Rash and Burke 1978).

This chapter has been based on Frankel and Nordin (1980), Gray's anatomy (1977), White and Panjabi (1978), Jayson (1981), and Hagberg (1982).

Properties of the intervertebral disc

The physical properties of the intervertebral discs and joints have been investigated in several studies (Virgin 1951, Hirsch and Nachemson 1954, Brown et al 1957, Rolander 1966, Galante 1967, Farfan et al 1970, Kazarian 1972, 1975, Kazarian and Graves 1977, Kazarian and Kaleps 1979, Markolf and Morris 1974, Adams et al 1980). The results have been obtained from human specimens, containing at least half of the upper and half of the lower vertebrae plus the disc in between. Measurements of resulting deformations have taken place in test rigs, during administration of various load conditions, such as compressive load, bending moments and torques. The discs exhibit visco-elastic properties. Consequently they react partially elastically, i.e. they deform when a load is applied and immediately return to their original height when the load is removed, which happens for vibration and impulse forces and other loadings for short periods of time (Virgin 1951, Hirsch and Nachemson 1954). The discs display an increase in stiffness with increasing deformation (Hirsch 1955). This relationship is non-linear and the stiffness increases faster than the compression of the disc. There is also an increase in stiffness with increased rate of deformation (rate-dependency) (Farfan et al 1970, Kazarian and Graves 1977). Besides, the discs are also viscous, i.e. creep is seen when the discs are under load for extended periods of time. This means that the discs continue to compress during that period. The rate of this reduction of disc height decreases over time until a state of equlibrium is reached, i.e. the height decrease stops. After unloading, the opposite takes place, i.e. an expansion which is quicker in the beginning but lessens with time. Correspondingly, load relaxation takes place, meaning that if a disc is compressed to a certain height, the load will decrease over time (Markolf and Morris 1974). A higher load will result in a higher rate of creep. Also this relation is non-linear (Markolf and Morris 1974). The discs also display hysteresis. The creep characteristics also depend on other factors such as the age of the subject, the vertebral level, the state of degeneration of the disc and the temporal pattern of preloads or vibratory loads (Kazarian 1972). A degenerated disc becomes thinner, loses its elasticity and tends to creep faster in the beginning after a load has been applied, but reaches its equlibrium faster (Kazarian 1975). Examples of material constants such as Young's modulus and the coefficient of viscosity can be found in Kazarian and Kaleps (1979).

The physical properties of the discs are important for their ability to dampen and withstand impulse forces and vibration. These factors are also significant for the risk of injury involving accidents in which the back is exposed to large forces. A well known example of this is ejection from military aircraft.

The disc behaviour under load can be described mathematically by using different models to describe the visco-elastic response. Burns and Kaleps (1980) showed that simple Kelvin unit models were suitable. One Kelvin unit consists of an elastic element (spring) attached in parallel with a viscoid element (dashpot). Many Kelvin units can be connected together in series or in parallel and thus model different characteristics. It is uncertain how many relaxation periods are involved in the response of the disc (Burns and Kaleps 1980, Kazarian and Kaleps 1979). The following simple one-Kelvin unit model can, for example, describe the disc height as a function of time through the equation:

$$H(t) = A + Be^{-Kt} \tag{1}$$

where $H(t)$ is disc height as a function of time and A, B and K are constants.

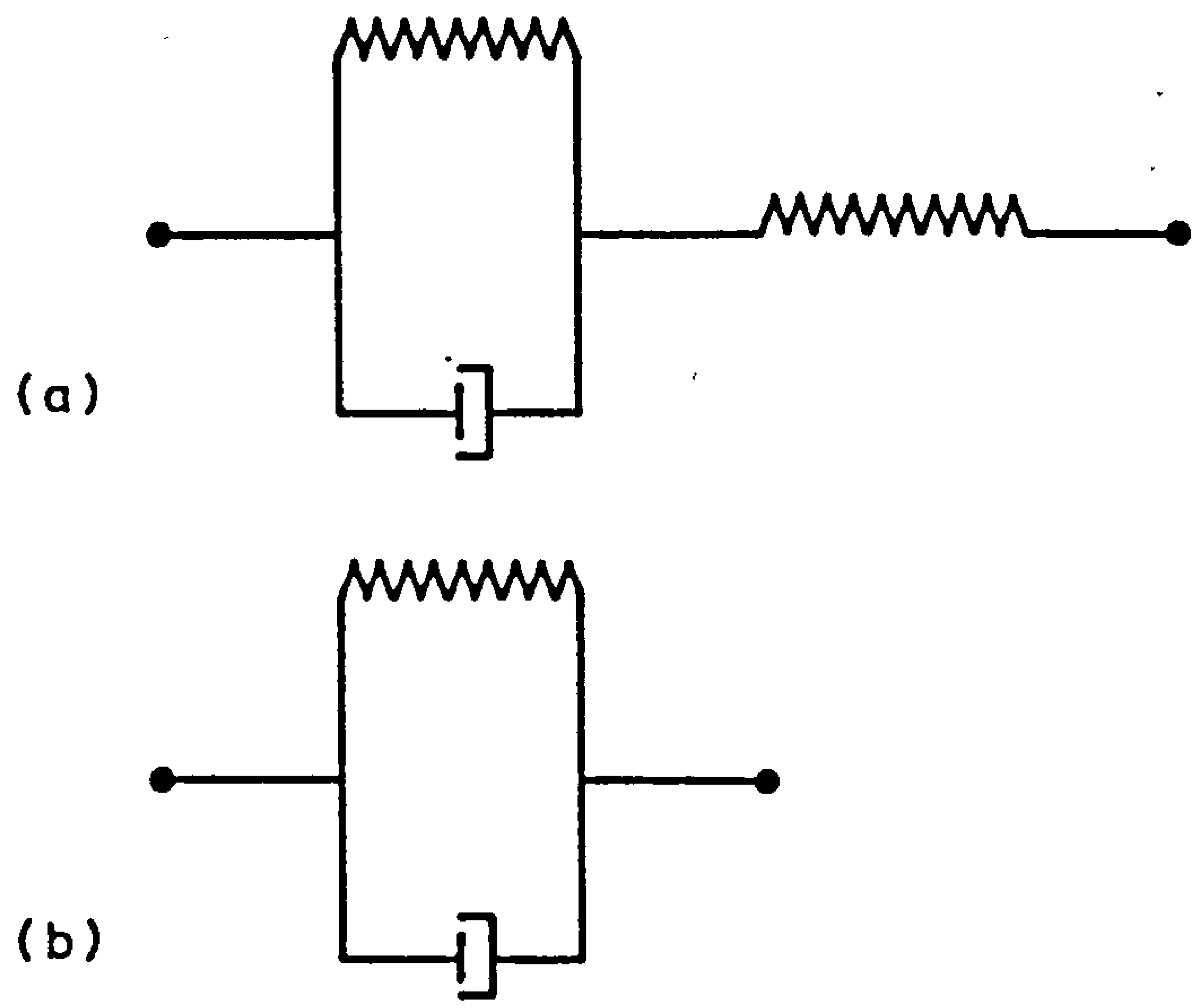


Figure 8. A three parameter Kelvin solid model (a) and a Kelvin unit (b).

Great interest has been directed towards disc degeneration and its causes. Nachemson (1970) has proposed that the discs supply of nutriments is critical, changes in which could lead to degeneration. The disc consists of a network of collagen fibres in a gel of proteoglycans and water. A young disc can bind approximately 90% water, but with an increase in age, this value decreases to about 65% (Krämer 1973, Holm 1980). The structure also becomes more fibrotic and fragmental, and the end-plates increase their amount of calcium salts, thereby becoming more brittle (Kazarian and Kaleps 1979).

There are two mechanisms for the nutritional supply of the disc. One is diffusion, which means that nutrients diffuse in to the disc from its periphery or through the end-plates. The speed of diffusion depends on the osmotic pressure. Also the molecular size and charge are of great importance for the diffusion and the resulting concentrations (Holm 1980). The other mechanism, the pump mechanism, means that increased load on the disc results in an outflow of fluid and thereby a decrease in disc height (Virgin 1951, Armstrong 1958, Krämer 1973). The opposite occurs when the load is released, i.e. an influx of fluid to the disc and an increase in disc height. Kraemer et al (1985) showed that a disc after a long period of loading and water loss gets a higher concentration of electrolytes. This increases its osmotic absorption force and also aids holding back the remaining water. After the disc is unloaded, water is absorbed and the disc regains its height. The same phenomenon has been shown after injection of saline in the disc, when disc height increases of up to 2.5 mm occurred

(Markolf and Morris 1974). Height increase of a disc specimen after an injection, and subsequent creep due to a 300 N load was demonstrated by Brinckmann and Horst (1986) (see Figure 9). Examples of activities which load the discs are standing or sitting. Unloading can correspond to lying in bed (Fitzgerald 1972, Krämer and Gritz 1980). On the basis of these results, Grandjean (1981) argued that alternating loadings and unloadings of the spine due to movements or dynamic work are ergonomically beneficient, because they will pump fluid in and out of the discs and thereby improve the nutritional supply.

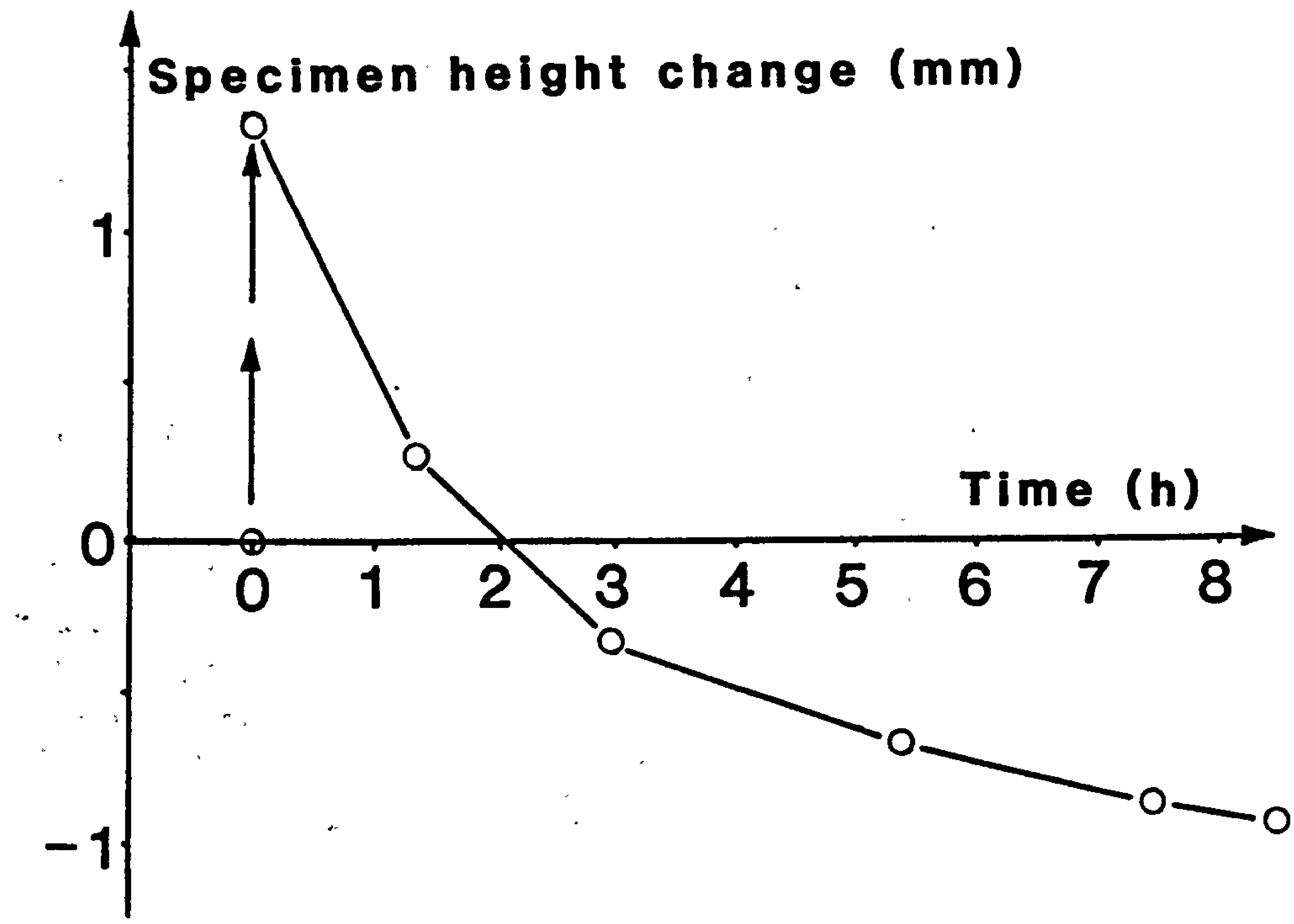


Figure 9. Height change of a disc specimen after an intradiscal injection of chymopapain at $t = 0$ hours. The specimen was thereafter held under 300 N static load. Redrawn from Brinckmann and Horst (1986).

The mechanisms causing creep are not fully known. Fluid exchange according to the pump mechanism and structural deformation are the most likely explanations. Koeller et al (1984) considered that a load on the disc increases the disc pressure, which causes increased tensile stress and bulging of the annular fibrosus. Since the annular fibres are visco-elastic, they will also extend due to creep, i.e. disc height creep is to a large extent due to creep of the annular fibres according to Koeller et al.

The disc height is an interesting factor to consider in the discussion of possible causes of back pain. A decreased disc height reflects increased disc bulging, decreased room for the nerve roots, increased load on the apophysial joints (Adams and Hutton 1980), increased stiffness of the disc and also an effect on the nutritional supply. There is little knowledge of how disc creep affects the stability of spinal segments. However, Koeller et al (1984) were of the opinion that increased creep of the disc decreases the stability of the joint. There are reports that the stiffness of motion segments can be decreased in certain directions and increased in other directions as a result of preloads (Panjabi et al 1977).

Body height changes

The body height of people changes throughout the day. Forssberg (1899) mentioned that it is well known that the body height decreases over the day and regains during the night. This has also been shown by Beneke (1897) and Backman (1924). From his material of over 1200 people, De Puky (1935) found that people were, on the average, 1% shorter by the evening then in the morning. Corresponding figures were 2% for children and 0.5% for 70–80 year-old people. Forssberg (1899) considered that the majority of the body height loss originated from the spine. He showed this by measuring body height in both the sitting and the standing position, finding that the decrease in body height was approximately the same. De Puky (1935), Forssberg (1899) and Markolf and Morris (1974) attributed the body height decrease to a decrease in disc height.

Forssberg (1899) also showed that cavalrymen who rode forcefully during one day, decreased their body height more than when they rode casually and did not expose themselves to any heavy activity during another day. By applying loads on the shoulders, Fitzgerald (1972) showed that the greater the load, the greater was the decrease in body height. He considered this decrease in body height to be dependent upon creep and fluid leakage from the discs, which was also confirmed by Gritz (1975) and Krãmer and Gritz (1980). The body height increased when the load on the spine was partially removed by letting the participants of the experiments lie down. This effect was also recognized for astronauts in space flights, who spent days or weeks in weightlessness. By the return to the earth, they could have experienced an increase in height up to 5 cm (Jayson 1981). Spinal traction was also shown to lead to increased disc height and increased body height (Worden and Humphrey 1964).

Pain mechanisms

There is a substantial amount of research about the physiology of pain. It has been shown that there exist special pain receptors (nerve endings), which respond to an external stimuli, for example skin pressure or heat, and give rise to pain sensations. Psychophysiological experiments have shown that for some stimuli, there can be a very good agreement between the subjects estimation of the intensity of the sensation and the objectively determined intensity of the response in the sensory neurons

(Dudel 1978). However, pain is difficult to define or assess objectively. It refers to the individual's subjective sensation or emotion. The amount of pain experienced is influenced by culture, expectations, motivation and such individual factors as age, sex, personality and social background (Weisenberg 1977). Further, factors such as memory of pain, attention, distraction and anxiety all influence the pain experienced.

Pain from the back, neck or shoulders is particularly complex, and should rather be referred to as symptoms than diseases. A variety of structures and diseases can give rise to back, neck or shoulder pain, ranging from infections or tumors to nerve root pressure or muscle spasm. Several causes can give rise to similar symptoms, and conversely, one cause can produce several different symptoms (White and Panjabi 1978).

In their classical article, Melzack and Wall (1965) presented the "Gate theory" of pain. The essence of the theory is that there exist gates in the path-way of nerves, which can open or close the transmission of impulses sending pain. Other nerve signals from the periphery of the brain can close the gate, and thereby give pain relief.

A flow of impulses from nerve receptors, caused by the normal pattern of movements of the body and by pressure and touch of the skin, probably works as a pain inhibitor in the daily activities. If there is a lack of impulses or stimulation, as for example at immobility or possibly also if there is a continuously repeated pattern of impulses, the gates would consequently open and increase the pain (Andersson et al 1984).

Recently, a group of substances named endorphins was discovered. These are naturally produced in the body and are very forceful pain inhibitors, even more forceful than morphine. The endorphins have an inhibitory effect on the transmission of pain impulses between nerves. Increased production of endorphins are considered to take place during physical exercises, especially at high intensity levels (Terenius 1983, Harber and Sutton 1984).

An afferent flux of nerve signals will also activate this pain modulating system. Recent studies have shown that low frequency (1–2 Hz) electrical stimulation by using skin electrodes releases endorphins while high frequency (50–100 Hz) stimulation does not (Andersson et al 1984, Han and Terenius 1982). It is therefore possible that muscle contractions, which already are of low frequency, can decrease the pain sensitivity. If so, a work situation with very low demands on muscle activity and movements would have a tendency to increase feelings of pain. In any case, sitting work precludes the possibilities of getting endorphin production due to hard physical work activities.

In most cases, the particular reasons for spinal pain are not known. For a majority of people, the symptoms disappear by themselves within a few weeks or months. In spite of that, a considerable number of people become severely disabled due to back pain (Horal 1969). There is agreement that mechanical factors play an important role in the etiology of spinal pain. Striking similarities occur between low back pain and neck pain. Both the cervical and the lumbar spine are lordotic and relatively mobile; the age of onset of the pain is 30–50 years; the frequency with which they affect the population is relatively high and the patterns of factors influencing the pain are similar. Lowest incidence of back pain occur from the thoracic spine (Hult 1954 b, White and Panjabi 1978).

In spite of the fact that most causes of spinal pain are unknown, several mechanisms have been proposed. The major theories are the sciatic nerve theory, the sacroilliac joint theory, the psychoneurosis theory, the muscle spasm theory, the disc theory and the facet joint theory. Since structures such as the annular fibres, the ligaments, the facet joint capsules and the muscles have nerve endings, direct pain can be a result of physical, chemical or inflammatory irritation of any of these structures. Any of the mentioned types of irritation on the nerve roots can induce nerve root pain (White and Panjabi 1978). Pressure on a nerve root can for example be caused by a bulging or herniated disc. Such a protrusion of a disc most often occurs in the posterior-lateral side, which is close to the nerve roots. The pain is then associated with the body segment innervated by that nerve. The sciatic nerve is one such example, where the pain can radiate to the leg. Consequently, the location and manifestation of nerve root pain can be used to locate the segment level of the spine where the damage occured.

Further, facet joints have shown signs of arthritis secondary to disc degeneration (Nachemson 1976). Micro-fractures in the cartilage endplates of the lumbar vertebrae have also been mentioned as a possible cause of disc degeneration due to changes of the fluid transport to the disc (Chaffin and Park 1973). Increased load on the facet joints is also in some cases considered to cause inflammation and back pain (Calliet 1975).

Frymoyer and Pope (1978) reviewed the role of trauma in low back pain. They summarized some possible causes of back pain due to trauma, including that trauma can cause increased degeneration. Torsion can cause disc herniation and facet micro-fractures, compression can cause endplate micro-fractures and repeated flexion/extension and shear stresses can cause spondylolisthesis (a forward displacement of one vertebra over another).

Finally, referred pain or indirect pain is another mechanism which has not been fully explained yet. It is believed that referred pain is produced by irritation of the pain receptor system. This irritation or pressure is perceived to come from another part of the body than it originated from, or in other words the pain is referred to that body part (White and Panjabi 1978).

The most common symptoms of low back pain can be classified according to Table 1.

Table 1. Classification of low back pain. After Nachemson and Andersson (1975), cited in Bergquist-Ullman (1977).

LOW BACK PAIN
Acute: 0–2 months' duration **Chronic:** More than 2 months' duration **Recurring:** Symptoms recurring after an interval of no symptoms

SYMPTOM DIAGNOSIS
Insufficientia dorsi Tiredness and light ache or pain provoked by repeated or forceful movements or by some other mechanical stress. The troubles are localized to the lumbar region. The back feels stiff or weak and the patient tries to avoid certain types of stress which he knows will give this feeling of unease. **Lumbago** Ache and pain localized to the lumbar region with an eventual radiation over the gluteal region, the hips or the lower part of the abdomen. This syndrome is aggravated in the acute stages by all movements and loads, in the more chronic stages only by certain movements and loads on the lumbar spine. The syndrome can set in suddenly or the onset may be over a shorter time period. **Sciatica** Ache and radiating pain in one or both lower extremities. This is aggravated in the acute stages by all movements and loads to the lumbar spine, in the more chronically ill only by certain movements and loads. The symptoms can be either acute or set in over a shorter time period. The clinical picture includes numbness, paresthesia and a feeling of weakness in one or both lower extremities. **Rhizopathy** This is a special form of lumbago-sciatica or sciatica characterized by the fact that the radiation of the symptoms in the leg is according to the segmental innervation. Most often the patient has neurologic signs according to the affected segment. **Lumbago sciatica** Symptoms as in both lumbago and sciatica. One of these can dominate the picture.

Diseases of the muscles and tendons are for example tendinitis, rupture, inflammation, spasm, and myalgia. Among the work-related shoulder diseases, rotator cuff tendinitis and rotator cuff ruptures are well known (Hagberg 1982). Occupational Cervicobrachial Disorder (OCD) is common among assembly line operators and other workers in repetitive tasks, but the symptoms are diffuse and the origin is little known. The most common hypotheses are repeated micro-trauma of the muscle due to repetitive movements, or local ischemia of the muscle due to a static work load during long time periods, or a metabolic disturbance in the muscle (Kvarnström 1983).

Back, neck and shoulder pain in industrial tasks, and their relation to loadings

The knowledge concerning causal relationships between environmental factors and back, neck or shoulder pain is very limited. A number of epidemiological studies have investigated the relationship between work factors and pain. Most of these studies have been cross-sectional, and few have been carried out as longitudinal cohort or case-control studies. Very often the measures of exposure have been crude classifications, which means that it has seldom been possible to use the results as a direct base for preventive measures. Exposure measures which have been used are for example branch of industry, occupational group, or classifications of work characteristics such as "heavy physical work" (defined as sweating, high energy demand, certain occupations or branches), "heavy lifting", "bending", "twisting", "forceful movements", "static postures", "repetitive work", and "vibration exposure". In industrial jobs, several of these categories are often present at the same time and are also related to one another. Thus, it is very difficult to draw conclusions from epidemiological studies, because the measures of exposure have been so unspecific. It is also of great importance that the definition of the disease is specific in order not to "dilute" the results, which is something that can be questioned in many studies, especially in questionnaire studies.

In several epidemiological studies, relationships between exposure and musculoskeletal pain or disease have been observed. As a result of these, it is recognized that mechanical factors such as frequency, duration, peak level and distribution of loads as well as the posture itself are fundamental to the incidence of pain and disease (Andersson 1981, Wickström 1978, Hernberg 1984, Troup 1984, Chaffin and Park 1973, Hagberg 1982).

Increased rates of back pain or degenerative back diseases have been observed for several occupational groups in industry, for example miners, foundry workers, metal industry workers, vehicle drivers, electronics industry workers and cotton mill workers (Wickström 1978). Pain or disease from the neck or shoulders has been observed among drivers of heavy work machines, welders, meat cutters, telephone operators, punch card operators, office workers, VDU-workers and electronics industry workers (Hagberg 1982). From the view point of prevention, the studies of specific work factors and their relation to increased risk are more interesting than just studies of risks in certain occupations.

Injury

It is considered that the occurrence of a sudden stress may damage the joint cartilage and thereby cause osteoarthrosis. It is also well recognized that peak forces on muscles and tendons can cause ruptures, which are more likely to occur if the structure already has a decreased strength due to factors such as inflammation or ischemia (Hagberg 1982). In many back pain patients, the pain occurred after a sudden twist or an unexpected extra stain in connection with heavy lifting, even though actions of that type are common and only occasionally result in symptoms (Hult 1954 b). This has been confirmed by other investigators, who found that back pain often originated suddenly after a pronounced strain, as after a fall, after slipping or because of some other unexpected incident, often in combination with bending, lifting and twisting (Hirsch 1955, Magora 1973, Bergquist-Ullman 1977). Lawrence (1955) claimed that trauma is an important factor for disc degeneration. Magora (1973) also held the opinion that unexpected maximal efforts are particularly harmful. This view has been somewhat modified by Troup (1965) and Chaffin and Park (1973), all being of the opinion that only a small proportion of low back disorders can be attributed to accidents, and that low back pain is not simply caused by the event which occurred when it first appeared.

Static work postures

It is a general ergonomic rule that static work postures involving contorted or constricted postures, static muscle load and long term joint load, especially in the extreme range of motion, can cause discomfort and disease in the structures involved. It is therefore important that possibilities are provided for changing posture and relieving the structures from prolonged load (van Wely 1970). In industrial jobs where people work stooping for a long time, increased rates of back pain and degenerative changes have been found. Examples of occupational groups involved are floor moulders, cotton mill workers, turners, and mine workers working at low seam heights. (Partridge et al 1968, Mehnert 1969, Lawrence 1955, Zuidema 1973 cited in Wickström 1978). Stooping postures also aggravate the pain among many back pain suffers (Biering-Sørensen 1983 a). Static work postures are considered common sources of neck and shoulder pain and muscle fatigue (Chaffin 1973). This has been demonstrated in industry amongst welders whose jobs involve raised arms (Herberts et al 1981), and in jobs requiring statical sustaining of the arms (Maeda 1975) or of the neck (Partridge and Duthie 1968).

Sitting postures are also static in many respects, and have in several cases been shown to be related to increased risk of pain from the back, neck and shoulders. This is described in more detail later in this literature review.

Bending and twisting

It is difficult to separate exposure to bending and twisting from exposure to lifing, since lifting often involves those movements. Magora (1973) found a relation between low back pain and excessive bending. Chaffin (1973) showed that bending the head forward more than 15° caused discomfort and muscle fatigue. The combination of bending and twisting was found by Troup et al (1970) to be the most frequent factor for the occurrence of back injuries. Buckle et al (1980) also found bending and twisting to be a frequent factor for the occurrence of back pain, often in combination with slipping. Twisting of the neck in drivers of heavy work vehicles is also believed to be the reason for the increased rates of neck pain in this occupational group (Tamminen et al 1981).

Lifting

Heavy and frequent lifting seems to be one of the strongest causes of back pain and degenerative back disease. However, a moderate amount of lifting is not considered to cause back pain symptoms or diseases (Hult 1954 b, Kelsey 1975, Chaffin and Park 1973, Magora 1972). Often lifting is performed in a twisted and sideways bent posture, which has been found to be an especially risky lifting situation (Magora 1972, Troup et al 1970). Magora (1972) and Calliet (1975) came to the conclusion that workers in jobs where the force could not be judged or where the loads were higher than expected, were at greater risk.

Chaffin and Park (1973) showed that the higher the lifting strength required to perform the job, the higher the incidence of back pain became, a finding also indicated by Snook (1978). The adverse effects due to lifting depend on several factors such as the weight, shape and position of the load, the posture, repetitiveness, speed and period of lifting (Chaffin 1975). Stubbs (1981) found indications of an increased rate of back pain in jobs regularly demanding intra-abdominal pressure (IAP) peaks of more than 13.3 KPa (100 mm Hg). In the lifting strength recommendations published by Davis and Stubbs (1980), they considered a maximal "safe" load to be when IAP was below 12 KPa (90 mm Hg), which corresponds to lifting a maximum of 50 kg in an optimal posture and during otherwise good lifting conditions. Lower limits were recommended for older people, women and repetitive tasks.

Examples of occupations in which heavy lifting is present and where increased risk of back pain has been shown are mining, dock work, building work, and work in food industry (Hult 1954 b, Partridge and Duthie 1968, Lawrence 1955, Wickström 1978).

Carrying, pulling and pushing

Carrying is related to lifting in the sense that it does in principle necessitate a lift, but the opposite does not have to occur. Heavy work was defined by Becker (1961) as lifting or carrying objects weighing 16 to 45 kg for more than 30% of the work time or an equal exertion of pushing and pulling. According to Davis and Stubbs (1980) a maximum force of 294 N (30 kp) was recommended for two handed pushing and 490 N (50 kp) for two handed pulling. The recommendations given were lower for less optimal postures, larger distances of the load from the body, older people, women, and repetitive tasks. Further, Damkot et al (1984) showed an increased rate of back pain for workers involved in pushing activities. Also, Frymoyer et al (1980) found, in a retrospective study, a significantly increased rate of back pain in jobs involving each of the activities carrying, pulling and pushing. An increased rate of back pain was also found among mail-carriers compared to office clerks (Niemi and Voutilainen 1957).

Heavy physical work

It has been shown in many studies that back pain is more common and severe among people with heavy physical work than among people with light work (Hult 1954 a, Hult 1954 b, Anderson and Duthie 1963, Troup 1965, Rowe 1969, Magora 1970, Helander 1973, Chaffin and Park 1973, Bergquist-Ullman 1977, Svensson 1981). Hult (1954 b) showed in a large survey that people employed in physically heavy jobs had a higher prevalence of low back symptoms, compared with people doing other types of work. The difference between the groups were more pronounced when considering only the cases with severe back pain. Magora (1970) and Rowe (1969) both found a higher rate of back pain among workers in heavy industrial tasks compared with sedentary tasks. A more stringent measure of exposure than just heavy physical work was used by Chaffin and Park (1973), when they showed increased risk of getting back pain in high back stress jobs, after having assessed the relation between the strength capabilities of the personnel and the stress required.

The degeneration of the discs is a normal process, due to ageing. This process has been shown by Hult (1954 a), Kellgren and Lawrence (1952), and Lawrence et al (1966) to be accelerated among people with heavy jobs. However, the existence of a relationship between disc degeneration and back pain is not accepted yet, at least not for moderate or light degeneration (Andersson 1981, Wickström 1978).

Forceful movements, such as jumping and even coughing, increase the spinal load. Job activities performed very rapidly and those tasks where the required force cannot be judged, lead to jerky movements and a higher degree of muscular and spinal load. These tasks may contribute to back pain according to Calliet (1975). It has also been shown in Frymoyer's (1980) epidemiological study, that coughing had a modest but significant relation to back pain, which might further emphasize the importance of forceful movements.

No difference was found for the prevalence of neck and shoulder pain between people with heavy work and people with light work (Hult 1954 b). Partridge and Duthie (1968) showed that office employees even had a higher frequency of neck and shoulder pain than dock workers. The use of heavy physical work as a measure of exposure gives a very unspecific measure for describing job characteristics related to posture and loadings of the neck and shoulders. The load on the local structures of interest is a more relevant measure, which also has been used more frequently in recent literature.

All the factors mentioned, injury, stooping, bending, twisting, lifting, carrying, pulling, pushing, and also to a large extent heavy physical work, increase the load on the spine. They also often aggravate the pain for people already suffering from back pain. It is therefore considered that the spinal load should be kept low in order to prevent low back pain (Andersson 1980).

Repetitive work

The occurrence of low back pain increases in jobs demanding more repetitive activity, such as lifting, bending, twisting, carrying, pulling, and pushing (Hult 1954 b, Chaffin 1973, Magora 1972, 1973, Troup et al 1970, Lawrence 1955, Bergquist-Ullman 1977). Also other symptoms seem to be more common among workers in repetitive jobs. A particularly high risk of neck and shoulder pain also seems to be present in repetitive work (Luopajärvi et al 1979, Bjelle et al 1981, Kvarnström 1983). It must be observed that continuous and repetitive arm movements give rise to static muscle load in the shoulder muscles. Repetitive work in seated tasks is dealt with in more detail later in this literature review.

Vibrations

It has been shown in several studies that people exposed to whole body vibrations in their work report an increased rate of back pain. Among these occupational groups, sitting vehicle drivers dominate, for example drivers of cars, trucks, trains, buses, lorries, tractors and forest vehicles (Andersson 1981). This is also reported in more detail later. However there have also been reports concerning seamen and various other non-driving occupations (Frymoyer et al 1980).

Muscular activity

Strong static muscular contractions are impossible to hold for long time periods, both due to the physiological fatigue and the pain which arises. Monod (1956), and later also Rohmert (1960), have shown that a static contraction of 100% of the maximal voluntary contraction force

(MVC) only can be sustained for a few seconds, 50% of MVC can be sustained for approximately one minute, and 20% of MVC can be sustained for approximately 10 minutes. The relation was described by Rohmert, using the following equation:

$$T = -1.5 + \frac{2.1}{\left(\frac{k}{K}\right)} - \frac{0.6}{\left(\frac{k}{K}\right)^2} + \frac{0.1}{\left(\frac{k}{K}\right)^3} \tag{2}$$

where T is maximum holding time in minutes, k is the force developed and K is the maximum voluntary contraction force.

As a result of these investigations, it was considered for a long time that static muscular contractions should not be higher than 15% MVC. Similar experiments were repeated by Björkstén and Jonsson (1977), but for longer time periods. Their results showed that only 8% of MVC could be sustained for 1 hour. Jonsson et al (1981) considered that the static load for work periods over one hour should not exceed 2–5% of MVC. Monod (1972) performed experiments with intermittent static contractions, which showed that a substantial increase of the maximal holding time or of the load could be obtained if rest pauses were allowed for, which was also confirmed by Björkstén and Jonsson (1977).

The importance of physical activity for maintaining the strength of muscles and tendons is well recognized. There are also several other physiological effects which occur due to inactivity, such as reduction in the physical working capacity (Kilbom 1986). It can be concluded that the relationship between physical activity and the risk of adverse effects seems to be U-shaped. Too much and too intensive muscle activity or too little both seem to cause an increased risk of disorders.

Seated work tasks — ergonomic considerations

The sitting work posture is advocated in many situations, because it has several advantages compared with the standing posture. Energy consumption, heart rate, oxygen consumption, muscular activity, hydrostatic blood pressure in the feet and lower legs, and the demands on the cardio-vascular system are lower when sitting (Grandjean 1973, 1982). As a result of this, the posture can be maintained longer and the onset of fatigue can be delayed (Weddell and Darcus 1947). Sitting instead of standing increases the stability and the possibilities of performing tasks demanding high precision, small manipulative movements or visual fixation. Tasks which require the use of foot operated pedals or controls, are advantageous to performe sitting instead of standing (Kroemer 1971).

A standing posture demands static or intermittent muscle activity in the ankle joints, hip joints and along the spine. Sometimes neither the agonist, nor the antagonist has to be active, because of passive locking of the joint due to ligaments. This is particularly the case for the knee joints

(Portnoy and Morin 1956, Floyd and Silver 1955, Aitken 1949). On the other hand, standing has the advantage of enabling people to move more freely, and is therefore advocated in tasks demanding exertion of large forces or walking a few steps, as for example when having to reach over large work areas (Damon et al 1966). It is also possible to have attention over a larger field of vision when standing (Laurig 1969).

Many criteria have been proposed throughout the years as a basis for recommendations of seat design and the ergonomics of sitting. The number and type of these criteria have increased. It is also clear that certain criteria have been frequently referred to during some time periods and less often during other periods.

The spine and the pelvis

In a study from Israel, Magora (1972) compared people in occupational groups who had different amounts of sitting, walking and standing in their jobs. The results showed that people in jobs demanding a long time in a sitting posture, and also people in jobs demanding a long time in a standing posture with few opportunities of sitting, had a higher risk of getting back pain compared to people who could frequently change between sitting, standing and walking activities. This study points to the importance of taking the temporal pattern of loads, activities and postures into account. Wood and McLeich (1974) pointed to the unexpected intervertebral disc morbidity in insurance and banking workers, groups who spend a long time sitting at work. Hult (1954 b) noticed a relatively high rate of back pain among people employed in sedentary jobs. Also Eklundh (1967) indicated that sitting tasks gave a high risk of back pain. In all, very little epidemiological data exist about back pain in non-driving sitting tasks.

People driving vehicles in their jobs have been shown to have an increased rate of back pain in several studies. Kelsey (1975) found that the risk of getting a herniated disc was particularly high among people driving motor vehicles, especially lorries, in their jobs. Increased risk was also connected with car driving to and from work. In addition, people who sat for more than half the time in their jobs had a higher risk of developing herniated discs than people who sat for less than half the time. There was also a possible relation between little physical activitiy in leisure time and disc herniation. Buckle et al (1980) found increased risk of back pain for those driving to work, and the risk was higher for people driving more mileage. Further, high rates of back pain were shown among tractor drivers (Rosegger and Rosegger 1960), forest machine drivers (Jonsson et al 1983), fork lift truck drivers (Siktbehov för gaffeltruckar 1973), and Grand Prix racing drivers (Burton and Sandover 1985). This last study showed increased risk for racing drivers compared to non-racing drivers and also an increased risk when the suspension was stiffer. The vibrations of many vehicles are at frequencies similar to the body's natural frequency. Thus, the transmission through the spine might be amplified and the potential risk of damage increased (Pope et al 1984). It has also been shown that the incidence of back pain can differ significantly between users of chairs of different designs (Fitzgerald and Crotty 1972).

It is not known if the main cause of back pain among vehicle drivers is vibration exposure, exposure to impact forces, the sitting posture, long term sitting or inappropriate chair design (Troup 1978). Many studies however indicate that vibration exposure is of great importance.

Other studies have not been able to confirm sitting as a risk factor for back pain. Those studies have used the total time spent sitting at work per day as a measure of exposure (Frymoyer et al 1980, Svensson 1981). No epidemiological studies have investigated the relation between back pain and more specified measures of the temporal pattern of sitting.

Many articles have focused upon that the spinal shape as crucial, and therefore many criteria of optimal posture have been proposed. Keegan (1953) pointed to the "normal" shape of the spine with a lordosis in the lumbar and cervical regions. His definition of "normal" shape was minimal wedging of the intervertebral discs, especially the fourth and fifth lumbar discs, and minimal strain in the annular ligaments. Others have referred to "uneven pressure distribution" of the anterior and posterior parts of the lumbar discs in flexion (Münchinger 1964, Rizzi 1969). This argument has later been shown to be inaccurate for young lumbar discs, which still have hydrostatic properties, since the pressure distribution in that case is uniform over the whole end-plate. Degenerated discs however, display a non-uniform pressure distribution when the end-plates are inclined (Horst and Brinckmann 1980). The vague terms "well-balanced" spinal curve, "good posture" or "a posture similar to standing" have.also been mentioned frequently. Schoberth (1962) referred to the possibilities of changing the posture around the relaxed upright sitting, which in other words is minimizing the muscular effort and the static muscle load needed for sitting. Adams et al (1980) discussed the moment of an intervertebral joint resulting from the angle of flexion. Minimal moment is consequently another possible criterion of the "normal" or "relaxed" posture of the spine.

The tilt of the pelvis has a substantial influence on the lumbar curvature. The hamstring and gluteal muscles exert passive muscle forces when they are extended, which occurs for small angles between trunk and thighs. As a result of that, the pelvis is tilted backwards and thus creates a lumbar kyphosis. The opposite occurs at large angles between the trunk and thighs (Keegan 1953). In that posture, the psoas and quadriceps muscles and the ilio-femoral ligaments (Schoberth 1962) cause a forward tilt of the pelvis, and thereby an exaggerated lumbar lordosis is created (Keegan 1953).

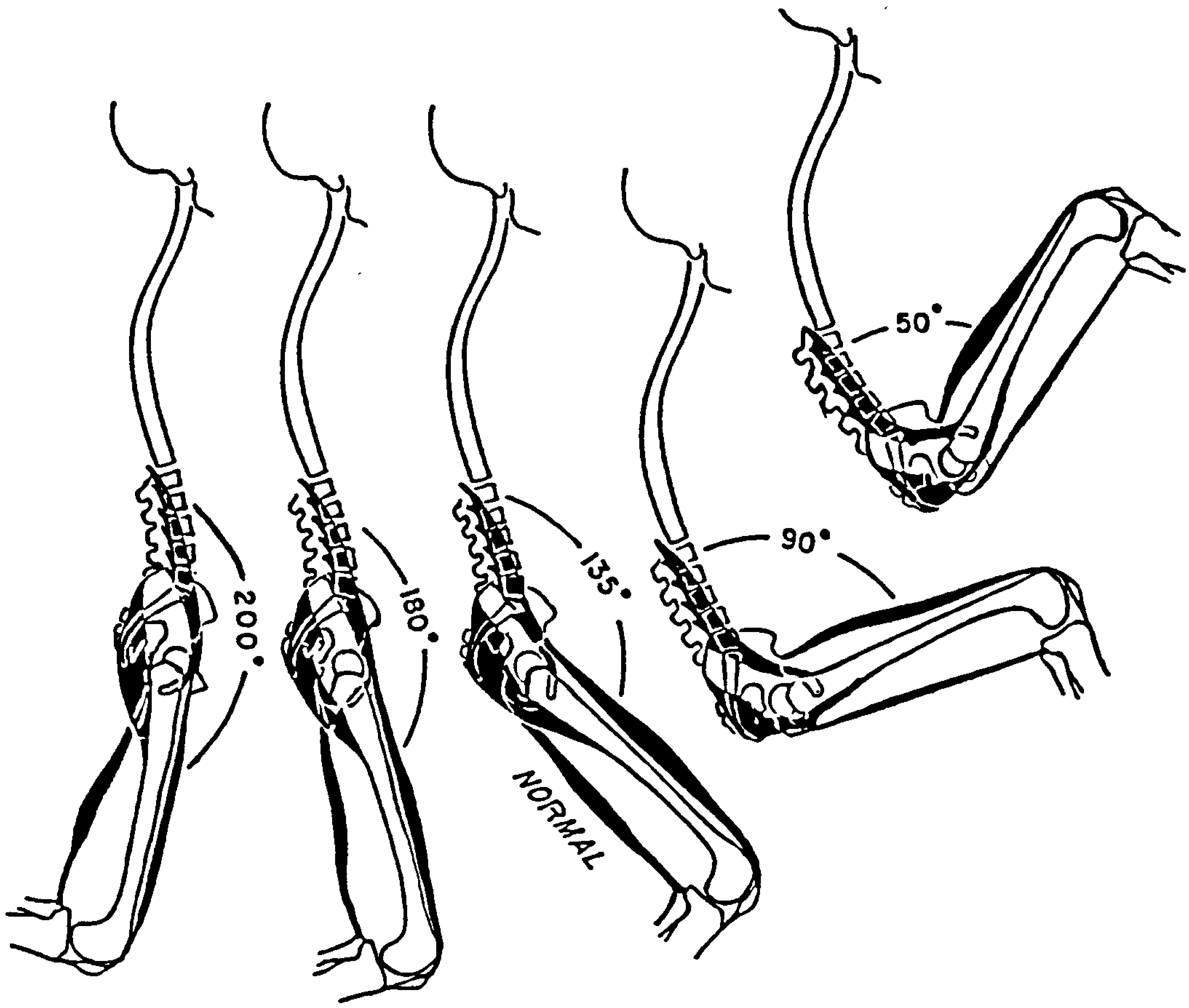


Figure 10. Pelvis tilt as a function of trunk-thigh angle. Reproduced from Keegan (1953).

The knee joint angle will also affect the lumbar shape. Straight knees tilt the pelvis further backwards and thereby act towards lumbar kyphosis, but the influence of the knee angle is of less importance than the angle between the trunk and thighs (Keegan 1953). In unsupported sitting, also the position of the centre of gravity in relation to the ischial tuberosities affects the pelvic tilt. In the anterior sitting posture, when the centre of gravity of the trunk falls in front of the ischial tuberosities, the pelvis tilts forwards. In the posterior sitting posture, the reverse takes place (Schoberth 1962). Also a third posture can be distinguished according to Schoberth, which is the middle sitting posture when the centre of gravity falls through the ischial tuberosities.

In standing, the pelvis is slightly forward tilted (Keegan 1953). He also claimed that the "normal" posture of the lumbar spine and the pelvis occurred when the angle between trunk and thighs was 135° and the knee angle also was 135°. His study was based on x-ray pictures of only four subjects, so the results might be little representative. Santschi et al (1964) studied the human posture under the conditions of weightlessness and relaxed muscles. No external or internal moments acted on the joints, so they assumed a balanced position or a joint angle in the physiological mid point, which can be referred to as a "normal posture". The angle between the trunk and thighs was under these conditions found to be 126°.

In unsupported sitting with 90° angle between trunk and thighs and at the knees, the pelvis has tilted approximately 30° backwards, compared to the standing posture (Andersson et al 1979). Since the pelvis is tilted by passive muscle forces, tight or short hamstring muscles would cause an exaggerated tilt in sitting, especially in postures with extended knees. Stokes and Abery (1980) confirmed this, but they also found a considerable individual variation in hip flexion ability among their subjects. Tight hamstrings were found to be relatively common among a group of non-sporting people with sedentary work activity (Johansson and Wendel 1986). There is little data on how sitting work affects the length of the hamstrings. The shape of the lumbar spine is mainly dependent on the pelvic tilt. There might also be an angular movement in the sacroiliac joint, affecting the lumbar shape (Bendix et al 1985). Andersson et al (1979) considered that there was some but little movement in the sacroiliac joint. An increased angle between trunk and thighs in sitting postures, would decrease the tendency to flattening of the lumbar spine.

Disc pressure measurements have given knowledge about loadings of the discs and changes of the loads with posture, activity, force exertion, and equipment design (Nachemson 1981). It is evident from Table 2 that sitting, especially without or with an inappropriate lumbar support, in many cases gives an increased load on the discs compared to standing. Increased forward bend of the trunk and also forward lifted arms increase the disc pressure, and lifting of weights causes further increases (Andersson et al 1974 b).

Table 2. Disc pressure measurements on the L3 disc for a person weighing 70 kg in different activities (Andersson et al 1974 b, Nachemson and Elfström 1970).

Activity	Load on the L3 disc
Supine	250 N
Standing at ease	500 N
Sitting with a full-size backrest inclined 110° and a lumbar support	400 N
Sitting upright with a lumbar support	500 N
Sitting upright without support	700 N
Forward bending 20°	600 N
Forward bending 40°	1000 N

Disc pressure measurements have also been performed on subjects sitting on chairs of various design (Andersson et al 1974 b, c, Andersson and Örtengren 1974 b). The results showed that all of the following factors resulted in decreased lumbar disc pressure: increased inclination of the backrest, the use of armrests, and increased depth of the lumbar support. Increased disc pressure occurred in unsupported sitting and also when performing activities such as pressing foot pedals or operating levers.

The relationships between the load on the disc and the postures in connection with external forces have been described and validated in biomechanical models (Schultz et al, 1982 a, b). In addition to compressive forces or loads on the spine, there are other loading conditions which can be distinguished, namely lateral shear forces, anterior-posterior shear forces, lateral bending moment, anterior-posterior bending moment and axial torque. These loading conditions on the spine are resisted by different substructures of the spine, such as the disc, ligaments, muscles, and facet joints, depending on the loading condition or combination of loadings present.

Andersson and Örtengren (1974 a) performed EMG measurements of the erector spinae muscles at several spinal levels from the lumbar to the cervical spine, when their subjects sat in chairs with various backrest inclinations and lumbar supports. Increased backrest inclination decreased the muscle load in the erector spinae muscles, especially in the lower part of the spine. The position and protrusion of the lumbar support influenced the muscle activity to a minor degree. Unsupported sitting, particularly in the anterior posture, increased the back muscle activity (Andersson et al 1974 a). Floyd and Ward (1969) came to the conclusion that sitting comfortably erect, supported with the lumbar backrest, and with the trunk slightly rounded, gave a minimum of muscle activity in the back, neck, and shoulder muscles. The pronounced erect posture increased the muscle activity.

The neck and shoulders

Neck and shoulder pain is an increasing problem in seated industrial tasks. Few controlled epidemiological studies have been performed. The studies reported in the literature are relatively recent. Several characteristics of the tasks have been identified in jobs where the risk of getting neck and shoulder pain is high. These are repetitive arm movements, high speed movements of fingers, hands or arms, little variability of work movements or posture, long periods of work without rest for the arms, precision tasks, need for large forces, static arm postures, excessive forward tilt of the neck, lifted arms, elevated shoulders, small workpieces, small work surfaces, a high work pace, short work cycle, monotonous jobs, no variation in tasks, high demands of continuous concentration, and sometimes poor illumination (Waris 1979, Kvarnström 1983). Backward bending of the neck seems to cause more neck pain than forward bending (Carlsöö and Hammarskjöld 1985, Hansson 1983). Repetitive twisting of the neck is also considered to cause increased rate of neck pain (Rugarn and Jonsson 1982, Tamminen et al 1981). All the above-mentioned job characteristics are based on observations from several occupational groups such as assembly workers, machine sewing operators and packers (Westgaard and Aarås 1980, Maeda 1977), punch card operators (Maeda 1975), cash register operators (Ohara et al 1976), film rollers (Itani et al 1979), coil winders (Kvarnström 1983), and industrial workers (Kuorinka and Koskinen 1979, Kvarnström 1983). Increased rates of neck and shoulder pain have also been seen among vehicle drivers (Hedberg and Lipping 1981), fork lift truck drivers (Siktbehov för gaffeltruckar 1973), and heavy work vehicle drivers (Tamminen et al 1981, Jonsson et al 1983).

When the head is held in an upright position, its centre of gravity falls approximately through the body of the fourth cervical vertebra. In this posture, the head balances with the aid of small intermittent contractions of the neck muscles (Williams and Lissner 1977). Neck flexion causes flattening of the cervical spine and also an increased biomechanical load on the muscles and on the discs of the neck. The cervical spine is very mobile in flexion, extension, lateral bending, and rotation (White and Panjabi 1978). Also translational movements of the head are possible, which means that neck posture and movements are very difficult to measure and describe. Visual demands in industrial tasks, i.e. viewing angle and viewing distance, often force the worker to sit with a forward inclined head. A comfortable tilt of the head is considered to be 17–29° in sitting, which corresponds to a line of sight of 32–44° (Lehmann and Stier 1961). Kroemer and Hill (1986) found that the preferred line of sight was around 34° below horizontal.

A tilt of the head of around 30° or more in sitting tasks causes muscle fatigue and discomfort when held for longer time periods, as in some work situations. Angles of 15° or less seem neither to cause fatigue nor discomfort (Chaffin 1973, Grandjean 1981). In many tasks, an excessive tilt of the head is needed due to the visual demands, which causes pain in the neck (Grandjean 1981).

The positions of the arms also affect the loadings on the muscles of the neck. Even small degrees of abduction and elevation of the arms increase the muscle load noticably, particularly on the trapezius and deltoid muscles (Hagberg 1982). Work postures with upper arms abducted more than 30° rapidly cause fatigue and discomfort (Chaffin 1973). Tichauer (1978) studied the effect of upper arm abduction on performance and energy consumption in sitting packing work. He showed that the optimal angle was 8°, and that the performance decreased rapidly, whilst the energy consumption increased at angles above 23° of abduction. The shoulder discomfort and fatigue also increase with higher vertical position of the hands or at longer horizontal distances from the body (Chaffin 1973). The optimal arm position, considering shoulder muscle load, is considered to be with the upper arm approximately perpendicular in the sagittal plane and slightly abducted in the frontal plane. Also no elevation of the shoulders should be present. Repetitive and monotonous arm movements, even without loads in the hands, cause increased load on the trapezius and supraspinatus muscles (Hagberg 1981).

Andersson and Örtengren (1974 c) performed EMG measurements on subjects sitting in chairs with and without armrests, but without work activity. They showed that armrests reduced the muscle activity in the neck and shoulder muscles. Others have found that armrests have little or no influence on the shoulder muscle activity in some work situations (Lindbeck 1982). In some cases, the shoulder muscle activity could increase when armrests were introduced for tasks such as lever operation or typewriting (Lindbeck 1982, Lundervold 1951).

Internal organs

A sitting posture with a 90° angle between trunk and thighs reduces the volume of, increases the pressure on, and can displace organs in the internal cavities of the body, especially if the spine is kyphotic. The oxygen intake might be impaired, due to decreased space and increased pressure on the lungs (Garner 1936, Burandt 1970). This might not be of any greater significance for most work tasks, but there has been anecdotal reports that musicians playing wind instrument in orchestras increase their performance and capacity of breathing when increasing the angle between the trunk and the thighs.

Prolonged pressure on the abdominal cavity due to sitting posture has been reported to be associated with impairments of the digestive system (Grandjean 1981). Rosegger and Rosegger (1960) reported a high frequency of stomach troubles among tractor drivers. The reasons were not known, but vibrations and the cramped sitting posture were believed to be partial causes. Holdstock et al (1970) considered that physical activity stimulates the colon peristalsis. Little physical activity, as in prolonged sitting, can therefore cause constipation. Recently, several studies have shown a moderate but significantly increased risk for colon cancer in sedentary jobs (Garabrant et al 1984, Vena et al 1985, Gerhardsson et al 1986). The reason is not known, but believed to be that the slower colonic transit increases the time carcinogenic agents in the food are in contact with the mucous membranes of the colon. Also, slackening of the abdominal muscles has been reported due to work involving prolonged sitting, leading to a "sedentary tummy" (Grandjean 1981).

Surface pressure

When sitting, some parts of the skin are subjected to pressure. This pressure affects the blood flow. If the pressure is large enough, it causes superficial ischemia in the capillary blood vessels (Landis 1930, Edwards and Duntley 1939). Also the tactile receptors of the skin can be subjected to pressure, which causes sensations of discomfort after some time. Certain body areas have a lower density of nerve receptors, and therefore those parts have a lower pressure sensitivity. The skin above the ischial tuberosities has few nerve receptors and is therefore well adapted in this respect to withstand the pressure caused by sitting (Kohara 1965). Furthermore, if the skin is subjected to pressure, the muscle tissue beneath will be compressed. Muscle tissue has a rich supply of blood vessels and nerve endings, which can be affected by excessive pressure. As a result, numbness or even painful sensations in the muscles of, for example, the buttocks can appear (Floyd and Roberts 1958, Jürgens 1969, Babbs 1979). The function of nerves can also be impaired when affected by pressures. The sciatic nerve passes between the thigh muscles, fairly close to the underside of the thigh. This area is open to receive pressure from the chair, especially if the edge of the chair "cuts" in just behind the knee. The ulnar nerve is also open to pressure at its passage through the elbow. The femoral vein passes through the popliteal area, and is particularly sensitive to pressure in that region, which also the sciatic nerve is. The result of pressure on the vein is constricted venous blood flow. The symptoms caused by pressure on the nerve and vein are pain, discomfort, numbness and anesthesia in the lower legs and feet (Åkerblom 1948, Weddell and Darcus 1947, Burandt 1970). There are reports that if the pressure distribution is changed by mechanical means, for example by intermittently inflated and deflated air cushions, the sitters do not experience as much discomfort from their buttocks as they would otherwise. Also, as a result, the blood circulation can be improved (Burns and Stockman 1958, Hertzberg 1949). This indicates that it is possible to withstand the pressure for short periods of time, but that prolonged pressure gives rise to adverse effects.

Blood circulation

The venous blood pressure in the feet is higher in standing and lower when lying, compared to the sitting posture. The vertical distance between the heart and the feet is a major determinant of the hydrostatic venous blood pressure in the feet (Pollack and Wood 1949). In static postures, such as sitting, fluid from the blood passes through the capillary membranes into the interstitial space and thereby causes swelling of the lower legs and feet. This oedema can amount to a volume increase of 2-5% It causes feelings of heaviness in the legs, distension of feet, and discomfort (Whitney and Gear 1965, Pottier et al 1969, Winkel 1981).

Older women are said to be especially prone to this effect, due to hormonal reasons (Kroemer 1971), and so are pregnant women. Swelling of the feet increases with higher hydrostatic blood pressure, vasodilatation due to increased temperature and constriction of the venous blood return due to under-thigh pressure (Pottier et al 1969). It has also been pointed out that acute joint angles at the knees, can cause discomfort due to constriction of the blood flow or pressure on the nerves (Drury and Francher 1985). Parallel to foot swelling in immobile sitting tasks, there is also a decrease of foot temperature, another source of discomfort (Winkel 1985, Formeller 1975, Burandt 1970). The intermittent contractions and relaxations of the calf muscles in walking aid the blood flow, acting as an extra pump. This effect is therefore called the "musculo-venous pump". Winkel (1981) has shown that there is little foot swelling for people when they interrupt their sitting by taking a short walk every 15 minutes, compared to when they sit all the time. Stranden et al (1983) have shown that foot activity in sitting, as using foot pedals or just moving their ankles, result in lower blood pressure and less foot swelling.

The reason for the development of varicose veins is not known; however, long term standing and prolonged sitting on chairs have been claimed to cause varicose veins, especially when the venous blood pressure is constantly high. Two arguments make the hypothesis probable. The disease is only prevalent in countries where chair sitting is common. Also the stress on the veins is fairly high and constant in sitting, in contrast to oscillating stress which might strengthen the veins (Alexander 1972). Changes between sitting and standing posture and some walking can then be recommended as prevention.

Further, people in seated jobs are more prone to suffer from pain due to haemorrage (Schoberth 1979), and they are possibly also afflicted more often.

Thrombosis in the deep veins of the lower legs can be caused by long term constricted sitting with a duration of about 1 hour and in most cases substantially more. The risk is considered to increase if pressure on the popliteal area is present or if there is little or no muscle activity in the calf muscles. There are also individual risk factors. Thrombosis has been recognized to occur in long distance flights, train, bus, car journeys, driving, and TV-watching (Homans 1954, Naide 1957, Haeger 1966).

Heat and moisture

Exchange of heat takes place between the seated person and the chair surfaces. Cold seats and seats with too high a heat conductivity can be very unpleasant to sit on. This is a problem in vehicles (Elnäs and Holmér 1981). It has been claimed that sitting on cold seats is a risk factor for urinary infections and prostatic problems, but there is no definite evidence. It is however commonly accepted that the symptoms can get worse for people with back pain or muscle pain when they get cold and wet, but there is no evidence that cold and wet work situations can be the primary cause of the disorders (Wickström 1978). Also, sweat evaporates from the skin. If the clothing of the seated person or the upholstery of the chair is not permeable enough, the skin in contact with the seat will be wet by condensed sweat, a very unpleasant feeling, well-known to everyone. This effect is to a large extent dependent on the air temperature. The problems get worse with higher air temperatures but are not particularly affected by the air humidity (Andrén et al 1975). The problems of heat and moisture in the seat surface increase with prolonged sitting. Disabled people, using wheelchairs, risk getting "sit-ulcers" and infections due to long term sitting, high pressure, shear forces, high temperature and humidity of the skin (Landis 1930, Andrén et al 1975).

Discomfort

The terms comfort and discomfort are often used in connection with chairs and users of chairs. Herzberg (1958) defined comfort as absence of discomfort. Branton (1969) held a similar view, when stating that the best possible situation in seating is to achieve a "state of non-awareness" of the seat. The perception of pain is influenced by emotional, motivational and cultural factors, and the reactions will vary with sex, age, personality and social background (Weisenberg 1977). The differences between discomfort, perceived exertion, and pain are difficult to establish. Pain and discomfort are reactions of the body for the purpose of indicating the need for relief, which for example can be movements or a change of posture. Therefore, these reactions protect the organism from damage or injury (Melzack 1973). It is often assumed that regularly experienced discomfort during work is related to the development of disease in the long term. The importance of comfort is, on these grounds, further emphasized and commonly accepted as an ergonomic criterion.

This literature review has pointed to a large number of physiological causes of discomfort. The individual integrates and weighs all the various perceptions, and therefore the subjective interpretation is the individual's estimation of the inappropriateness of the situation. In addition to the physiological causes of discomfort already mentioned, the possibilty of free movements in the chair and the absence of restrictions are often mentioned as criteria connected with comfort (Schoberth 1979, Floyd and Roberts 1958, Weddell and Darcus 1947). Branton (1969) suggested that the stability of a sitting person is connected with comfort. Shackel et al (1969) drew the conclusion that comfort is such a complex phenomenon that it can not be assessed with any "objective" criterion.

Postures and movements of sitting persons and the seating arrangements are also dependent on psychological and sociological factors. An upright sitting posture, without using the backrest or sitting on the front part of the chair, is associated with alertness, arousal, interest, activity, attention, and in some cases also insecurity and tensions. The opposite, a slumped posture is associated with lack of interest, indifference, low activity, relaxation or even repulsion (Mehrabian 1968 a). The status and social rank are also related to the chosen position of the chair and the posture. A person tends to face a higher status person, but can more often have a less direct shoulder orientation towards a lower status person. Further, an upright sitting posture, a more tensed posture and less spread legs is preferred by subordinates, while dominating persons sit more relaxed. A proud or arrogant posture is communicated by an expanded chest, erect head, and raised shoulders, while a depressed posture is communicated by drooping shoulders, a sunken chest, and a bowed and forward bent head and trunk. Equals prefer to sit at a closer distance to one another, and could more often sit side by side than people with different ranks (Lott and Sommer 1967, Mehrabian 1968 b).

There are also means of communicating ranks by the furniture. A large desk, visitor chairs placed at a distance from the desk, and a higher, larger and more exclusive chair used by a manager are means of creating dominance over the visitor or employee (Fast 1970). In environments where people are unacquainted, the occupation of seats follows certain social rules, for example to sit down too close to an unknown person can be interpreted as an intrusion. The term "personal space" has been used for explaining sitting behaviours and attitudes in these situations (Fast 1970). These factors are important in every day life, and should also be considered in work seating.

Criteria for ergonomic design

There are a number of statements, which are often referred to and commonly accepted as criteria for good ergonomic design. These have been dealt with by Ayoub (1973), van Wely (1970) and Corlett (1979). One of the main criteria is that the load on the spine should be kept low. The reasons for this are epidemiological evidence about the relationship between spinal load and back pain, the relationship between spinal load and accelerated degeneration of structures of the spine, and the fact that spinal load often aggravates already present back pain (Andersson et al 1980, Biering-Sørensen 1983 a). Further, the spinal posture should be kept in an S-shape, resembling the posture in standing as much as possible. This posture can be argued both from the anatomical point of view and from the minimum load point of view (Keegan 1953, Andersson et al 1974 b, Andersson et al 1979, Adams and Hutton 1980). Also, the posture of the trunk and the head should be upright and balanced so that there is a minimum of static muscle load to hold the posture, and the upper arms should be hanging down close to the vertical. In other words, static muscle load should be avoided (van Wely 1970, Monod 1972). According to a broad definition of ergonomic principles, the design of optimal working conditions should regard "human well-being, safety and health" (International Standard ISO 6385 1981). Therefore, discomfort due to the work situation should be minimized. In addition, it is believed that short term discomfort which arises every day at work can lead to disease in the longer term (van Wely 1970).

In summary, the following conventional criteria for ergonomic design are often referred to; keep the load on the spine low, aim for upright postures and an S-shape of the back, avoid static muscle load, and minimize the discomfort.

Design of work seats and workplaces

Workplaces

Giving general recommendations for the design of industrial workplaces is difficult because of the extreme variation of tasks. The appropriate design would be dependent also on the user, the chair, and the environment. Most of the recommendations, found in the literature, are aimed at machine operation, bench work with small details, vehicle driving, or console work. These recommendations are not sufficient for industrial workplaces, since they only cover a small part of the existing tasks. However, a very brief summary of some recommendations and comments on this will be given as follows.

Insufficient space is one important factor to consider, because it can cause constrained work postures. Space requirements are often based on anthropometric data.

Table 3. Space requirements of workplaces for a seated operator (Damon et al 1966, Kroemer 1971).

	Space requirements	
	Minimum (cm)	Recommended (cm)
Vertical distance seat to ceiling	104	
Lateral clearance	60	104
Leg-room height	60	68–75
Leg-room depth	65	no limitation
Leg-room width	40	65
Horizontal distance front edge of the bench to the work area		15–30
Work area height		65–76
Work area height for precision task		< 100

Recommendations like these are crude, because they do not consider factors which are specific for the particular work situation. For the ceiling clearance, factors such as head gear, access to the seat, backrest inclination, and required movements are of great importance. The lateral clearance is dependent on clothing and the postures and movements required by the arms and the trunk (see Damon et al 1966).

The required leg-room is dependent on the sitting posture chosen. High sitting, sitting with an increased angle between trunk and thighs or reclined sitting on a low chair cause different space requirements compared to upright sitting with 90° angles at the knees and the hips. The horizontal distance to the work area, and its height, are dependent on the visual demands, i.e. detail size, viewing angles, demands of overview and visibility. The distances also depend on the position and postures of the hands and arms (Grandjean 1981). The demands on an optimal position for the hands and a comfortable line of sight are often in conflict, which causes difficulties to find an acceptable position of the work area. In other cases there might be demands of precision or concentration which affect the distances chosen. Factors which increase the space requirements in general include heavy tasks, the use of tools, and the possibility to do the work in different postures.

Long horizontal reach distances, and especially their time demands, must be considered. A sloping work surface is one possiblity to decrease the disadvantages of too long reach distances for the arms, and the need for forward head tilt (Bendix 1986). Possibilities for changing the posture are very important, and in the best situation it should be possible to change between sitting and standing work (Grandjean 1982). Haberer and Weinmann (1978) have recommended that workplaces should be planned for sitting, with the exception of tasks demanding exertion of large forces or movements within a large area. The tasks should then be planned so that they also require getting up from the chair and some walking.

Anthropometric data

Anthropometric measures form a basis for the design of optimal dimensions of work equipment and workplaces. In all design processes, it is important to know which user population the equipment should be appropriate for. Age, sex, nationality, and occupation have to be controlled, but there are also other influences such as the range of joint motions, postures chosen, and clothing. A bad anthropometric match is only one of several possible sources of inappropriate design, but correct use of anthropometric information allows a good match for a selected proportion of the population. An example of anthropometric data is shown in Table 4. The corresponding Swedish population is a few cm taller in stature and leg length, but the other body measures are comparable or include smaller differences.

Table 4. Anthropometric data (estimates) relevant to seat design for a British adult population, nude subjects, and measures in cm. After Pheasant (1982).

	Males percentile					Females percentile				
	1st	5th	50th	95th	99th	1st	5th	50th	95th	99th
Stature (without shoes)	158	163	174	185	189	147	151	161	171	175
Sitting height	83	85	91	97	99	77	79	85	90	92
Elbow rest height	18	19	24	28	30	17	19	23	27	28
Buttock popliteal length	42	44	49	53	55	43	44	48	53	54
Popliteal height	39	40	44	48	50	37	38	42	45	46
Elbow breadth	37	39	45	51	53	26	30	39	47	51
Hip breadth	30	32	36	40	41	30	32	37	43	45
Sitting acrominal height	52	55	60	65	68	49	51	56	62	64

Work seats

No general classification of work seats has been made from the view point of the task and workplace requirements in the literature. Several investigators have only referred to a "work chair" or an "office chair". A few more detailed descriptions have also been reported, for example chairs for secretarial tasks (Woodson 1954), assembly tasks, forward leaning tasks (Grandjean 1982), console work (Kroemer 1971), welding (Palmgren 1984), and heavy machinery driving (Keegan 1962).

Diffrient et al (1974) made an attempt to classify seating according to the backrest inclination and to connect the inclination with various suitable activities. Upright sitting with a backrest inclination of 0–5° was considered suitable for work. In the alert posture, the backrest inclination was 5–20°, and it was considered suitable for console operator work tasks and driving. The relaxing posture was connected with a backrest inclination of 20–30°, incorporated for example into passenger seats. Some results from research on work chair dimensions are presented in Tables 5 and 6. These results include both upright and reclined postures. The tasks in Tables 5 and 6 referred to as industrial tasks, factory tasks, or just work, are in many cases equivalent to bench work with small and light weight components handled in a small work area, in other words tasks similar to office tasks from the postural point of view. These recommendations therefore become similar to those for office seating.

Table 5. Literature recommendations regarding dimensions and design of seats for work chairs.

Source	Height (cm)	Length (Depth) (cm)	Width (cm)	Slope	Shape	Desk height (cm)	Task	Comments
Panero and Zelnik 1979	36-51	39-41	43-48	0-5° rearward			work, secreterial	
Van Cott and Kinkade 1972	38-46	30-38	38-46	3-5° rearward			work, office	
Diffrient et al 1974 a	35-52	38-41	> 41	0-5° rearward		63-76	office, desk work	
Woodson 1954	38-46	38	> 38				secreterial	
Hansson et al 1984	39-51 or 44-59 for forward tilted seat			forward and backward			type-writing	
Murrell 1969	35-46	38-41	43 (48 with) armrests)	3-5° rearward	flat		factory and office	Footrests for short people; armrests 22-23 cm above seat
Kroemer 1962-1967*	41-49	35-40	35-40	0-7° rearward	flat	72-75	office and factory	
Stier 1959	40-43	35-40	35-40	5-7° rearward	flat	75	office and factory	Dimensions derived from small to medium size people
Grandjean 1981	38-53	38-42	40-45	4-6° rearward in the front	moulded	74-78	work	Slight hollow in the seat
Grandjean 1973	40 or 38-53	40	40	3-5° rearward in the front	flat or slightly concave		work	Distance seat - work surface 27-30 cm
Grandjean 1963-1967*	45-53	32-40		3° rearward	flat	70-78	work	Footrests for short people
DIN 68877 1981	42-54	38-42	40-48		flat or slightly contoured		work	
Laiss and Wuensch 1964*	37-59	35-40	35-40	0-5° rearward			work	Footrest often necessary
Schoberth 1962	45-48	40	< 42			78-80	work	Footrest necessary
Dreyfuss 1959	38-46 or to 75	31-38	38	0-5° rearward			work	If the seat is adjustable to 75 cm, footrest is needed
Huc 1952*	45	40	40	0°	flat		work	
Kroemer 1971	40-50	40	40	±6°	almost flat		standard work	

*after Kroemer (1971)

Table 5. (continued)

Source	Height (cm)	Length (Depth) (cm)	Width (cm)	Slope	Shape	Desk height (cm)	Task	Comments
Grandjean 1982	38–54	38–44	40–45	7° rearward	slightly contoured	74–78	work, forward and backward posture	
Diffrient et al 1974 b	39–49	38–41	41	5° rearward	slightly contoured		sewing, console work	
Keegan 1962	46	40					machinery	
Branton 1974	40–43	38	46	0–5° rearward			industrial	
Ayoub 1972	40–50	40	40	3–5° rearward	flat and concave in centre		industrial	
British Standard 4141 1967	38–48	35–38	> 40	0–5° rearward	flat	> 66	industrial	Footrest at least 35 × 35 cm
Arbeidsinspectie 1961*	42–52	38–40	> 38	3° rearward of the front proportion only	concave, radius 85 cm		industrial	
Diffrient et al 1974 c	38–47	41–46	41	7° rearward	slightly contoured		industrial, crane, lift truck	
Dunlap and Kephart 1954	37–44	41		9–11° rearward			truck driving	
McFarland, Damon and Stoudt 1958	39	43	> 48				truck driving	
Dupuis 1958	40	35–40	> 44				tractor driving	
German Standard VDI-richtlinien No 2782 and 2783 (after Grandjean 1980)		> 43	> 48	10–16° rearward			driving	
McFarland and Stoudt 1961	25–35	46	> 46	7° rearward			car driving	
Domey and McFarland 1963	25–35	46		7° rearward			car driving	
Jones 1969	30	43		7° rearward			car driving	
Grandjean 1980	25–30	44–55 or 50 for Europeans		10–22°, preferably 19°	slightly moulded		car driving	Side supports recommended; chair movable forward – backward > 15 cm

*after Kroemer (1971)

Table 6. Literature recommendations regarding dimensions and design of backrests for work chairs.

Source	Lower edge to seat (cm)	Upper edge to seat (cm)	Height (cm)	Width (cm)	Horizontal depth (cm)	Backrest inclination	Comments
Panero and Zelnik 1979	8-18		15-23			95-105°	
Van Cott and Kinkade 1972	adjustable > 10		15-20	30-35		swivel 10-20°	Backrest curvature 5 cm
Diffrient et al 1974 a	12-18		15-23	33		95-100°	Lumbar support horizontal radius 31-46 cm, vertical radius 25 cm
Woodson 1954				> 30		105°	
Hansson et al 1984	adjustable		20-35				Tilting backrest
Murrell 1969	> 20		10-20	< 33		95-110°	Tiltable about a horizontal axis, curved with radius 40 cm
Kroemer 1962-1967*						upper part 115°	Lumbar pad 18-20 cm above seat
Stier 1959						110-115°	Lumbar pad 18-20 cm above seat
Grandjean 1981		48-50		32-36			Lumbar pad 10-20 cm above seat, horizontal radius 40-50 cm
Grandjean 1981		adjustable	30	38	adjustable		Slightly convex lumbar pad
Grandjean 1973		55-60	20-30	30-37			Backrest radius 80-120 cm
Grandjean 1963-1967*	> 12		20	< 32	34-44	90-120°	Lumbar pad adjustable 14-24 cm above seat
DIN 68877 1981		> 32	> 22	36-40			
Laisz and Wuensch 1964*	18-20					Lower part 90°, upper part 100-110°	Lumbar pad
Schoberth 1962	14					upper part 104-110°	Lumbar pad 16-20 cm above seat; backrest to shoulder
Dreyfuss 1959	8-21		13-20	30-36		95-105°	Backrest concavity 40-45 cm
Huc 1952*						105-120°	
Kroemer 1971	lumbar support 8-15	26-33	18	32	35-42		Saddle shaped and tiltable ±15°

*after Kroemer (1971)

Table 6. (continued)

Source	Lower edge to seat (cm)	Upper edge to seat (cm)	Height (cm)	Width (cm)	Horizontal depth (cm)	Backrest inclination	Comments
Kroemer 1971	full-size < 12	50–60		> 38		105–120°	Lumbar pad 18–20 cm above seat
Grandjean 1982		48–50		32–40		upper part 107°	Backrest radius 40–50 cm, lumbar pad 10–20 cm above seat
Diffrient et al 1974 b		33–41		31–33		100°	Lumbar support vertical radius 25 cm
Keegan 1962	> 10					105°	Lumbar support slightly convex in sideview
Branton 1974	13	23–33	10–20			95–110°	
Ayoub 1972	10–15	28–33	18	33	35–43		Slightly convex in profile, tiltable ±15° against vertical about a horizontal axis
British Standard 4141 1967	15–28	25–41	10–13	28–33		80–110°	Pad swivel ±20°
Arbeidsinspectie 1961*	12–22	28–38	16	30	36–46		Tiltable about a horizontal axis
Diffrient et al 1974 c		56		31–33		102°	Lumbar support vertical radius 25 cm
Dunlap and Kephart 1954						99–114°	
McFarland, Damon and Stoudt 1958		46–51		> 54			
German Standard VDI-richtlinien No 2782 and 2783 (after Grandjean 1980)		> 50	> 50	> 48		110–115°	Lumbar pad 14 cm above seat
McFarland and Stoudt 1961			46–53	> 51		112°	
Domey and McFarland 1963						107–117°	
Jones 1969						108°	
Grandjean 1980		50				ajdustable 90–120°	Lumbar support 10–14 cm above compressed seat surface; side supports recommended

*after Kroemer (1971)

There is agreement that the seat height, measured from the floor to the front part of the seat pan, should not be higher than the lower leg length plus allowance for shoes. This assumes a relatively horizontal seat. Higher seats impose increased pressure on the undersides of the thighs in the popliteal area. Too low seats increase both the pressure on the ischial tuberosities and the tendency towards lumbar kyphosis (Floyd and Roberts 1958). They also decrease the stability of the legs and can cause muscular tensions (Branton and Grayson 1967, Lundervold 1951). Consequently, the popliteal height plus allowance for shoe height is the major determinant. It should also be considered that rising from a low chair demands substantially larger muscle forces than rising from a high one (Ellis et al 1984). If the seat is inclined forward or rearward, it gets more difficult to define and measure the height of the seat, but the main consequence would be a different seat height recommendation. The seat height recommendations for rearward inclined seats in cars often vary between 25 cm and 35 cm according to Table 5. A restricted head-room is often the reason for these low seats in vehicles. For other work seats, the recommendations vary considerably too, and seat heights above 53 cm are mentioned, as can be seen in Table 5. The highest values however assume the use of a footrest. In some cases, fixed seat heights are recommended, but in the more recent literature a range of adjustability is more often advocated. Some authors assume the use and adjustment of a footrest in order to obtain an appropriate height for the lower legs. For high sitting, which is used in workplaces designed for standing work, a footrest is also necessary. It is difficult to draw conclusions from these various recommendations regarding the seat height of a chair for a particular work task.

The seat width is determined by the width of the buttocks of the user population, and also by the need for stability and the requirement to move in the chair (Darcus and Weddell 1947). There seems to be agreement on a seat width of at least 40 cm for industrial seats. Driver seats are generally recommended to be wider, as shown in Table 5, but a maximum seat width is not given.

The seat depth is important for giving enough thigh support and also adequate clearance between the lower legs and the front of the seat at the same time as the backrest is fully used. Too large seat depths cause pressure in the popliteal area and forwards-sliding in the seat to a slumped posture. Adequate clearance is considered to be approximately 5–10 cm (Ayoub 1972, Asatekin 1975). A fixed seat depth would then be appropriate for only a small proportion of the population. Many researchers have recommended a seat depth for industrial seats of 35–40 cm, preferably adjustable by a horizontal adjustment of the backrest. Drivers' seats tend to be deeper than that. One reason for this might be that drivers are predominantly men. Considering the anthropometric data in Table 4, it is questionable whether the recommendations are appropriate for 95% of the population.

Rearward inclined seats have the advantage of preventing the buttocks from sliding forward. Thereby, the use of the backrest is aided. The disadvantage of the rearward inclination is the decreased angle between the trunk and the thighs (Floyd and Roberts 1958). On the other hand, a forward inclined seat has the advantage of creating an increased angle between the trunk and the thighs, but the disadvantages are sliding forwards on the seat and possible increased muscle activity in the legs and the back (Lundervold 1951). In older literature a rearward inclination was recommended for work seats, often 3–5° and sometimes up to 7°. The present recommendations tend to be that the seat inclination should be adjustable, around −6° to 6° (Kroemer 1971). For driving tasks, the seat inclination has been recommended to be around 7° rearward or more (Andersson et al 1974 c, Grandjean 1980). The highest values are intended for car seating. Tiltable seats with a greater range of forward tilt have also been proposed during recent years, and chairs of this type are also manufactured currently. The seat height is closely dependent on the seat inclination. The lack of agreement regarding seat inclination for industrial seats seems to be considerable.

There is a general agreement that the seat shape should be flat or have a slight concave shape in the lateral plane. A pronounced bucket shaped seat prevents people from changing posture and thus the pressure distribution of the buttocks, and it is therefore unsuitable (Darcus and Weddell 1947). Further, it will only fit some people, who happen to have the same size of buttocks. There is a consensus that the front of the seat should be rounded (waterfall front) in order to avoid pressure in the popliteal area. The seat should be flat in the anterior-posterior plane according to Kroemer (1971). Grandjean (1982) advocated that a slightly contoured seat with a flat rearward inclined surface in the front under the thighs and slightly upwards again in the back of the seat, is perceived as more comfortable. All edges should be softly rounded. Schneider and Lippert (1961) proposed a seat shape in which the rear third was raised with a 32° forward inclined wedge, while the rest of the seat was inclined 4° rearwards. The purpose was to tilt the pelvis forward. However, this shape was found ineffective and uncomfortable by Burandt and Grandjean (1964), and it is therefore not advocated. Side supports are beneficial in situations with lateral forces, but the disadvantage is that they can also restrict body movements (Grandjean 1980). Drivers' seats have particular demands for damping vibrations. Not only the construction of the base of the seat, but also the properties of the seat cushion are important in this respect. Side supports have no function in seating when lateral forces are absent.

Work seats should have padding and upholstery. In some work environments this is not possible due to other demands. A stiff padding of 2–3 cm is considered to give a comfortable pressure distribution, and sitting does not become unstable (Grandjean 1982). A slightly different recommendation is that a comfortable seat should have a 3.5–4 cm layer of medium density foam padding over a 1–1.5 cm layer of firm closed-cell padding (Diffrient et al 1974). The upholstery should exhibit good friction properties in order to prevent the buttocks from sliding, and it should be permeable for moisture (Kroemer 1971). The surfaces should be easy to clean (Diffrient et al 1974). Non-flammable materials are necessary in certain workplaces, for example when welding. An alternative solution has been developed, incorporating inflatable air cushions in the seat. By inflating these in sequence, the pressure on each area of the buttocks is relieved at regular intervals, which decreases discomfort and is therefore beneficial in tasks which require periods of long term sitting (Hawkins 1974).

The backrest is the most important chair feature for preventing pelvic tilt. Further, it gives stability and support for the trunk and decreases the load on the back. A high and upright backrest is not beneficial in upright and slightly forward bent sitting postures (Andersson et al 1974 b). In these postures a lumbar support or a low backrest is sufficient for tilting the pelvis and maintaining enough stability without needs of static muscular activity. The height of a lumbar support in industrial tasks has mostly been recommended to be 10–20 cm, according to Table 6. During recent years there have been recommendations up to and around 30 cm (Grandjean 1982). Also another backrest has been proposed by Grandjean (1982) in forward bending or upright sitting work postures. It is 48–50 cm high, has a lumbar convexity 10–20 cm above the seat, and the upper part is inclined 17°. Only the lumbar convexity is used in upright or forward bent postures. The chair can also be used in a rearward inclined posture, leaning against the whole backrest such as when resting or performing other tasks. The recommendations for the distance between the seat and the upper edge of the backrest varies considerably, from 25 cm to 60 cm. Larger values than 33 cm are advised against by some ergonomists, because the backrest will then interfere with the shoulder blades (Floyd and Roberts 1958). Too high backrests also interfere with tasks which involve twisting of the trunk (Donati et al 1984). Otherwise there is no indication of how to choose backrest height.

If the lower part of a backrest does not give enough clearance for the buttocks, it will push the sitter forward on the chair. For the small size backrests or lumbar supports, most researchers have recommended at least 10 cm between the seat and the lower edge of the backrest.

The shape of the lumbar support should be convex in the sagittal plane, in order to follow the lumbar curvature and not cause high pressure from its upper or lower edge. A radius in the sagittal plane of 25 cm has been proposed (Diffrient et al 1974). The most pronounced part of the lumbar support should be at 17–21 cm above the seat in order to follow the contour of the back, and the figure is valid for people of different heights (Åkerblom 1969). Other authors have expressed the view that the support should be provided at the 3rd to the 5th lumbar vertebra, since most of the bending of the spine takes place there. It is generally agreed upon that the shape of the backrest in the horizontal plane should be concave in order to conform with the sitter's back. The radius should be 40–50 cm (Grandjean 1982). These recommendations give the lumbar support a "saddle shape". In tasks with reclined postures, it is necessary to use high backrests. They allow trunk muscle relaxation and increase the stability of the trunk substantially. The heights of these full-size backrests have been recommended to be between 46–60 cm above the seat. The shape should incorporate a lumbar convexity, up to 5 cm (Andersson et al 1974 c), which is placed 17–21 cm above the seat (Åkerblom 1969). These values vary however; Diffrient et al (1974) have proposed 23–25 cm and Grandjean (1982) 10–20 cm above the seat. The upper part should be inclined rearward 100–120°, but the recommendation varies as can be seen in Table 6. A horizontal concave radius about 40–50 cm should be provided in the lumbar region, and about 60 cm at the upper edge of the backrest. There is also some disagreement about these figures. A concave backrest shape increases the stability of the trunk, especially when lateral forces are present. Side supports increase the stability of the trunk further, and are therefore recommended in vehicles (Grandjean 1980). The effectiveness of the concave shape and of side supports increases with increasing backrest inclination.

The width of backrests or lumbar supports for industrial work has in older literature mainly been recommended to be 30–36 cm. There are however some more recent recommendations around 40 cm. Wide backrests increase the possiblity to change posture in the seat and can perhaps also increase the stability. Too wide backrests interfere with the mobility of the sitters, and should therefore be avoided (Tichauer 1976). The difference in recommendations is further emphasized by proposals of backrest widths of more than 48 cm for driving tasks (see Table 6).

There is agreement that the backrest should tilt around a horizontal axis, in order to follow the contours of people's backs better and allow for postural changes. The tilting movement should preferably have some resistance. The range of rearward tilt or inclination of the pad has mostly been stated as 80° to 110°, and in some cases more (see Table 6). Few of the literature references have specified the range of adjustment of the backrest in the forward-rearward direction, but it seems as if a range of at least 8–10 cm is needed so that correct seat depth can be obtained.

The backrest should have padding and upholstery in order to distribute the pressure on the back, but not so soft that it loses its shape. A slightly softer foam for the padding of the backrest should be used compared with the seat (Diffrient et al 1974). Some recommendations have meant that the backrest does not have to be absolutely stiff in the forward-rearward direction, because a slight elasticity could be perceived as comfortable. Westgaard and Aarås (1984) have introduced a chair with an "active backrest", when redesigning workplaces in the electronics industry. It is spring loaded in order to follow the sitter's lumbar back irrespective of the lean of the trunk, and thereby it exerts a backrest force on the lumbar back all the time. This solution can be questioned from a biomechanical point of view, but the active backrest has not been sufficiently evaluated yet.

The provision or omission of armrests has been much discussed. In tasks where the lower arms can be placed on the armrests for some periods of time, they unload the shoulder muscles and are therefore recommended (Andersson and Örtengren 1974 c). In tasks with a substantial amount of arm movements, armrests can hinder and cause the sitter to lift the shoulders to avoid interference. Armrests have thus been advised against in these types of tasks (Lundervold 1951). Armrests can also interfere with the workbench, causing problems in bringing the chair close enough to the work. An advantage is that they assist when changing posture in the chair, and getting up from the chair becomes easier (Kroemer 1971, Ellis et al 1984). Few recommendations for the dimensions and design of armrests which are in agreement with one another can be found, which probably is due to the various demands of different tasks. The height of the armrests have been recommended to be adjustable at least between 20–25 cm above the seat. A figure like this is however very difficult to give, and it depends heavily on the anthropometry of the sitter and on the task, for example the precision demands. Armrests are normally not used in vehicles, except for work machines with a number of manoeuvre functions built into the extension of the armrest.

Some investigators advocate the use of footrests. The chair height should be adjusted so that the work surface height becomes suitable for the arms and hands, and then the footrest is adjusted for correct height in relation to the seat. Others prefer to avoid footrests, starting by adjusting the seat in relation to the floor, and then adjusting the work surface according to the arm position. Footrests can also be built into the chair, especially high chairs for use in workplaces for alternating sitting and standing. Too small footrests can restrict leg movements.

Swivel seats are normally used, for example at L- and U-shaped workplaces, but there can be exceptions when the swivel needs to be locked. There should not be any obstruction under the front part of the seat, in order to permit the feet to be tucked back under the seat if desired. Obstructions also cause difficulties when rising from the chair (Keegan 1962, Murrell 1969). The base of the chair should be stable and large enough to prevent turning over. Most authors recommend five feet at present, forming a circle with a diameter of 40–45 cm (Grandjean 1982). It is considered that leg branches which are too long can increase the risk of tripping accidents. A three legged base of an industrial chair has been proposed by Palmgren (1984), because it is more stable when used on uneven industrial floors. The disadvantage is of course that it can tip easier.

Castors can increase the risk of muscular tensions in the legs (Lundervold 1951), and are therefore discouraged in jobs demanding precision movements or large forces (Ayoub 1972). However, it is considered by several ergonomists that castors with some friction are preferable since they facilitate moving around in the workplace when that is required by the tasks (Hansson et al 1984, Grandjean 1982).

It has been shown above that chair design features are, to a large extent, dependent on the work task. Remarkably few specifications of quantified influences in this respect have been reported. This means that the recommendations from the literature are not detailed enough to provide a designer with sufficient background data when designing work chairs for different work tasks. In addition to that, there is disagreement concerning several chair features. There are also different approaches regarding the compromise between ergonomic demands and other demands as to what is considered feasible from the manufacturing and economical point of view. One example is whether certain chair features should be adjustable or not.

Alternative seating

The sit-stand seat has been proposed as a compromise between standing and sitting work. The posture of the users is upright and the angle between the trunk and the thighs is approximately 135° (Laurig 1969, Bendix et al 1985). The sit-stand seat is not meant to be used continuously, but rather to provide a change from standing. It also has advantages in workplaces where the knee space is restricted for conventional sitting postures. The design of these seats varies from flat inclined seat pads, bucket seats, "horse back" saddles to "bicycle" saddles. No general design recommendations can therefore be given, possibly with the exception of the seat height. The recommendations given are approximately 65–90 cm and adjustable (Grandjean 1982, Bendix et al 1985, Palmgren 1984). It is debated whether the sit-stand seats should have a backrest. The reasons for advocating sit-stand seats is that they decrease the load on the feet compared to standing, maintain a lumbar lordosis (Bendix et al 1985), and give decreased EMG activity in the back muscles, compared to a conventional chair. The most important advantage is perhaps the possiblity to come closer to the task compared to conventional sitting, and therefore reduce the load on the back, neck, and shoulders (Palmgren 1984). The use of sit-stand seats has however not been very wide-spread in industry.

Mandal (1976) proposed a work chair with a 15° forward tilted seat to be used in tasks involving forward bending. In addition to this, the workbench surface should be inclined 10°. Advantages claimed for this design are a less backward tilted pelvis, easier maintenance of lumbar lordosis, less pain among back pain sufferers, less neck flexion, and a better pressure distribution on the buttocks. This concept has however been critisized by others (Enevoldsen and Ward 1976), claiming that forward tilted seats will cause discomfort due to sliding forward on the seat and increased muscle load in the legs. It has also been argued that the less flexed posture obstained is more due to the inclined table than the seat (Bendix 1986). Burandt (1969) evaluated the influence of forward inclined seats on pelvic tilt. He found that the pelvis could tilt further backwards with the forward inclined seat compared to a flat seat, which is contradictory to the results from others.

The Balans chair has been constructed in Norway, in an attempt to design a chair with the advantage of increased angle between the trunk and the thighs, but preventing sliding forwards on the seat. It consists of a forward sloping seat pan and two knee supports but no backrest. The chair is supported on wood rockers. The Balans chair has been evaluated in library work by Davis (1982) and by Drury and Francher (1985) in typing and terminal using tasks. Both investigations concluded that the chair decreased the subjectively perceived discomfort from the back, but on the other hand, the subjects felt increased discomfort from their knees and lower legs. Also it was pointed out that the posture from the hip joints to the feet becomes static and locked.

Another alternative seat for sitting with an increased trunk-thigh angle has been proposed by Ullman (Ullmanstolen 1985). The front part of the seat pan has been tilted 18° forward and the rear part is horizontal. This chair has not been evaluated yet.

Methods for evaluation of work seats

A large number of methods for evaluation of the ergonomics of work seats have been proposed and used in the ergonomics literature. Few methods have won general acceptance, and it seems as if most researchers devise their own methods, adapted for each study in order to solve the particular problems involved. The methods however reflect the variety of criteria which exist and therefore also the multi-dimensional character of the problem. A brief overview of the most important methods reported as being used in chair evaluation, is given below.

Comfort

The user's own perception of comfort or absence of discomfort from a chair is perhaps the most important determinator for a persons acceptance of the chair and for his or her future use of it. A large number of methods for the assessment of comfort and discomfort have been presented (Shackel et al 1969, Corlett and Bishop 1976, Wachsler and Learner 1960, Le Carpentier 1969, Bendix and Hagberg 1984, Barkla 1964). Questionnaires and interviews have been common techniques, in which the subjects have been asked to assess their judgements of the chair, choosing between verbal statements. The other alternative has been ratings of the subjective feelings of comfort or discomfort, using continuous scales or scales with discrete steps. These subjective methods seem to be more accepted today then earlier. Shackel et al (1969) used "General comfort rating", in which subjects expressed their rating in relation to verbal sentences describing several feelings ranging from comfort to pain. They also used "Body area comfort ranking", a forced-choice technique also used by Bennett et al (1963). Corlett and Bishop (1976) used "Body mapping", a method where the perceived discomfort was rated on a scale and also related to a body part defined by a manikin. Shackel et al (1969) also used a "Chair feature checklist", in which the subjects were asked to select an appropriate statement of nine chair features. The method of "Fitting trials" was used by Jones (1969), in which the subjects adjusted the dimensions of the seat and workplace until the subjective comfort was maximized. "Direct ranking" was used by Shackel et al (1969), in which subjects had to rank a number of chairs, which all were presented at the same time for making the comparisons easier for the subjects. Ratings, questionnaires, and interviews are inexpensive methods, especially if standardized methods are used. The evaluation and interpretation of the results can however be difficult, as can the prevention of errors and irrelevant influences.

Drury and Coury (1982) presented and used a methodology for chair evaluations, which in addition to comparisons with "Anthropometric data and principles" also contained "Fitting trials" and "User comfort evaluation".

There is some disagreement on the time needed for performing experiments on the subjective evaluation of chairs. The time periods used range from 5 minutes (Wachsler and Learner 1960) to several hours. However, the subjective methods have by many authors above been considered rapid and effective. It should also be noted that Shackel et al (1969) found that expert judgements on chair design were not valid as predictors of the preferences of a population.

Several authors have tried to establish an objective measure for discomfort. Grandjean et al (1960) and Branton and Grayson (1967) claimed that uncomfortable chairs caused more frequent and more intensive movements of the sitter. Coermann and Rieck (1964) were of the same opinion, after having measured both shifts of the centre of pressure of the sitter and perceived comfort. Others have not been able to confirm these results, at least not for small differences between chairs. Only experimental methods and subjective measures can be recommended at present as measures of comfort (Rieck 1969, Schackel et al 1969). The subjective methods are easy to perform in field studies, but it is difficult to avoid irrelevant factors influencing the judgements.

Biomechanical methods

An advantage with biomechanical methods is that they are non-invasive. Static models normally demand less expensive equipment compared to dynamic models. On the other hand, dynamic models increase the accuracy of the calculations, especially in dynamic work, but the complexity also increase substantially, and the data collection becomes much more comprehensive. Presently, there is very little reference data from dynamic models, compared to static models, which means that loads from dynamic models are still of limited use. There is a span in the complexity of existing biomechanical models from simple calculations performed by ergonomists in the field, using a pocket calculator, to sophisticated computerized laboratory models. Disadvantages are that the simple models have limited accuracy. Higher accuracy can be accomplished but requires more input data such as obtained from sophisticated equipment and photographs of undressed subjects, which can be difficult to manage in field studies (Garg et al 1982, Nordin 1982).

Biomechanical models for predicting loads have been based upon results from both EMG and disc pressure measurements (Schultz et al 1982 c). These existing models and further developments can be frequently applied for the evaluation of seated tasks and workplaces. Not only the lumbar back, but also the neck and shoulder joints are suitable for estimation of the biomechanical load in seated tasks (Jonsson 1983).

Measurements of postures and movements

The general posture such as slumping, sitting upright, etcetera, has often been evaluated from direct observation or from filming or photographs (Branton and Grayson 1967, Persson and Kilbom 1983, Karhu et al 1977). Some of these observations, or perhaps rather classifications, also include the posture of the trunk, head, arms and legs. More detailed analysis of the spinal curvature has been performed by measurements from photographs taken in the sagittal plane (Schoberth 1962). Further, more detailed information of the spinal posture has been obtained from x-ray photographs (Schoberth 1962, Andersson et al 1979). However, manual analysis of postures from films and photographs are time consuming, especially if the sampling rate is high. Posture has often been evaluated in relation to criteria of what is considered or has been shown to be a "good" posture.

Other methods which have been used include goniometers (Grandjean et al 1983) and optical devices (Less and Eickelberg 1973). Posture and movements can also be measured with opto-electrical methods, for example CODA-3, SELSPOT II, and VICON. Some of these systems might impose constrictions on the subjects due to cables or other equipment which has to be connected to them (Mitchelson 1985). These methods require a free line of sight, just as photography and filming, and the measurements become more complicated if the task necessitates turning around or moving in large areas. Recently, several measurement equipments for continuous measurement of posture or joint angles have been presented. One example is an equipment for long term recording of sitting, standing, or walking activity. The signals from a small knee goniometer and a foot switch under the heel are recorded on a portable tape recorder, and from a computerized analysis, the total time spent in each activity and the number of transitions are calculated (Johnson et al 1982). There is a shortage of suitable equipment and methods for continuous recording of work posture and subsequent analysis. One measurement system, named "Miniman", was presented by Milner and O'Brien (1985), in which a number of joint angles are recorded, using elastic resistance strain gauges attached to the skin over the joint.

Pressure and forces from the chair

The distribution of the pressure between the seat and the buttocks has been measured with equipment of varying sophistication. As many as 960 inductive load cells linked to computerized data aquisition with a frequency of 1 Hz were used by Stumbaum and Diebschlag (1981), and 30 air proof rubber balls connected to 30 manometers were used by Jürgens (1969). Mandal (1981) used three blood cuffs, placed on the seat pan of the chair. The measurements are difficult to perform because the measurement equipment affects the pressure distribution. It has also been difficult to relate the perception of comfort to a particular pressure distribution, which means that the pressure measurements are of limited utility.

The load on the feet is an interesting measure, since it relates to the pressure distribution of the buttocks, the seat height, and the tendency to slide off a sit-stand stool (Stumbaum and Diebschlag 1981, Stier 1959). The total forces exerted by the sitter on the seat, backrest, and floor have been measured by Stumbaum and Diebschlag (1981), when assessing a measure of the activity and the temporal pattern of the sitting activity. The forces exerted from the sitter on the chair and floor has been used for calculations of some biomechanical parameters such as the location of the centre of gravity of the trunk in relation to the ischial tuberosities (Schoberth 1962). The friction forces between the sitter and the seat are also important measures, and also the friction forces between the chair and the floor in order to prevent undesired sliding movements. The coefficient of friction has been assessed as the quotient between the maximal force when sliding occurs and the reaction force (Lundervold 1951). The methods for measuring these forces are interesting because they permit a description of the temporal pattern of various sitting activities, and they also give an indication of the loads acting on the sitter.

Electromyography

Electromyography (EMG) is the only wide-spread method by which muscle load in the body can be directly measured. The electric activity of the muscles can be recorded with wire electrodes inserted in the muscle or with surface electrodes on the skin immediately over the muscle. The method has been developed considerably, and it can now be performed in industrial production environments. A great number of EMG studies in sitting tasks and evaluations of chair designs have been performed (Åkerblom 1948, Lundervold 1951, Andersson and Örtengren 1974 a, Burton 1984, Palmgren 1984). Only superficial muscle groups can be measured with surface electrodes, which is a limitation. Wire electrodes have the disadvantage of being more difficult to handle, especially in field studies. The method has a disadvantage of being posture dependent (Nordin 1982), i.e. the relation between the EMG signal and the muscle force is dependent on the joint angle. Neither can passive muscle forces be detected. There are techniques not only to measure the force exertion of the muscle, but also to measure the physiological fatigue of the muscle by analysing the frequency shift of the signal (Chaffin 1973, Örtengren et al 1975).

The EMG method has been shown to give particularly useful information about chair design (Andersson et al 1974 a–c, Andersson and Örtengren 1974 a–c), and is probably one of the important methods for future studies. However, the EMG activity seems not to be the most relevant method for evaluation of certain chair features according to Jonsson et al (1981), Burton (1984) and Palmgren (1984). They found no or little difference between various backrest heights or makes of office chairs, but postural changes could be detected. The method is nearly the only alternative for assessing the load on muscles due to postures, movements and force exertion, a factor considered very important for the genesis of musculoskeletal disorders (Örtengren and Andersson 1977).

Foot swelling

The measurement of foot volume is performed by placing the foot in a plethysmograph which is filled with water, kept at a certain temperature. The volume of the foot is equal to the volume of the displaced water. Repeated measurements during the working day give the basis for the volume increase of the foot. The apparatus is simple and can be used in field studies (Winkel 1985). Foot swelling represents a measure of the physiological response to inactivity in sitting, and to chair design. The method is appropriate for evaluation of task influences, but mainly those related to lower leg movements and seat pressure in the popliteal area. To some extent, aspects of chair design might be assessed with the method.

Measurements of physiological work load and blood pressure

Measurements of heart rate and oxygen uptake have been performed for various sitting postures. The circulatory strain is affected by static muscular work (Kilbom 1976), but the measures are considered neither relevant, nor particularly sensitive for the evaluation of chair features.

The blood pressure of the veins in the foot has been measured by inserting a needle in the vein, and recording the pressure via a pressure transducer (Stranden et al 1983). The blood pressure is related to the swelling of the foot and also to the calf muscle activity. This method to measure blood pressure has been used in the laboratory, but will not be a particularly useful alternative for chair design evaluations in the field.

Disc pressure measurements

The intervertebral disc pressure is measured by inserting a needle with a pressure sensitive tip in the centre of the disc of a subject (Andersson et al 1974 b). The L3 disc has normally been used for these measurements. The method requires young subjects with non-degenerated discs. It is a highly sophisticated laboratory method which only has been performed in a few university hospitals. These measurements have given very important basic knowledge about chair design, but they will not become frequently used. For routine evaluations of work seat designs, other methods must be used.

Heat and moisture

Important aspects of the properties of the upholstery and padding of a seat are heat and moisture. Measurements can be done with thermistors and moisture sensors, for example with moisture sensitive semiconductive materials. These are placed between the seat surface and the sitter (Andrén et al 1975). Other techniques have also been used for moisture measurements, for example the increased weight of a piece of blotting paper placed under a sitting person. The knowledge of properties of appropriate materials for work seats in this respect is relatively good, so measurement does not need to be used as a routine method.

Anthropometry

The application of anthropometry allows the best possible dimensional fitting between the user population and the equipment to be designed, in this case the chair. For that, three types of information are needed: the anthropometric characteristics of the user population, how these characteristics influence the design, and the criteria for an effective match between the product and the user (Pheasant 1986). Anthropometric surveys of populations have been performed by several investigators (Hooton 1945, Ridder 1959, Pheasant 1986). The dimensions of chairs can be checked with simple devices such as scales or measures. The dimensional fit, which is important in the process of designing chairs, can also be used as a basis for the choice of appropriate chairs in existing workplaces. A good seat should allow a range of postures, and this can be permitted by using anthropometry in the seat design process. There is however a limitation regarding the availability of anthropometric surveys for specific user populations.

"Fitting trials" (Jones 1969) was mentioned earlier, in which the best possible dimensional fit of chairs are tested by a group of users. Both comfort and anthropometric criteria are then evaluated.

Assessment of the task and workplace

There is no accepted or widely spread method for describing the task and its requirements. Techniques which have been used are trained observer, structured or free notation, questionnaires, videofilming, photographs, time measurements, linear measurements using scales, force dynamometers, and checklists. The method chosen is mainly due to the nature of the problem.

Performance

The performance in the task can be assessed in many ways. It has been measured as speed of performance or the quality of the job performed, for example the number of errors (Less and Eickelberg 1973, Lueder 1985, McLeod et al 1980). Another approach is to assess the maximal performance possible in a task, for example measuring the maximal force which can be exerted with the hands or the feet for different chairs (Darcus and Weddell, 1947). These measures are suitable for field studies, but it has been difficult to obtain significant results when using measures of speed and accuracy of performance. Another method which can be used in field studies is recording of the total length of time periods when the seat or the workplace is used, and the average time in work and in rest for all spells in a comparison between alternative designs (Corlett and Bishop 1976).

Epidemiology

Epidemiological studies are still rare in the field of ergonomics of seated tasks. The results from such studies would be important and more are needed. Several difficulties are however present. They are expensive, cannot give detailed design recommendations and are time consuming to carry through, particularly as it can take many years for the consequences of a poor seat to develop. Case-control studies seem to be a suitable form of study (Kelsey 1975). The exposure measures are badly developed, and in cross sectional studies, selection can mask the effects (Hernberg 1984).

Analysis of the temporal pattern of loads and postures

All loads and postures are and can be described as continuous functions of time. From these, measures of the temporal pattern can be assessed. Unfortunately, this has been too much neglected in earlier investigations. For practical use, a few simple measures to describe the temporal pattern are needed, and this necessitates data reduction. Because several measures have been used in previous investigations and also with different definitions, it is difficult to compare the results. The average or mean value has often been used (Andersson and Örtengren 1974 a). Chaffin (1973) used peak loads from static biomechanical calculations. Measures of frequency and duration have also been applied, but these measures demand additional definitions (Winkel and Bendix 1986). Jonsson (1983) used an amplitude-probability distribution, which can estimate the static level, and the levels of the median and the peak loads. Amplitude histograms were used by Andersson and Örtengren (1984). There is a need for further development in this field, in spite of the work already done.

The extent of the problem

The literature review has pointed out a number of undesired consequences of inadequate seating. These can be mainly grouped under three headings, namely discomfort, disease and productivity loss. In those cases where the design of the work seats results in discomfort, disease or productivity loss, it is likely that this has an impact not only on the well-being of the people involved, but also on the economy of the individual, the company and the society.

There are some statistics available on the extent of musculoskeletal diseases and their economic consequences. Little material and statistics exist about the relation between seated work tasks and associated diseases. The following summary thus has to deal with musculoskeletal disorders irrespective of whether they have been caused by seated work tasks or not. The most commonly used measures are short and long term sickness absence, premature retirement, staff turnover, work injuries and occupational diseases records. Sometimes hospital care, visits to medical doctors, the number of operations, or enquiries are also be used. The statistics referred to below are Swedish if nothing else is mentioned.

Musculoskeletal disorders

It is difficult to estimate the prevalence or incidence of discomfort, pain or disorders from the musculoskeletal system. Clinical assessment and questionnaire studies are common in such investigations. The results of questionnaire studies are highly dependent on the formulation of the questions with respect to the definition of the symptoms and their localisation. Also the time period referred to is very important.

Few investigations have looked into all body parts of a general population in this respect. One Swedish questionnaire study of a working population referred to pain after work every day or every second day. Pain from the upper part of the back was present in 12.3%, from the lower back 12.0%, from the shoulders, arms and elbows 12.3%, from the hands or wrists 6.1%, and from the hips, legs, knees and feet 13.7% (The working environment in figures 1985). People could thus experience pain from more than one body part. The prevalence of neck and shoulder complaints varies between different investigations, but most results have shown a rate up to and around 20% in general populations (Hagberg 1982). In another study of almost 13,000 men and women from various occupational groups with a standardized questionnaire (Andersson et al 1984), 30% had experienced neck complaints at least once during the last 12 months, and 15% during the last seven days. Shoulder complaints had been experienced by 31% during the last 12 months, and by 15% during the last seven days. Complaints from the upper back had been experienced by 13% and 6% respectively, and complaints from the lower back by 41% and 16% respectively (Referensdata till YMK formulären 1985).

The extent of musculoskeletal disorders is further emphasized by results showing that they were the most common cause of impairment (Kelsey et al 1979).

Sickness absence

The most common cause for sickness absence is musculoskeletal diseases, which count for over 20% of the total number of days lost. Diseases of the respiratory system, including colds, dominate sickness absence for short term illnesses, and the musculoskeletal diseases dominate for long term illnesses (Svensson and Andersson 1981, Säll 1974). Back pain is the dominant symptom. It has been estimated that 2.6 days are lost a year on average due to back pain, which is more than 10% of all days lost. That is approximately as many lost days as for colds and other upper respiratory ailments, the second most common cause (Helander 1973). Neck and shoulder pain is also a common cause of musculoskeletal sickness absence, but not as common as back pain. Long term sickness absence, defined as more than 6 days in each case of sickness, counts for over 80% of the total sickness absence. This measure is also considered to be a better indicator of work environmental influences than short term sickness absence. 20% of the long term diseases are due to musculoskeletal diseases (The working environment in figures 1985).

According to a questionnaire study, the prevalence of musculoskeletal disorders was approximately 12% for people employed in production and transport, and 7% for people employed in office and white collar jobs. The forest industry, textile industry and mechanical industry, show high rates in this respect. The statistics show clear differences between various occupations and working environments (Yearbook of environmental statistics 1979).

The number of sickness benefit days per year was shown to be affected by the working environment, measured with the criteria in Figure 11.

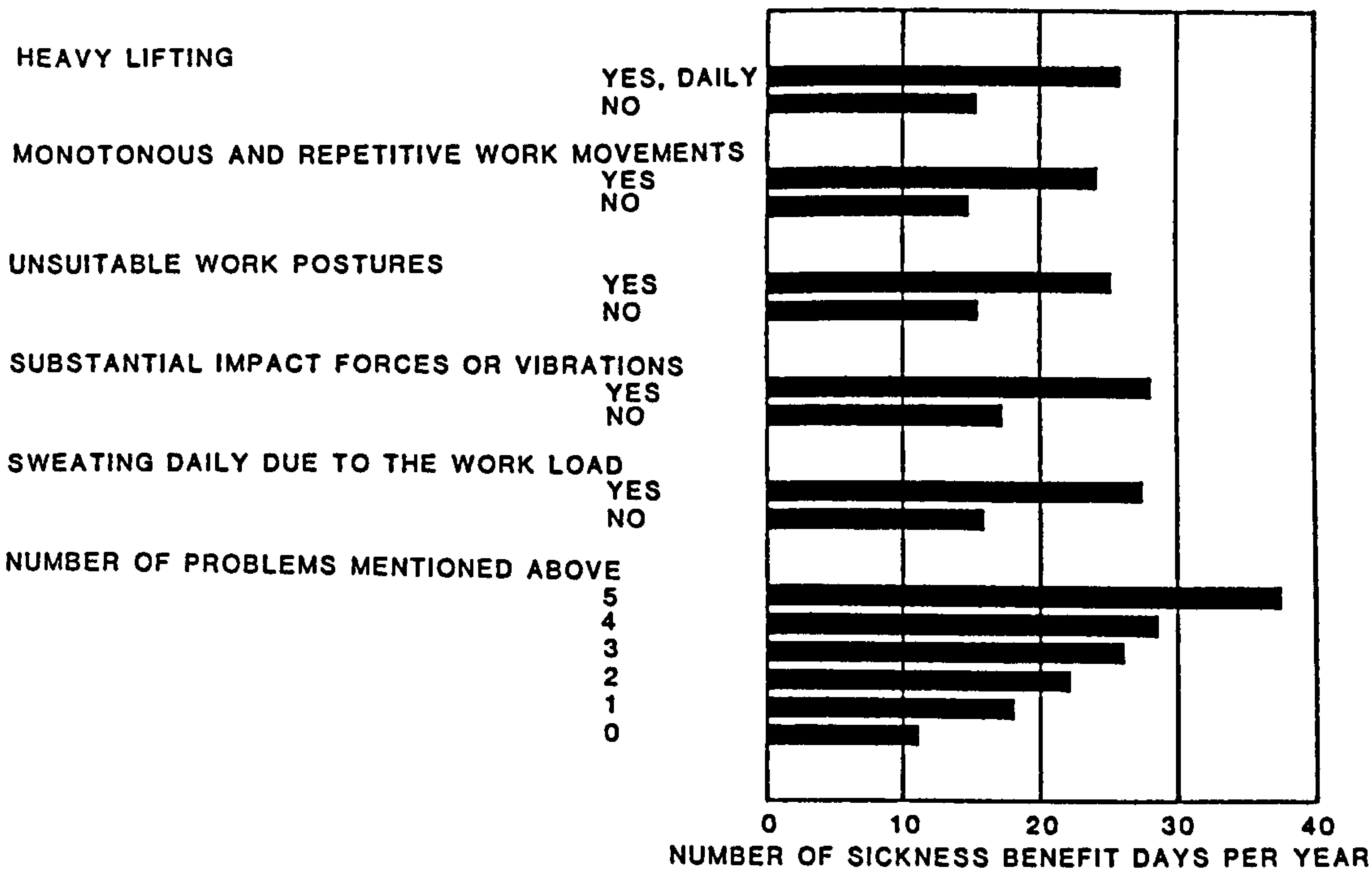


Figure 11. Sickness absence as a function of various working environment conditions. Reproduced from Yearbook of environmental statistics (1979).

Sickness absence is on the one hand likely to be underestimated in physically heavy work due to selection of healthy and fit workers at employment. Also turnover and the existence of a latency time until work-related diseases arise underestimate the work related sickness absence. The fact that heavy work tends to aggravate the symptoms among people already suffering, will overestimate the figures (Yearbook of environmental statistics 1979, Jõnsson and Lyttkens 1981, Andersson 1981). It has been estimated that at least 30% of the musculoskeletal diseases are related to work according to a Danish investigation (Litske 1985). Conclusions about causes of musculoskeletal sickness absence should be drawn with care, since there are several socio-economic factors which have a substantial influence on the sickness absence. In addition to these figures of sickness absence, there are people who are impaired without being absent from work and have to take special care in their jobs.

Work injuries and occupational diseases

Work injuries and occupational diseases are often separated in the statistics. Musculoskeletal disorders related to loadings are classified in both groups.

A majority (51%) of the occupational diseases are musculoskeletal diseases, considered to be caused by loadings. That corresponds to the total number of people involved as 8,700 out of 17,600 per year, in relation to a working population of 4,250,000 (Broberg 1984). The onset is often gradual, and most of the work related occupational diseases have neck and shoulder diagnoses.

Approximately 15,000 out of 100,000 work injuries a year are considered to be caused by overloadings. The onset is often sudden and connected with a sudden overstraining. Most of these impairments originate from the back (Broberg 1984).

Several occupational groups are over-represented in the statistics of work injuries and occupational diseases caused by loadings. Examples of such occupations are several heavy jobs such as meat cutters (neck, shoulders and back), and forest workers (shoulders and back), but also sewing machine operators (neck and shoulders), female electronics industry workers (neck and shoulders), crane drivers (neck), motor vehicle drivers (back), and fork lift truck drivers (neck, shoulders and back). As an example it can be mentioned that fork lift truck drivers are reported 2.5 times as often for the neck compared to the average for all other occupations. The number of diagnoses from the back is dominating, followed by the diagnoses from the neck and shoulders. The relative number of men affected is higher than the relative number of women (Broberg 1984).

The occupational groups mentioned not only involve sitting tasks but also tasks performed standing. There are also other sources of error in the statistics, as for example no consideration of the number of working hours for the different occupational groups.

Premature retirement

More than 5% of the Swedish population claimed premature pension in 1977, and the number is increasing (Yearbook of environmental statistics 1979). Almost 40% of the premature retirements are caused by musculoskeletal diseases, and also that figure is increasing (The working environment in figures 1985). It was estimated in Denmark (Litske 1985) that at least 60% of the premature retirements were work-related. An over-representation of certain occupational groups can be seen, namely in heavy jobs as in forestry and mining, but also in textile work and for women in electronics work (The working environment in figures 1985).

According to a study of premature retirements in a district of Sweden, 3% of all cases were fork lift truck drivers (Fendell and Lidehäll 1985). The relative proportion of fork lift truck drivers in the Swedish population is 0.6% (Broberg 1984), which indicates a several times over-representation of premature retirements for fork lift truck drivers. Unfortunately the locations of the diagnoses cannot be interpreted from the Swedish statistics on premature retirements, so further conclusions are difficult to draw. Fendell and Lidehäll (1985) pointed at the possiblity that certain occupations become a retreat for people who get impairments in other occupations. It is possible that fork lift truck driving has been a retreat for people with back pain.

The statistics on premature retirements should be interpreted with care, because they are influenced by several factors, such as for example labour market policy.

Turnover

In a Danish study, Biering-Sørensen (1983 b) estimated that 6% out of a general working population had been forced to change jobs or work functions because of their low back pain, or 10% if the figure is expressed as a proportion of people who had experienced low back pain. In the same investigation, 24% of those who worked in spite of their pain had taken special precautions in their work because of low back pain, for example complete exemption from carrying and lifting tasks, change of work seat or change of work posture (Biering-Sørensen 1983 b). Taylor, cited in Andersson (1981), came to a similar conclusion when estimating that 4% of the population changed jobs because of back pain.

An attempt was made by Svensson et al (1976) to estmate the costs for the company, caused by worker turnover. The figure naturally varies depending on the characteristics of the job, but it was estimated that for unqualified jobs in a mechanical industry, the total cost on average for one turnover was equivalent to three months salary.

Hospital care and medical services

Anderson (1971) found from a British study that 22% of the back pain sufferers were referred to hospital and 6% were admitted for treatment. Biering-Sørensen (1983 b) found that 2.8% of the total population of people aged 30–60 years had been admitted to hospital due to back pain, on average two times. Those figures are in agreement with Svensson (1981), who found that 40% of 40–47 year old men had consulted a medical doctor, 3.5% had been admitted to hospital, and 0.8% had been operated upon. Benn and Wood (1975) found in their study of back pain that 2% of the population consult a general practitioner for back pain on average 2.9 visits, 0.1% is admitted to hospital, and 0.01% is operated upon. These figures are expressed on a one year basis.

In a study (Hertzman and Lindgren 1980), the total cost for all musculoskeletal diseases in Sweden was estimated at over 10 billion Swedish kronor in the year 1975. This would correspond to a substantially higher figure in the year 1985, perhaps 25–30 billion Swedish kronor (approximately 2–2.5 billion pounds), if only the inflation was considered. The figures are in the magnitude of 4% of the gross national product.

Calculations of this kind are very difficult, since the knowledge needed for classifying the causes as work-related or not is far from complete. Also it is very uncertain how to calculate productivity losses when there is overproduction and unemployment in a society.

The costs to the Danish society of work-related musculoskeletal diseases in 1984 was estimated by Litske (1985). Hospital care and medical services amounted to 1.3 billion Danish crowns, sickness absence due to accidents and illnesses 1.6 billion Danish crowns and premature pension 5.5 billion Danish crowns. The total sum is consequently more than 8.5 billion Danish crowns, or in English currency approximately 650 million pounds.

Attempts have been made to estimate some of the costs caused by the musculoskeletal diseases in Great Britain. The cost of back pain in relation to family practitioners, community services and drugs was estimated to be at least 60 million pounds a year (Wood and Badley 1980). The national cost for hospital care of patients with back pain in the USA was estimated at 590 million pounds in 1974 (cited in Biering-Sørensen 1983 b).

Productivity

Economic losses due to discomfort, and productivity loss as a result of seating are difficult to detect and estimate. Consequently there is a lack of scientific evidence regarding the effects of inadequate seating in those terms. McLeod et al (1980) concluded that there is little empirical evidence that task performance can be affected by adjustable and ergonomically designed chairs. In laboratory and field studies they found that performance decrements were difficult to detect, but they showed a reduced performance ability for people sitting on maladjusted seats. The reduction in performance ability was related to awareness of inappropriate seating. Other investigators have indicated that improved chair design and adjustable workplace design are profitable in VDU-work from a purely economic point of view (Lueder 1985), based on results showing that performance measured as the number of key strokes could be improved by 4%. Tichauer (1973) claimed that a well-constructed chair may add as much as 40 productive minutes to the working day of each individual.

Inadequate seating arrangements can cause increased and sustained exertion of muscles of the arms. It has been shown that this type of muscle exertion can lead to discomfort and decreased performance. The performance decrements are associated with increased muscle tremor, which increases the time to perform precision positioning tasks (Chaffin 1973). It seems reasonable to assume that if the discomfort distracts people from their tasks, the productivity will be decreased. There are however also indirect results which make it probable that unsuitable workplace design causes discomfort and productivity loss (Corlett and Bishop 1976), and that inadequate seating causes fidgeting (Branton and Grayson 1967), which then is likely to cause productivity losses.

Prevention

Prevention of back, neck and shoulder pain or disease in industry meets difficulties because of the limited knowledge concerning causative factors. Also individual factors and factors outside work contribute substantially as causative factors for the disorders.

Two different techniques of prevention can be distinguished. In primary prevention, action is taken in advance, as for example redesign of workplaces and tasks. The purpose is that the disease should never occur. Secondary prevention involves identification of symptoms or presymptomatic changes at an early stage so that therapeutic action may be effective.

Snook (1978) evaluated the following three preventive approaches: training/instruction, worker selection, and job redesign. He found that instruction programs in lifting techniques could not be shown to have an effect, and it was also considered doubtful whether worker selection was effective. The most effective approach was the redesign of workplaces and tasks, and Snook considered that with this action it could be possible to reduce the prevalence of back pain by 30%. Few attempts on evaluation of prevention of neck and shoulder complaints in repetitive and static tasks can be found in the literature. Itani et al (1979) however reported a decreased rate of neck and shoulder disorders to some extent after improvements of the working conditions among film rolling workers. The measures taken were a reduction of the total operation time, an increase of the number of rest periods, a reduction of the maximum continuous operating time, improvements of seat design, and also job rotation to some extent. Westgaard and Aarås (1985) also reported decreased rates of musculoskeletal diseases following a work environment improvement programme, involving redesigned work stations and chairs. This programme was also shown to be profitable for the company. The economic savings were gained from reduced absence, reduced labour turnover, reduced training and recruitment costs and increased production (Spilling et al 1986).

Discussion and conclusions

There is a substantial body of evidence that prolonged sitting can cause impairments of health and well-being. The adverse effects discussed are back pain, shoulder and neck pain, impairments of the circulation, impairments of the digestive system and pain or discomfort due to pressure on the skin and nerves. Also, the "Gate theory" (Melzack and Wall 1965) and the present knowledge about endorphins further emphasize the possibilities of perceiving increased pain in long term sitting and repetitive tasks. However, there is a shortage of epidemiological studies in the field. The body of evidence existing is qualitative, not quantitative.

Occupational vehicle drivers is one group particularly affected by back pain. Vibration is probably one of the most important risk factors for these drivers, but they are also subjected to prolonged sitting and in many cases unfavourable postures and inadequate seats. The relevance of prolonged sitting and unfavourable postures for the development of ailments among people in seated work tasks is little known.

The desirability of maintaining a lumbar lordosis during sitting, or at least avoiding lumbar kyphosis, has been recognized for a long time. Lordosis has also been shown to decrease the lumbar disc pressure. The relative importance of lumbar lordosis in relation to increased compressive loading is still not fully explained.

Back pain was earlier considered the major problem in industrial seating. During the last decade, shoulder and neck pain have been regarded with increasing concern, and are now the clearly dominating problems in repetitive sitting tasks. The mechanisms and direct causes of these problems are little known and there are few, if any examples in the literature of largely sucessful prevention. In many cases the reasons for the ailments seem to be more related to the tasks than to the seating. Tasks involving continuous and dynamic arm movements create static muscular tensions in the shoulder muscles, with similar consequenses as for static load.

There are remarkably few studies of work seating, taking the work activities into account or giving a through description of the tasks involved. Very often totally physiological criteria and only one or two methods have been used in the studies reviewed, in spite of the literature having pointed to a large number of relevant factors. It would seem that better understanding of the demands of the work in sitting posture and seat design is needed. In particular, little has been done on "high" seating, i.e. sitting on a high seat with the trunk at standing height. This seating arrangement gives possibilites to change easily between standing and sitting.

Work postures in which the joints are free to take several positions around their neutral position (mid point) seem to cause few problems. When the work task makes this impossible and requires the worker to take a static posture, a potential risk of musculoskeletal disorders is introduced. The greater the static muscular loads or the momental loads around the joint, the greater becomes the risk. Also, the longer time periods spent in that posture without breaks or other variable patterns of loads interrupting, the greater the risk gets. Hence, ergonomic considerations in work organization mean for example that periods of standing and walking should interrupt sitting.

There is also a shortage of general ergonomic methods for evaluation of seating. This is evidently so for measurements of posture, especially methods for describing the temporal pattern of loads, postures or activities. Several methods must be used for evaluation of seating.

A large number of recommendations for seat design are scattered in the literature. They are of limited use for guidance in the design of industrial tasks and seats. In other fields, there is a substantial amount of development of new chairs and design ideas, for example office seating and vehicle seating. Many of these alternative designs tend to have been used and sold in large numbers before they have been evaluated properly. In other words, science does not seem to be at the frontiers in this respect.

The costs of work-related musculoskeletal diseases are very high, and society pays for a great part of these costs. Some influence of inappropriate ergonomic design on productivity seem probable, but no clear evidence exist. Even if the costs quoted earlier are overestimated, some research effort would seem highly profitable.

It is evident that prevention of some of the adverse effects described is possible, and can be profitable, especially if the costs to society are taken into account. The importance of improved seating in relation to other improvements is uncertain, but adequate seating definitely has the potential for improving the well-being of the workers involved.

RESEARCH OBJECTIVES

The literature review demonstrated that there is no single criterion by which the appropriateness of a work chair can be evaluated. On the contrary, there are several factors which have been shown to be important, such as spinal load, muscle load, posture, redistribution of blood flow, surface pressure on the skin and the buttocks, pressure on nerves, pressure on internal organs, and joint loads. The temporal pattern of these loads and movements is also of great importance for the occurrence of adverse effects. The application of ergonomics often has the aim of avoiding diseases due to the work, minimize discomfort, and simultaneously maximizing the ease of performing the task. To achieve this, understanding and exercise of control over the factors causing the adverse effects is needed. Not only the anatomical and physiological requirements of the body must then be regarded. Nevertheless, there are many examples of studies in which the evaluation of chairs has been reduced to one or two anatomical factors. Adverse effects of bad seating can be discomfort, pain, disease, and productivity loss. Epidemiological studies and statistics on musculoskeletal disorders demonstrate the extent of these problems in seated tasks. They also emphasize the importance of considering postures and loads on the back, neck and shoulders. Epidemiological evidence further stresses the connection between occupations and specific adverse effects. The task, the workplace, the equipment used, the work organization, the individual and also the chair influence the postural behaviour and the loads imposed on the body. All these factors are closely connected and affect one another.

One of the most central influences is the visual demand. In most cases, the ability to see the work object is necessary. The worker often has to adopt a constant viewing angle, and sometimes also a certain eye position. The distance between the eye and the work object is also determined by the size of the work object, the contrast, and the lighting. In some tasks, the degree of postural freedom is heavily restricted due to the visual demands, in the worst case allowing only one head posture, e.g. in microscope use. In order to perform the task, the necessary actions or operations must be conducted. When this requires hand operation, the fingers and the hands have to be positioned and angled in a way which is appropriate for the performance of the task. This may often require certain postures to be adopted with the lower and upper arms, and sometimes also with the trunk.

In addition to the demands from the work, it is also possible to separate other influences, which are restrictions in the work situation. Examples of restrictions are limited space for the feet, knees or legs, limited space for the hands or the arms, and restrictions of the temporal pattern in machine paced work and assembly lines. The work demands define the degrees of freedom in which the work can be performed, and the restrictions reduce the freedom available. The worker is thus forced into a less varied pattern of loadings.

Clearly then, the work situation defines one or several possible postures to be taken, mainly for the hands, arms, neck, and back, in order to be able to perform the job. The worst situation is if only one posture can be used, and again microscope work is a case in point. If, on the other hand several postures are possible, the worker is able to reduce the postural loads by using these postures within the degrees of freedom given. It will thus become possible to choose the best posture available, and after a while, change to new postures. There are many other work influences on the postures and movements chosen, such as the operation of foot controls, the force needed, the demands on precision, the length of the work periods, the pace, and the concentration needed.

Furthermore, the characteristics of the individual, for example body size, strength, endurance, ability, strategy, and experience, will have an influence on the resulting postures and effects.

A main point from this discussion is that the design of the work chair can affect the postures, pressures, loadings, and their temporal patterns on various body part structures of the user. It therefore follows that chair design can also affect the risk of work injuries, musculoskeletal diseases, and other complaints. Changed chair design is therefore a way to change postures, loadings, and pressures, and thereby also change the risk of adverse effects, in other words alleviate or partially compensate for some of the work demands.

Two important functions of work chairs are that they should support the postures and permit the movements necessary to perform the work tasks. Support should be interpreted as reducing unnecessary static postural muscle loads when maintaining the postures involved. At the same time, the chairs must restrict neither work movements nor movements in the chairs for changing posture.

The industrial seat model

The approach of this research is that by understanding how the work influences are related to the responses and effects on the sitter, and to chair design, it becomes possible to control and manipulate chair design in order to minimize adverse effects. In this way, the effectiveness of the work chair can be increased by using a systematic analysis of the most important factors rather than empirical attempts. The term effective chair design, or appropriate chair design, is defined as a design which causes no or a minimum of adverse effects. Table 7 summarizes demands and restrictions arising from the work, the initial responses and effects, and the subsequent responses and effects. The choice of methods for measurement of a seat's effects and criteria for evaluation are also enhanced and facilitated by this listing. The demands and restrictions of the task and the workplace should be seen as objective descriptions, defining the execution of the task and the characteristics of the workplace. The use of the initial responses and effects as indicators of the appropriateness of the work seats in the process of evaluating them has many advantages. A number of methods for measurement already exist. These responses and effects can also be assessed and measured immediately, which is a major advantage for design evaluations. The subsequent responses and effects represent the adverse effects. They are also longer term in their manifestation and can be more difficult to measure. Looking to the initial responses and effects allows preventive measures to be taken in the stage before the adverse effects occur.

The system for work chair evaluation outlined here starts with the analysis of the work, from which responses and effects, and also methods of measurement can be decided upon.

A procedure such as this draws attention to the work factors of importance, to the basic causes of adverse effects, and to the determinants of chair design features. A substantial amount of knowledge is still needed about this relationship. The use of this systematic approach will facilitate the choice of work chair features in relation to the work, and it will, in the longer term, increase the knowledge and the accuracy of predictions and choices. It is important to note that in industrial tasks, the demands on the chair often conflict. The work chair should for example give support in forward bent postures, upright sitting and rearward inclined postures, and it should also improve the possibilities for rotation and sideways bending of the trunk. Consequently, in many cases compromises are necessary. From the worker's point of view, the best possible chair will be the one which is most effective in supporting him in performing the task and fulfilling all the necessary functions, whilst providing the least restriction on his movements and postures. The effects that can be achieved by changed chair design in a given work situation are limited. In improving the work, it is necessary to consider the integrated picture of the workplace, the task, the chair, the environment, the organization, and the individual. By no means should the chair be regarded as more important. In many cases, changes should rather be directed towards factors other than the seat, such as the workplace and the work task.

Table 7. A model for evaluation of industrial seats in relation to the work performed.

DEMANDS AND RESTRICTIONS	RESPONSES AND EFFECTS: INITIAL	RESPONSES AND EFFECTS: SUBSEQUENT
Work task Positions required (hands, arms, back) Movements required Force required (magnitude, direction) Precision required Time restrictions (frequency, duration) Space restrictions **Workplace** Size Height Distance Angle Object Aids Space and movement restrictions Acceleration forces Visibility Light Environmental influences **Individual** Anthropometry Capacity Psychological state	Postures (back, neck, arms, trunk, legs) Loads (back, neck, shoulders, arms, legs) Pressure (inner organs, skin) Influence upon the blood flow Discomfort	Discomfort Pain Disease Reduction in performance
Measures	**Measures**	**Measures**
Workplace dimensions Work weights Work forces Work reaches Work time patterns Anthropometry Strength	Biomechanical load EMG Shrinkage Rating scales Dilation of body parts Linear measurements Posture	Rating scales Clinical examinations Epidemiological studies

Both laboratory and field studies are necessary in the process of evaluating industrial seating. Emphasis must be put on final evaluations in the field because of the complexity and variation in tasks and equipment which can be found there. Particularly difficult are compromises between conflicting demands. There are, of course, many areas suitable for laboratory studies, for example upholstery and covering materials, which can be tested for firmness, friction, moisture permeability, heat conductivity, fire, water and soil resistance. To some extent, studies of comfort, posture, loadings, and safety aspects can be made in the laboratory also. These factors should, however, be tested in the task and work environments, and by the working population expected to use the chairs, before conclusions can be drawn with general validity.

Aims of the study

The general aim of the study has been to expand knowledge about the evaluation of industrial seat design and about the choice of industrial seats for workplaces and work tasks, particularly with reference to spinal loadings. In order to achieve the goal, a number of specific aims were set out, which were to:

- define a model which specifies those factors which influence the effectiveness or appropriateness of an industrial seat.
- find or develop methods to measure and evaluate the responses of certain of these factors on the individual when using work seats.
- evaluate these methods in both laboratory and field studies.
- incorporate the results into the industrial seat model, so that a range of appropriate methods of measurement is available for a full evaluation of a seat's effectiveness.

It was decided to direct this study towards the spine, including the neck. As pointed out in the literature review, spinal ailments seem to be relatively serious in their consequences, and the spine seems to be very important and relevant for the type of adverse effects which arise in sitting tasks, connected with the chair. Other types of ailments can be more affected by the task instead.

The study was not intended to deal with preventive measures directed towards vibrations, aesthetic design of chairs, or technical specifications for the construction, maintenance, or manufacture of chairs. Nor was there an intention that the results should be directed towards the production of proposals of specified norms for industrial seating.

The work in this study has also, since the start, been based on the condition that the measures must be short term measures such as body load, which is hypothesized to be a factor causing adverse effects. Epidemiological approaches would be too slow and expensive for the purpose of assisting the design or selection of work seating.

The study was designed to test the following hypotheses:

- 1 Different seated work tasks give rise to different loads on the body of the sitter.
- 2 If the chair design changes, the loads on the body and their responses may change as a result.
- 3 The appropriateness or effectiveness of a seat can be assessed using methods which measure the body loads, their effects and responses.
- 4 The work task is a major influence on effective chair design.

It was also decided during this work to investigate if different seated work tasks give rise to different responses and effects of loads, and if the effects of loads on the sitter change as a result of changed chair design.

Hypothesis 1 was tested in Studies I, II and III, but also a comparison of the results from Studies V–IX contributed. Hypothesis 2 was tested in Studies III and V–X. Hypothesis 3 was tested in Studies II–XI, and finally hypothesis 4 was tested in Studies V, VII, VIII, X and XI.

In summary, the study was carried out in five steps. A literature review was the first step. The description and categorization of influences on seat design in the industrial seat model were based on the literature review and later revised from the experience gained in the field studies. Methods which previously had been used for evaluation of seating were assessed in the literature review. These were found unsatisfactory for the study, so new methods were developed. The new methods were proposed and then evaluated and modified in laboratory studies. The last step was to apply all the methods in field studies, and to evaluate the methods and chair design features, and the industrial seat model.

Seat evaluation

A comprehensive evaluation of seating, particularly in industrial tasks, is a multi-dimensional and extensive problem. As pointed out in the literature review, there are several factors and criteria which can be sources of inappropriate design and therefore cause an unsuitable ergonomic situation. To avoid this, a number of methods have to be used simultaneously. However, more is known about some factors than others. For example, it is relatively well known how to choose properties of padding and upholstery in applied design. The aspects of interest in this study are methods of investigating effects of basic design features and dimensions of industrial work chairs, such as height, depth, angle and shape, of the seat and the backrest. According to the seat model, evaluation of the effectiveness of industrial seating uses the initial responses and effects, which the chairs give rise to among the sitters in the short term. The demands of the methods to be used in this evaluation are that they should take the work task into account and also be sensitive to the influences of the task. The methods must be applicable in the field. They should also be sensitive to different chair design features, they should be valid for the most important problem areas, and they should be non-invasive. It should also be possible to consider the temporal patterns.

On the basis of these demands and the limitations of the study, the initial responses and effects considered most important for this study were:

- loads on the spine
- effect of spinal loads
- postures
- subjective responses

These factors also line up with the principles or criteria for good ergonomic design mentioned in the literature review.

The requirements of the methods are consequently to identify and quantify the four factors mentioned above. Measurements of disc pressure, foot volume, blood pressure and anthropometric data were not employed because the methods did not fulfil the above-mentioned needs of this investigation. EMG measurement is a suitable method for chair evaluation, but was omitted in this study due to the limitations pointed out in the literature review.

Chair evaluations also have to be performed in the field as well, due to the complexity of the influences which exist in industrial work situations, which makes it difficult or impossible to simulate them in laboratory tests.

Loads on the spine

The requirements of the methods chosen were to assess spinal loads and muscle load. Also, the methods should demonstrate the changes of loads which occur due to postures, work tasks, and different chair design. Different loading conditions can be separated, for example compressive, shear, and momental loads. It was considered that in addition to spinal compressive load, also the shear load and momental load on the spine in the sagittal plane was of interest in sitting tasks. It is important to distinguish between loads on the spine, loads on substructures of the spine (for example discs and apophysial joints), and loads on the muscles of the back.

The use of biomechanical methods is attractive when considering the requirements above. They can be used to estimate and measure the loads on the body structures of interest. A static biomechanical model was considered to be the most suitable for this study. Other reasons for the choice of biomechanical methods were that they are non-invasive and that some methods can be used without the need for expensive equipment.

Biomechanical methods were consequently considered appropriate for assessing loads on the spine, but development of particular methods for this study was needed.

Effect of spinal loads

A measure of the effect of loads on the spine was another requirement of this study. There was a need for a method of this kind which would provide an objective measure and also would be directly linked to bodily changes of the spine. Further, a measure more relevant to how the individual is affected rather than measures of the loads was needed. No method existed which fulfilled these requirements.

It was shown in the literature review that spinal load causes disc height decrease, resulting in a body height decrease. Increasing spinal loads were also shown to increase the rate of the body height loss. Assessment of body height shrinkage should thus give a measure of the spinal load, or rather the effect of spinal loads. It was assumed from the literature review to be conceivable to develop a new method for measuring the effect of spinal loads. Other factors influencing body height shrinkage must of course be controlled. It was considered that chair design should be evaluated with the criterion of obtaining as little shrinkage as possible, which is in analogy with the criterion of keeping the loads on the spine as low as possible.

Postures

The requirements of the methods used were also to assess posture. The curvature of the spine in the sagittal plane needed to be assessed. Also the body posture, or rather the positions of the body segments, needed to be determined in order to provide the biomechanical model with input data. Further, there was a need for methods to assess rotation of the spine, particularly the cervical spine.

Photography and video-filming are commonly used methods for assessing posture in the sagittal plane. It was considered that photography would be suitable in this study for assessing spinal curvature and body segment positions. Video-filming was considered appropriate for assessing spinal rotation in laboratory studies.

Reasons for the choice were that photography is an inexpensive and quick method of assessing a work posture. It was considered that if largely undressed subjects were used with markers on their joints, the accuracy of determinating the posture could be very high, but the field applicability would however suffer in that case. Photographs of subjects in working clothes would allow some accurate measurement, especially if the clothes were elastic and tightly stretched over the skin, but otherwise there would be difficulties with accuracy.

In one of the field studies, it was judged that the only possible way of assessing head posture was to use special measurement equipment, consisting of a small portable system carried by the subject for recording head angles. The method used enabled evaluation of the temporal pattern. However, further development is needed for measuring and describing the temporal pattern of posture.

Subjective responses

The requirement on the methods used was that they should assess the discomfort experienced and the subjective preferences. Reasons for using the subjective response were that it reflects many of the factors influencing seat design, for example muscle load, joint load, surface pressure, impairments of the circulation, and microclimate. Not only overall discomfort, but also information about site, intensity, quality, onset, duration, and resulting impairments gives indications of the structures strained and reasons for that. Hence, subjective evaluations can give large amounts of information if a correct assessment is made. Further, subjective assessment is also valuable in field studies as a control that other methods used are relevant.

Subjective responses to loads and postures, which arise due to the chair and work task, were assessed with existing methods which were considered adequate.

METHODS

Loads on the spine

A biomechanical method for measuring the load on the lumbar spine in sitting, using a force platform

The first method developed in this project presents the biomechanical load on the L3 disc as a continuous function of time. This was obtained by computer calculations based on the signals from a force platform. The concept of the method was that a chair and a seated subject were accommodated on a force platform, which also included the feet of the subject. The total vertical load due to the chair and the subject, and also the moments around the horizontal axes were calculated from the four vertical load transducers of the platform. The trunk was assumed to be divided by a horizontal plane at the L3 level, and free-body diagram calculations were used. The lower body parts, under the plane, were assumed to be static during work as long as the feet did not move. Also the chair was immobile.

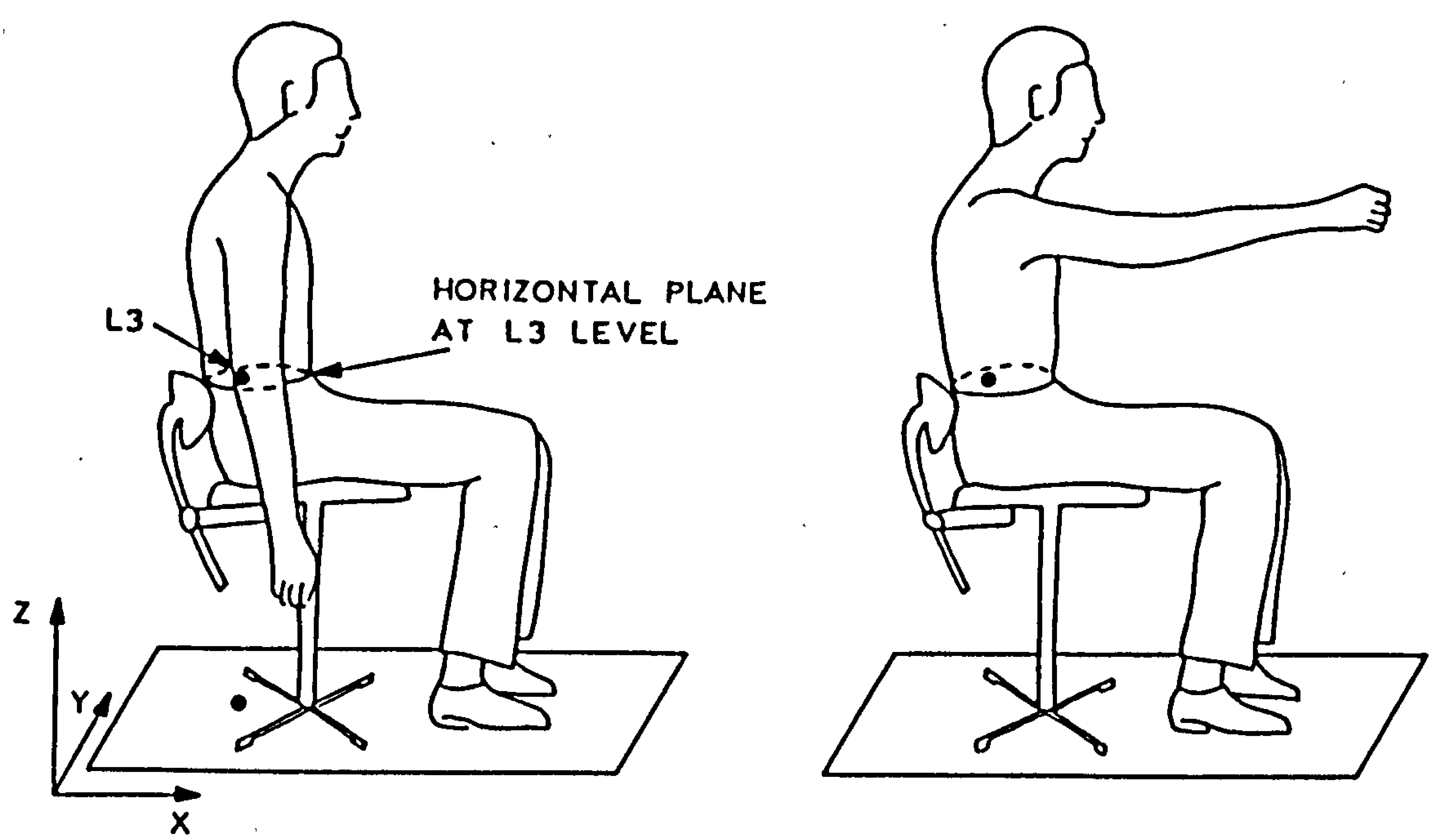


Figure 12. The seated subject, the chair and the force platform. Reproduced from Ergonomics, see Appendix 1.

Free movements of the arms, head, neck, and trunk took place. Also external vertical forces were allowed to act on the upper body, as when lifting weights or using arm supports from a workbench or a machine. It was assumed that when the subjects sat in an upright and balanced posture with the arms hanging, using a low lumbar support which gave the lumbar spine a lordosis, the centre of gravity of the upper body part was situated approximately above the L3 disc. This was based on the condition that no trunk muscle activity was needed to balance the trunk. The spinal load on the L3 disc was approximately 500 N when sitting upright on an office chair with a low lumbar support, according to disc pressure measurements (Andersson et al 1974 b, Nachemson and Elfström 1970). Changed body postures, as in bending the trunk or the head forwards or lifting an arm, increased the disc pressure, as did weight lifting.

The moment of the subject's upper body, which occured in other postures in relation to the balanced and upright sitting posture, was transmitted through the horizontal plane at L3 and to the force platform via the chair and the feet. This means that as soon as the subject leaned forward or lifted an arm, the forward acting moment from the upper body acting on the L3 plane increased, and the moment on the force platform increased too. This change of moment acting on the L3 plane was equal to the change of the moment acting on the force platform. The resulting increases of erector spinae muscle force and compressive disc load on the L3 disc were calculated according to the biomechanical model published by Andersson et al (1980) and Schultz and Andersson (1981). It was assumed that the moments were resisted by structures (mainly muscles) with one fixed lever arm for forward-backward acting moments, and with another lever arm for lateral moments. The compressive load on the L3 disc was hence calculated from the force platform readings. The assumptions were simplifications since the lever arm is dependent on several factors, for example the posture.

This method was also designed for vertical external forces acting on the upper body, by determinating the position of the vertical projection of the centre of the L3 disc on the platform, and calculating the moments around that point. The method did not deal with horizontal external forces. It must be noted that the measurement system registered the centre of pressure and not the centre of gravity, which means that acceleration forces due to fast movements of body segments in the horizontal plane gave rise to errors. The detailed mathematical background is given in Appendix 1.

The method was applied in Study I, in which a Kistler 9261A force platform, incorporating piezo-electric transducers, was used. The output signals were amplified, digitized and stored on discs, using a Digital Equipment Computer LSI-11/02. The sampling interval was 50 ms, and the total recording time 7 s. Analysis and graphical presentation of the results were performed on-line with the same computer. For more details, see Appendix 1.

A biomechanical model for assessment of spinal loads in seated tasks, using an instrumented chair

This model is a two-dimensional, sagittal-plane, static model, designed for seated work tasks. It allows the calculation of compressive, shear and momental load on the spine. The model also includes a procedure for calculation of the moment around the shoulder joints. It is valid for both horizontal and vertical external forces, acting on the body of the sitter. The model utilizes the fact that the sum of all forces acting on the body or parts of the body of the sitting person, in a static posture, is zero according to Newton's first law. In other words, the gravitational force, the reaction forces from the floor, seat and backrest, together with possible external forces due to the task, balance each other. This can be expressed in three equations, the horizontal and vertical force equlibrium and the moment equilibrium equations.

By using these equations, the output variables were calculated. These were the compressive and the shear forces in a horizontal plane of the trunk, the moment around the centre of the disc in the sagittal plane, the compressive load on the disc, and the moment around the shoulder joint. The horizontal plane could be chosen at any spinal level. Force data were obtained from an experimental chair, instrumented with eight load cells for measuring the reaction forces from the seat and the backrest. This also allowed the calculation of the positions of the reaction forces and moments acting on the backrest and the seat. In addition, the vertical force on the floor from the feet was measured with a calibrated scale. Lever arms were obtained from photographs. The method could be performed both in the field and in the laboratory. It was used in Studies II, V, VI, VII, VIII, and IX.

The equations of the model are:

$$F_f \sin f + F_s + F_e \cos e + F_h = 0 \tag{3}$$
$$F_f \cos f + F_r + F_v + F_e \sin e + mg = 0 \tag{4}$$
$$F_f d_f + F_r d_r + F_e d_e + F_h d_h + F_v d_v + F_s d_s + \\ + (m_b d_b + m_c d_c + m_d d_d + m_l d_l + m_k d_k) g = 0 \tag{5}$$

where

m – total body weight
m_b, m_c, m_d, m_k, m_l – weight of body segments
F_f, F_r, F_s, F_v, F_h – reaction forces
F_e – external force
d_i – lever arm between force i and the position for the moment calculation, $i \in \{b, c, d, l, k, f, r, s, v, h, e\}$
f – angle of reaction force from floor
e – angle of external force

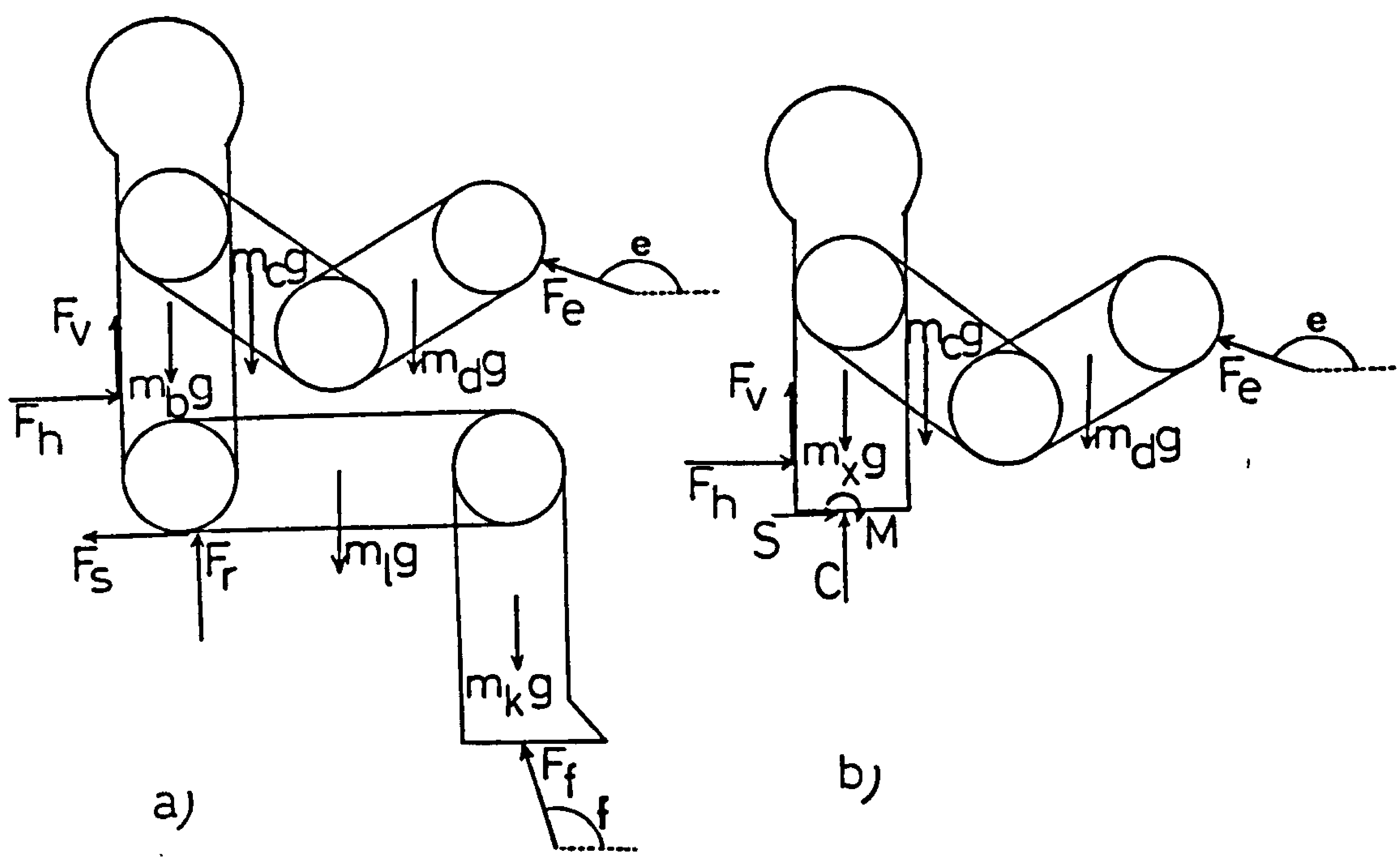


Figure 13. Forces acting on the body of a sitting person (a) and a free-body diagram of forces acting on the part of the body above a horizontal plane (b).

Forces acting on the body in the posterior direction or downwards, should be negative when used in the equations. Equation (3) includes the horizontal forces acting on the sitter, and equation (4) includes the vertical forces. The moment from all forces are included in equation (5).

The equations for the biomechanical loads are given in equations (6)–(10).

$$C = -(m_x + m_c + m_d)g - F_e \sin e - F_v \tag{6}$$
$$S = -F_e \cos e - F_h \tag{7}$$
$$M_x = -(m_x d_x + m_c d_c + m_d d_d)g - F_v d_v - F_h d_h - F_e d_e \tag{8}$$
$$M_{\text{shoulder}} = -(m_c d_{sc} + m_d d_{sd})g - F_e d_{se} \tag{9}$$
$$C_x = C + |M_x| : p \tag{10}$$

where

m_x – weight of head, neck and trunk above the plane at level x
C – compressive force in the plane at level x
S – shear force in the plane at level x
M_x – moment around the centre of the disc at level x
M_{shoulder} – moment around the sholders joint
C_x – calculated compressive load on the disc at level x
p – lever arm between the centre of the disc and structures resisting the moment M_x

Effect of spinal loads

Body height shrinkage

The normal body height decrease during a day is around 15 mm. In order to make the measure useful for ergonomics evaluations for experimental periods of 1 hour, a precision of 1 mm or less would be needed for the height measurements. To achieve this precision, stature was measured by means of a specially designed equipment. The first version, used in Study III, was modified technically, and also the procedure was changed before Study IV was performed. The description presented below pertains to the version of the equipment and procedure used in Study IV.

A major improvement of the measurement accuracy was achieved by requiring the subject to stand in an upright but slightly backwards leaning posture and supported at selected points along the back, whilst the measurements were taken. The subject's posture was controlled by using individually adjustable supports in contact with the back at each selected point. Instruction and practice improved the ability of the subjects to adopt a consistent posture from trial to trial.

The modified version of the measurement rig consisted of a stiff rectangular platform, 90×60 cm, reinforced by a framework of beams. A 210 cm high tube was attached to the frame at right angles. It could easily be removed from the frame for transport. Aluminium was chosen for its light weight. The entire rig could be tilted backwards between $0 - 20°$ by adjusting the length of its two front legs. A limited backward tilt permitted better muscular relaxation, and caused practically no change in compressive load on the spine due to gravity. Too much tilt was perceived to be more uncomfortable and also proved to be more strenous to get into and out of the measurement position. Pilot experiments indicated that an angle of 15° backwards was an acceptable value.

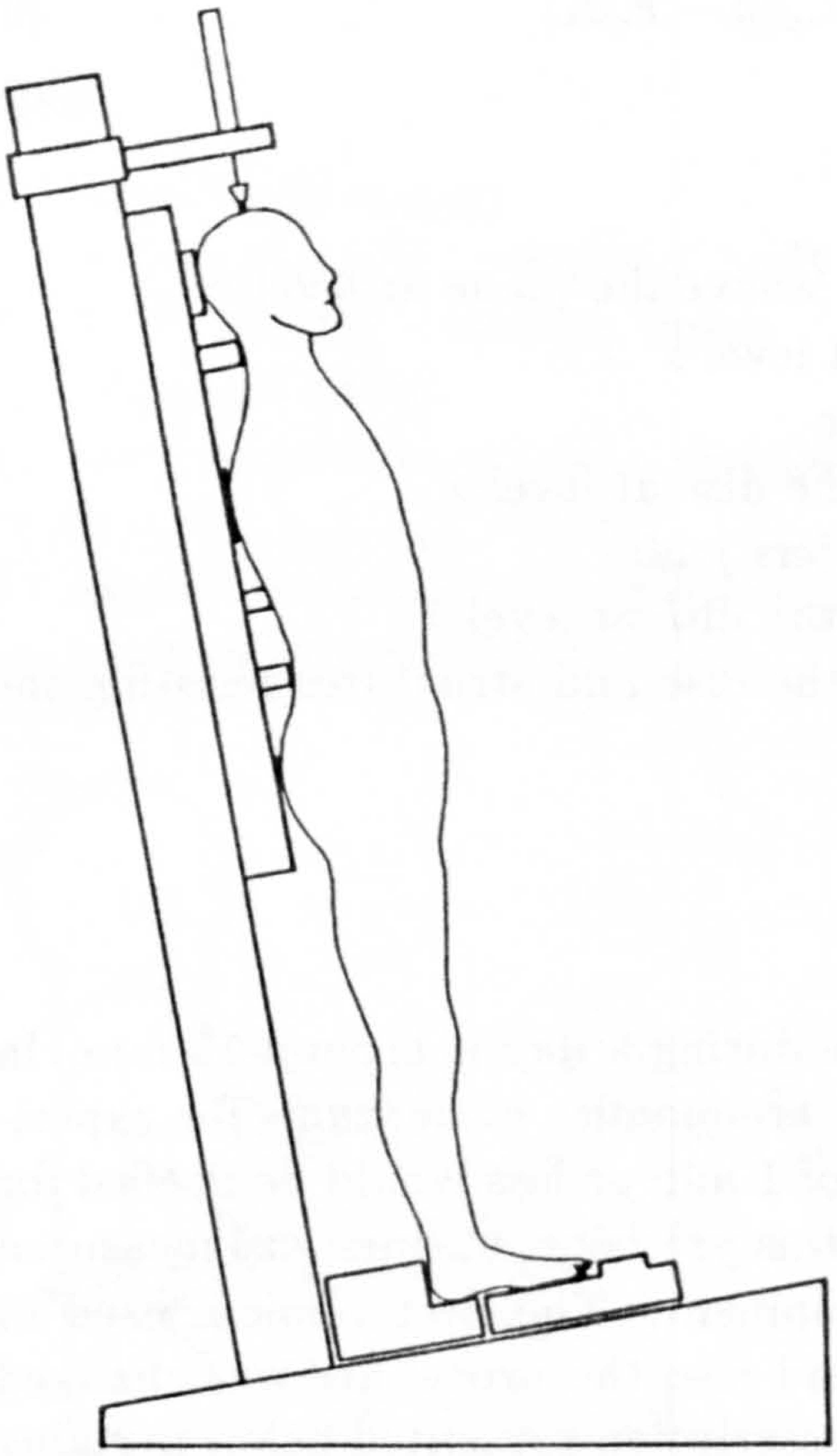
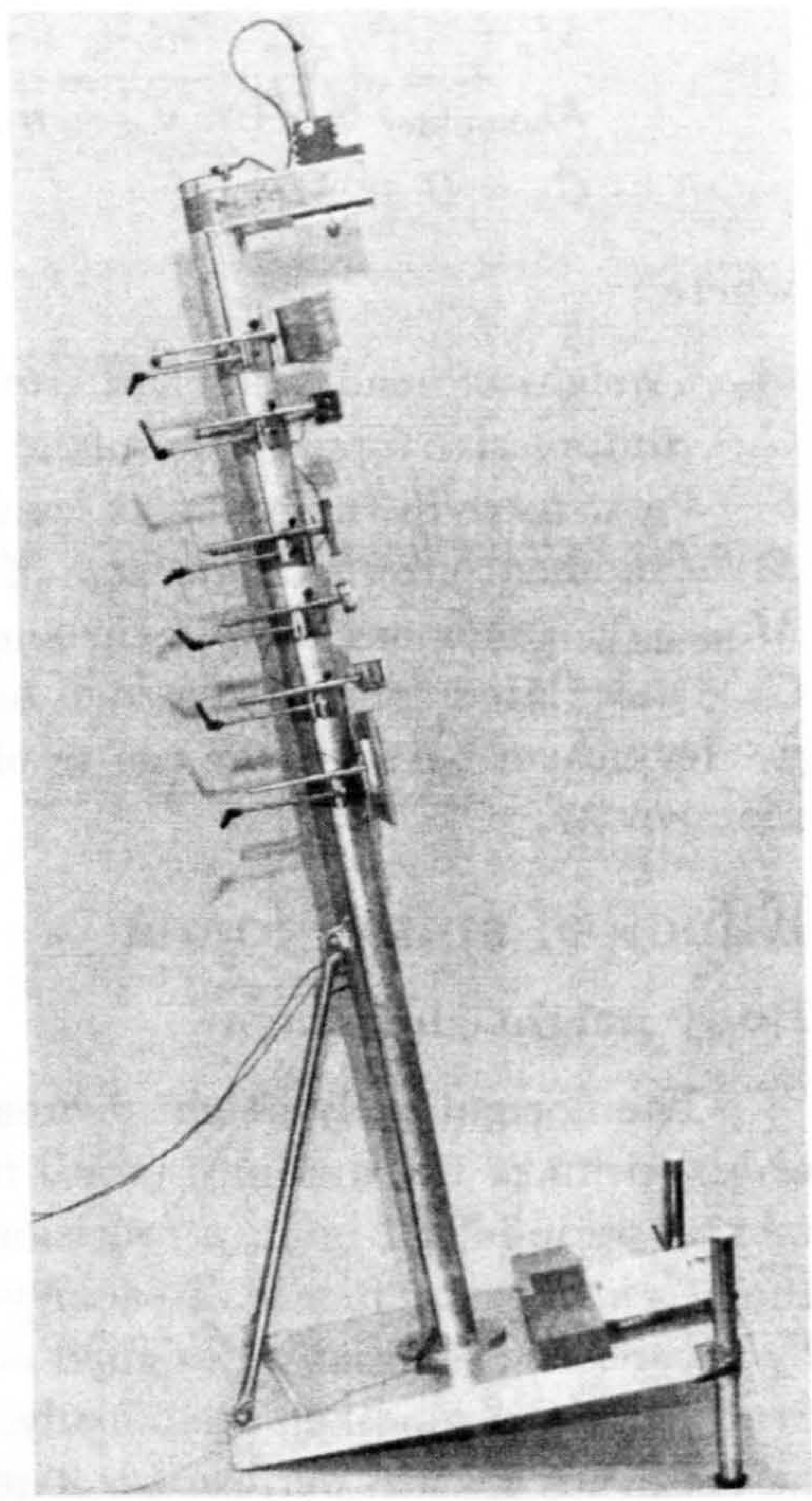



Figure 14. The principle for the body height measurements on the left, and the body height measurement equipment used on the right.

A rectangular wooden plate was placed on the platform, upon which two V-shaped profiles at a 20° angle to each other, were mounted for exact positioning of the participant's feet. The heels were thereby positioned 4 cm apart, and the soles were supported on a weighing scale with its top surface on the same level as the surface for the heels. This arrangement allowed accurately repeated foot positions and measurement of the weight distribution between heels and soles. A 5 kg variation of the weight on the soles was allowed. A larger variation could possibly increase the variability of the height measurements. The wooden plate and the scale could be moved slightly forwards or backwards, if a subject experienced knee instability or discomfort. By this action, the knees were locked in an extended position without causing a too high moment on the knees.

Six supports were mounted along the tube. They controlled the positions of selected points along the back, namely the sacrum, the mid lumbar spine, the lower thoracic spine, the mid thoracic spine, the mid cervical spine and the head. All of the supports could be adjusted in height, depth and to the sides in order to accommodate size variations of more than 95% of the population. Scales marked the positions of the supports for quick readjustment to an individual's previously used values.

The sacrum support consisted of a 9 cm high, 5 cm wide and 1.3 cm thick plate attached to a 20 cm high and 40 cm wide plate, both of wood. The larger one increased the stability around a vertical axis when standing against the supports, and made it easier for the subjects to step in and out of the rig. The four back supports were 2×5 cm, except for the mid thoracic support, which was 2×10 cm. All of the supports were rounded in the sagittal plane. Thin flexible brass sheets were mounted on these with a small air gap. These pieces of metal sheet were partially electrically insulated and constructed so that a very small force was needed to give contact between the support and the metal. Hence, they functioned as micro-switches. When all four switches made contact at the same time, a light bulb visible to the experimenter was illuminated. This arrangement ensured a more reproducible posture, even though the pressure against the supports could not be controlled.

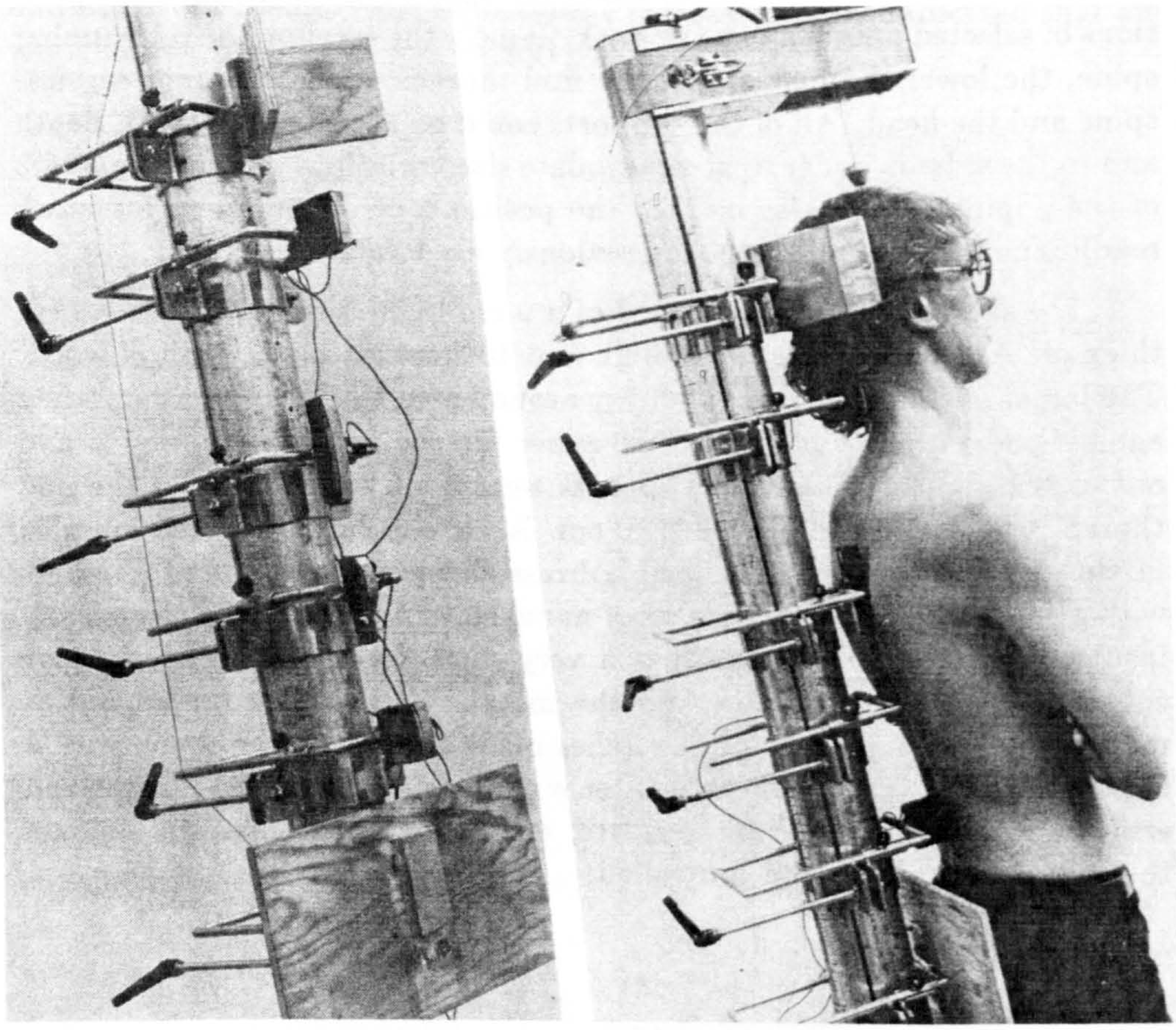


Figure 15. The back supports of the equipment on the left and a subject during measurement on the right.

The head support consisted of two wooden plates, 12 × 10 cm. These were mounted vertically in a V with 90° between them. This design of the head support increased the precision of positioning of the head. The subjects wore a spectacle frame with markers for collimation, allowing the participants to adjust the angle of the head themselves by looking to the front in a mirror. Both these arrangements positioned the head with an accuracy better than ±2 mm in the horizontal plane.

The height was measured by lowering a measurement head on to the top of the subject's head. It was connected to a linear transducer, which had an accuracy better than 0.05 mm. It could measure within a range of 14 cm and could be positioned on the central tube every 10 cm. The measurement head consisted of a 90 g weight, with five parallel cylindrical pins attached to the underside. These were 1 mm in diameter and 17 mm long. Four pins made up the corners of a 5.5 mm square with the fifth pin placed in the centre. This construction penetrated thick hair and did not cause feelings of discomfort or pressure upon the subjects' heads.

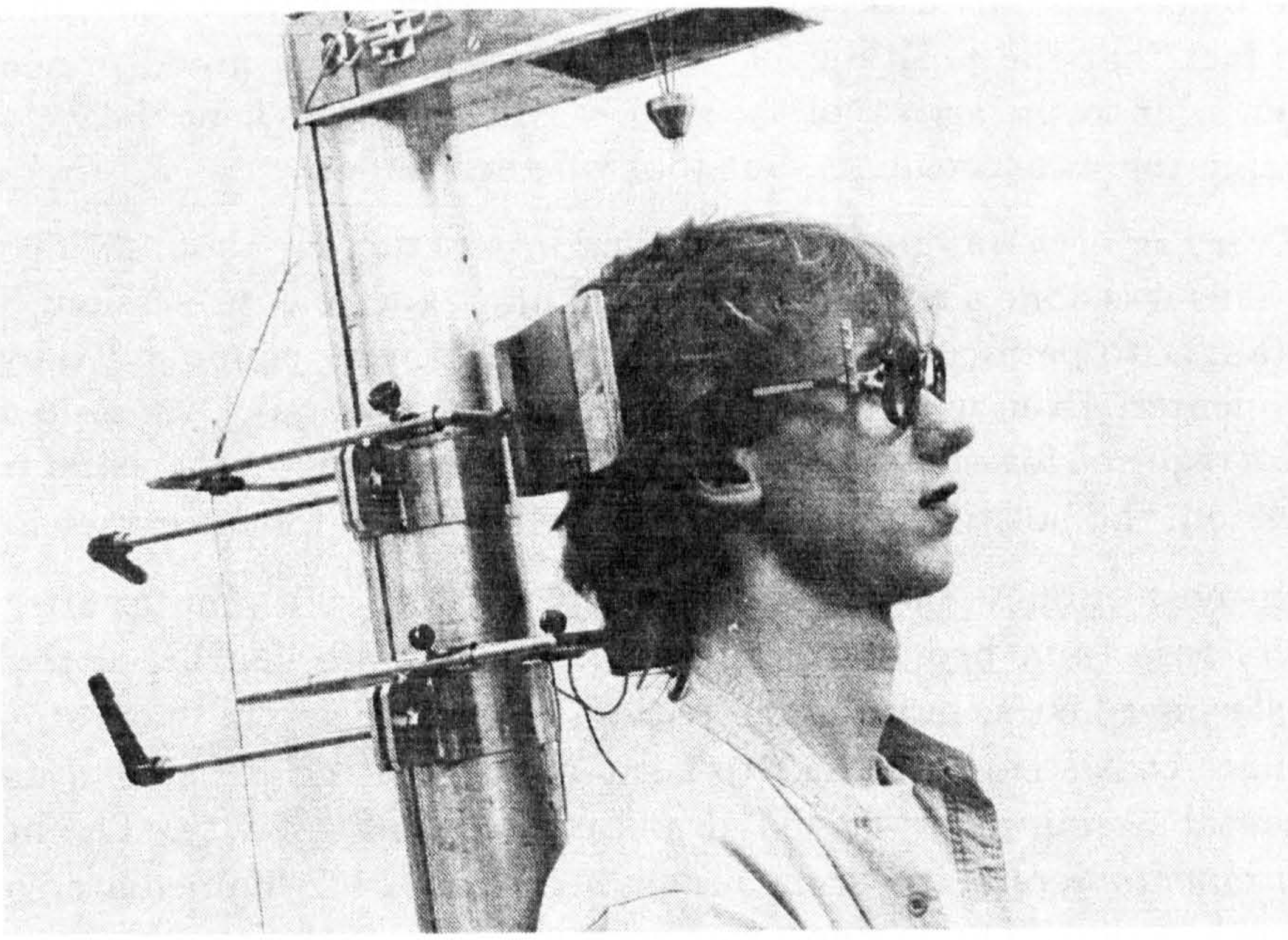


Figure 16. The measurement head, the head support, the cervical support, and the pair of glasses for controlling the head angle.

When performing the height measurements, the following procedure was adopted: The subject stepped into the rig, positioned the feet and leaned back against the sacrum support. The subject then folded the arms over the chest, inhaled, staightened the back and "rolled" the back against the supports from the bottom to the top. The head angle was adjusted by looking in the mirror, and then the subject exhaled to a relaxed level, relaxed muscle tensions and gave a signal when ready for measurement. During approximately one second the measurement head was lowered on to the subject's head, and after an additional second the height was recorded. This whole procedure was repeated five times, which allowed the determination of a mean value, giving a more correct approximation of the body height, and it also enabled the standard deviation to be calculated. Between every single measurement, the subject stepped off and back on to the plate for positioning of the feet, in order to avoid systematic errors due to foot position. If a subject noticed that a measurement felt strange or was different, a new measurement was taken to replace the old one. The experimenter noted the height readings, the weight on the scale, and the signal for contact with all four back supports. If there was no indication of contact or if the weight on the scale was outside of the approved range, a new measurement was taken to replace the incorrect one. Two additional measurements were always taken before each set of five measurements, in order to let the subjects get accustomed to the situation and to check that everything worked according to the plan. Small final adjustments often had to be carried out before the start of the experimental session, in spite of the fact that the positions of the supports had been noted previously and set prior to the arrival of the subject. The subjects kept their clothes on during the measurements, but took off their shoes.

Every subject was given training and instruction for about 20–60 minutes. This was done a few days before the first experimental session. They were taught to perform the procedures without being commanded by the experimenter. Even with little practice, the subjects quickly adopted the posture required for the measurement very consistently. On this first training session, the positions of the supports were noted for future sessions.

In most studies, the measurements started 75–90 minutes after the subjects rose from bed in the morning. They were instructed to keep their sleeping hours, morning activities, and travel to the laboratory or workplace consistent and close to their normal pattern. Usually, an experimental session incorporated 45 minutes of work activity. The height measurements were taken immediately before and then immediately after that work period. The method was used in Studies III–IX.

Postures

Photography

In four laboratory studies (Studies II, V, VI and VII), photographs were taken of the subjects in the sagittal plane and in one study also in the frontal plane. In Study II, the subjects were dressed in swim trunks, and their joint centres were marked for subsequent biomechanical evaluation. In the other laboratory studies approximate measures could be obtained because the subjects wore relatively tight clothing. In Study VII, photographs were also taken in the frontal plane for evaluation of lateral bending of the trunk and neck. Photography was also used in two of the field studies (Studies VIII and IX). The workers had to use their ordinary work clothes for safety and other reasons. These were fairly bulky. The photographs incorporated larger parallax errors since the camera had to be placed closer than 5 metres due to equipment and other workplaces obstructing the line of sight. Also parts of the worker were not visible due to machine design and the position of pallets.

Video recording

Video recording was used for documentation of work tasks, work postures and movements in Studies VII and XI. In Study VII, a laboratory study, the video camera was placed above the seated person for recording of the whole experimental session. The top of the head was marked with a stripe from side to side, and the left and right acromion were also marked. These marks allowed the angles of rotation of the head and of the shoulders to be evaluated from a TV screen with a protractor when the tapes were replayed. In Study XI, fork lift truck drivers were filmed in their ordinary work, for recording of work tasks and postures. The video-filming was performed during limited time periods in that study because of insufficient light, obstructions, and moving subjects. A large range zoom lens was used as an aid when trying to avoid obstructions of the line of sight and make use of the whole size of the screen. The recordings were only used for an overview, and no quantifications of postures were made.

Recordings of head posture

For the purpose of measuring neck rotation, flexion, and extension, an available prototype equipment was modified, tested, and used in Study XI. The modified version consisted of two main parts, a harness and a headband similar to those used for welding visors. The headband was fastened around the head of the subject. The harness, which consisted of a stiff aluminium frame with padding beneath, was placed on the shoulders of the subject and fixed in position with straps around the thorax and elastic braces attached to the waist belt. Its motion was considered to represent the thorax.

A square aluminium rod, suspended with universal joints, was connected to the headband. When the headband and the rod rotated in relation to the harness, this was registered via a potentiometer, which provided the measurements of head rotation.

Two inclinometers, consisting of a pendulum damped in oil, were also used. One was attached to the headband and the other to the harness. Head inclination was consequently measured in relation to the sagittal plane defined by the head irrespective of its rotation angle. Thorax inclination was measured via the inclinometer on the harness. The difference between the head and thorax inclination was considered to approximate neck flexion-extension.

Figure 17. The measurement equipment in use on a subject.

The signals from the equipment, and also a sound channel for task identification purposes, were recorded on a seven channel portable tape recorder (TEAC R 71). Reference values for each subject were obtained and recorded by letting them stand upright with a straight and balanced head, looking forward (zero) and then also performing maximal voluntary flexion, extension, and rotation of the neck to the left and to the right. This procedure was performed at the beginning and at the end of each recording session. For analysis, the tapes were played back and the signals were fed into an analysis system built up around a computer (PDP-11/34). The signals were digitized with a sampling rate of 5 Hz per channel. The signals were also recorded on paper using a potentiometer recorder (Linear 555), both for overview monitoring and more detailed visual evaluation of the temporal pattern of the head posture. A representative part of 8 minutes from each recording period was chosen for computer analysis. A purpose built rig was used in order to perform calibration of the equipment. Calibration measures were taken with 10° increments for all combinations of flexion, extension, and rotation, and calibration of the raw signals was done by the computer. In order to describe the temporal pattern, ámplitude histograms of neck rotation and flexion-extension were computed. In addition, a sample from each recording was plotted in an

X-Y diagram (Tektronix 4662). This allowed a simultaneous description of neck rotation and flexion- extension. In this type of diagram, frequently assumed postures stand out as clusters, thereby giving another description of the temporal pattern.

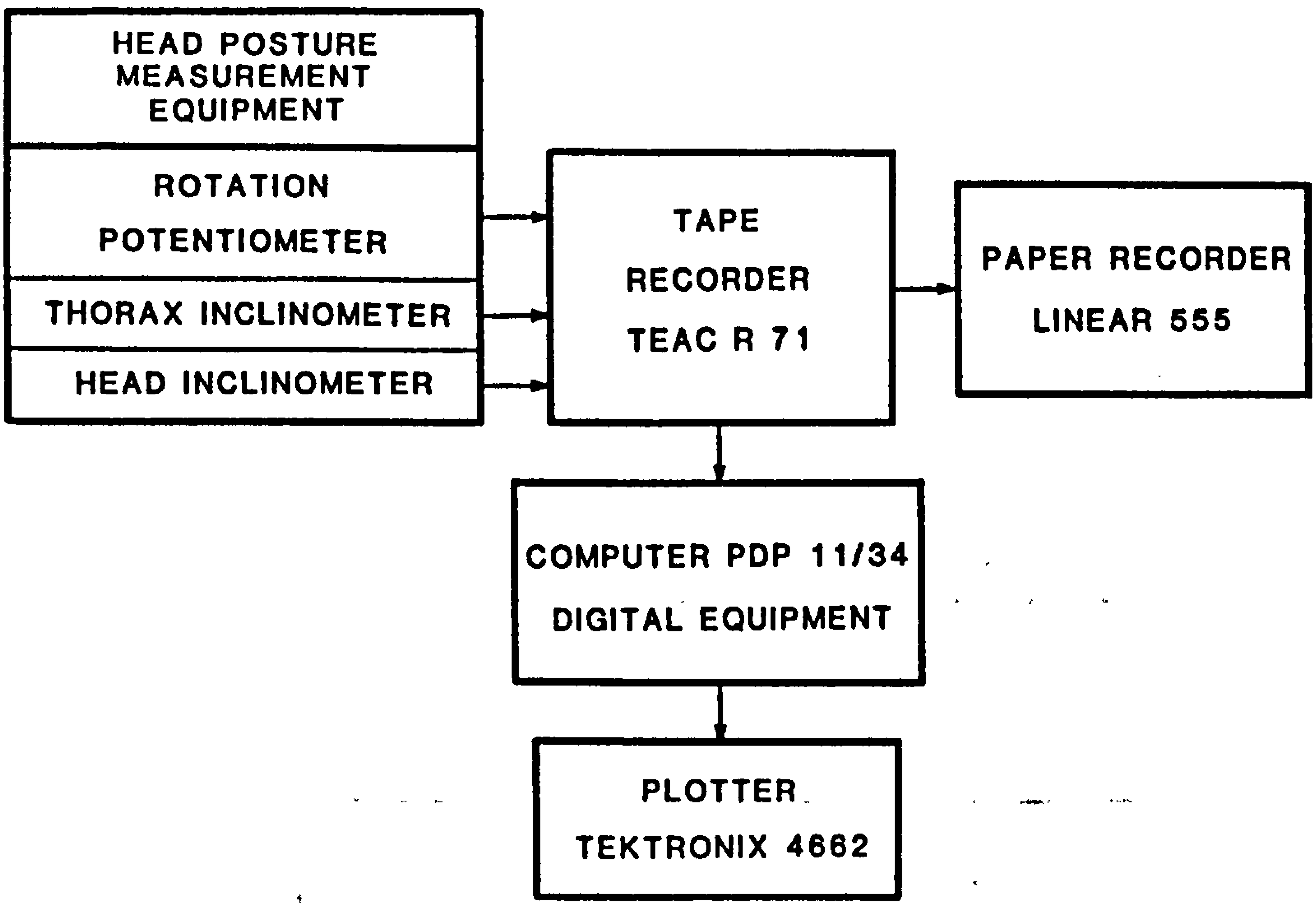


Figure 18. Block diagram of the measurement and analysis equipment.

Subjective responses

Discomfort ratings

The method used for discomfort ratings in Studies IV–X was basically the one developed by Corlett and Bishop (1976), but slightly modified. It was intended to assess the discomfort perceived at the very moment the rating was performed. Both the intensity and the body parts involved were recorded. The method involved rating of the intensity of the discomfort on a scale. Instead of using the originally devised scale with 5 or 7 levels, ranging from no discomfort to very, very high discomfort, a visual-analogue scale was used in these studies, It was graded from 0 (no discomfort) to 100 (very, very high discomfort). This rating was administered together with "body mapping", which means that the sites of discomfort were identified by pointing to a picture of a human body, marked off in sections and with a number for each predetermined body region. In these studies, the body map incorporated 10 body regions.

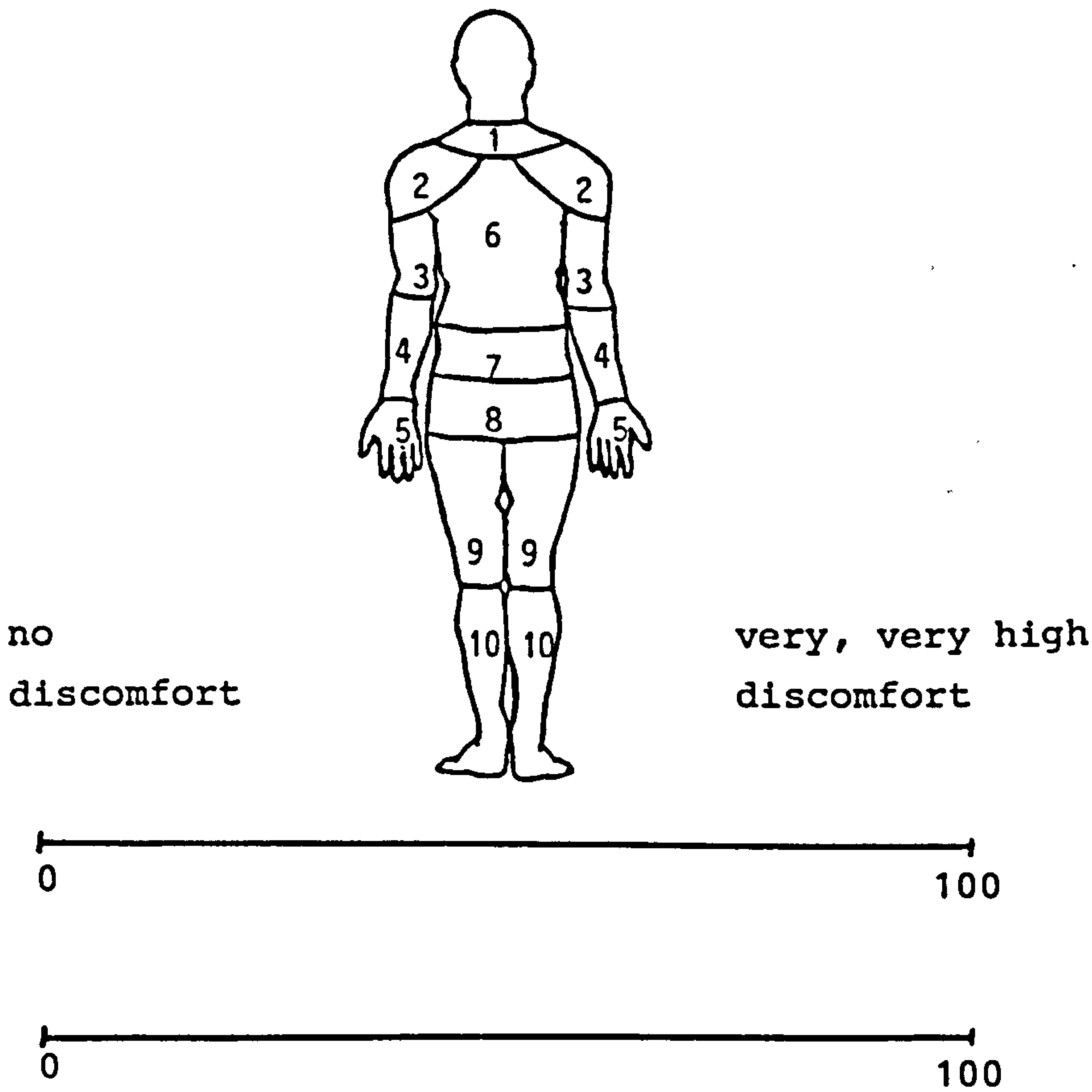


Figure 19. The body map and the rating scale used, translated from Swedish to English.

The complete forms are included in Appendix 7. They were administered by the experimenter. The first question presented to the subjects was whether they experienced any overall discomfort or not. If the answer was yes, the subject was then asked to mark on the visual-analogue scale how intensive the discomfort was. Thereafter they were asked to name the number code of the body part from which they experienced the worst discomfort, and mark upon an identical visual-analogue scale how intensive the discomfort was for that particular region. The subject was next asked to identify the second worst area of the body, giving its number code, and so on until all body parts which experienced discomfort were identified. After the last experiment was conducted, the subject was once again asked to make a relative comparison of the discomfort experienced from each body part in the two experimental conditions, using the same visual-analogue scale. Furthermore, the subjects were asked to choose the chair design they felt was best.

Interviews

In addition to the evaluation with rating scales, a final interview was conducted with the subjects in order to get a more complete picture of their experiences. In Study X, which was a field study, a questionnaire was also used, and a structured interview was conducted according to the questionnaire. This included descriptions of the work patterns, types of tasks, the subjects' comments, and also individual data. In addition, non-structured information about work tasks, exposure patterns, experiences and judgements of pain and discomfort were obtained. The questionnaire used is included in Appendix 8, translated from Swedish to English.

THE EXPERIMENTAL WORK

Study I. A biomechanical method for measuring the load on the lumbar spine in sitting, using a force platform

The development of biomechanical methods for seated work tasks and chair evaluation was according to the previous discussion considered important for this work.

The aims of the study were to develop a method for fast assessment of the time function of the lumbar spinal load in seated work tasks, and to evaluate the method against conventional biomechanical calculations, based on anthropometric data on body segments. The study was also performed in order to test hypothesis 1, namely that different tasks give rise to different loads.

The experiments

In this experimental laboratory study, the lumbar loads in a total of 15 situations were evaluated. These were obtained from the biomechanical method developed, incorporating computerized calculations of measurements from a force platform. The subjects sat in an upright and balanced posture on a work chair with a low lumbar support and with arms hanging. The chair and the feet were placed on the force platform (see the Methods chapter). The posture was held when the recording started and for approximately the first two seconds of the recording, giving the initial value, i.e. the minimum lumbar load for sitting in the chair corresponding to approximately that posture. Thereafter, the subjects moved to the new posture and performed the task according to the condition. They remained in the new posture until the recording finished after seven seconds. Meanwhile, for evaluation purposes, the experimenter manually measured the amount of displacement in the horizontal plane, of all the body segments moved and the horizontal distances between L3 and the external weights lifted. These values formed the basis for the calculation of the observed lumbar spinal loads. Anthropometric data from Clauser et al (1969) and Drillis and Contini (1966) were used to estimate body segment masses. The observed moments were calculated from these body segment masses and the horizontal distances and displacements. The same procedure was used to calculate the lumbar spinal loads as in the computerized calculations. The calculations were based on a similar approach as the one presented by Andersson et al (1980), and are given in detail in Appendix 1.

The conditions recorded were:

A Reaching forwards with extended right arm, no instructions about upper trunk movement.

B Reaching sideways with extended right arm, no instructions about upper trunk movements.

C As in A but with instructions not to move the trunk.

D As in B but with instructions not to move the trunk.

E Bending the head approximately 45° forwards.

F Bending the trunk forwards without flexing the thoracic and the cervical spines, so that the centre of gravity of the upper body changed approximately 10 cm.

G Bending the trunk to the right without flexing the thoracic and the cervical spines, so that the centre of gravity of the upper body changed approximately 10 cm.

H Changing the position of the right foot approximately 30 cm forwards.

I Slumping in the chair so that the knees were moved approximately 5 cm forwards.

J Holding a 2 kg dumb-bell approximately 20 cm forward and 20 cm to the right of L3.

K As in J but 40 cm forward and 40 cm to the right of L3.

L As in J but 50 cm forward and 50 cm to the right of L3.

M Holding a 4 kg dumb-bell approximately 20 cm forward and 20 cm to the right of L3.

N As in M but 40 cm forward and 40 cm to the right of L3.

O As in M but 50 cm forward and 50 cm to the right of L3.

Six subjects participated, three males and three females. Their mean age was 27 years (range 22–39 years), their mean weight was 69 kg (range 54–83 kg), and their mean height was 169 cm (range 156–183 cm).

In another experiment, condition P, the chair was placed on the force platform, and a 40 kg weight was placed on the chair. Another 2 kg weight was placed on the rear part of the platform. It was moved 600 mm forwards on the platform during recording, and this was repeated 5 times.

Results

The computer calculated results from condition P showed that the mean value deviated 1 N (0.4%) from the expected value and the standard deviation of the five measurements was 2 N (0.8%). It was estimated that the 2 kg weight could be positioned with an error of not more than 0.5%.

The results which demonstrated the very good precision and accuracy of the method and equipment.

The computer calculated results were presented as the graph of the time function of lumbar spinal loads as in Figure 20. From these data the temporal pattern of load was demonstrated. The numerical values of the loads were also calculated by the computer.

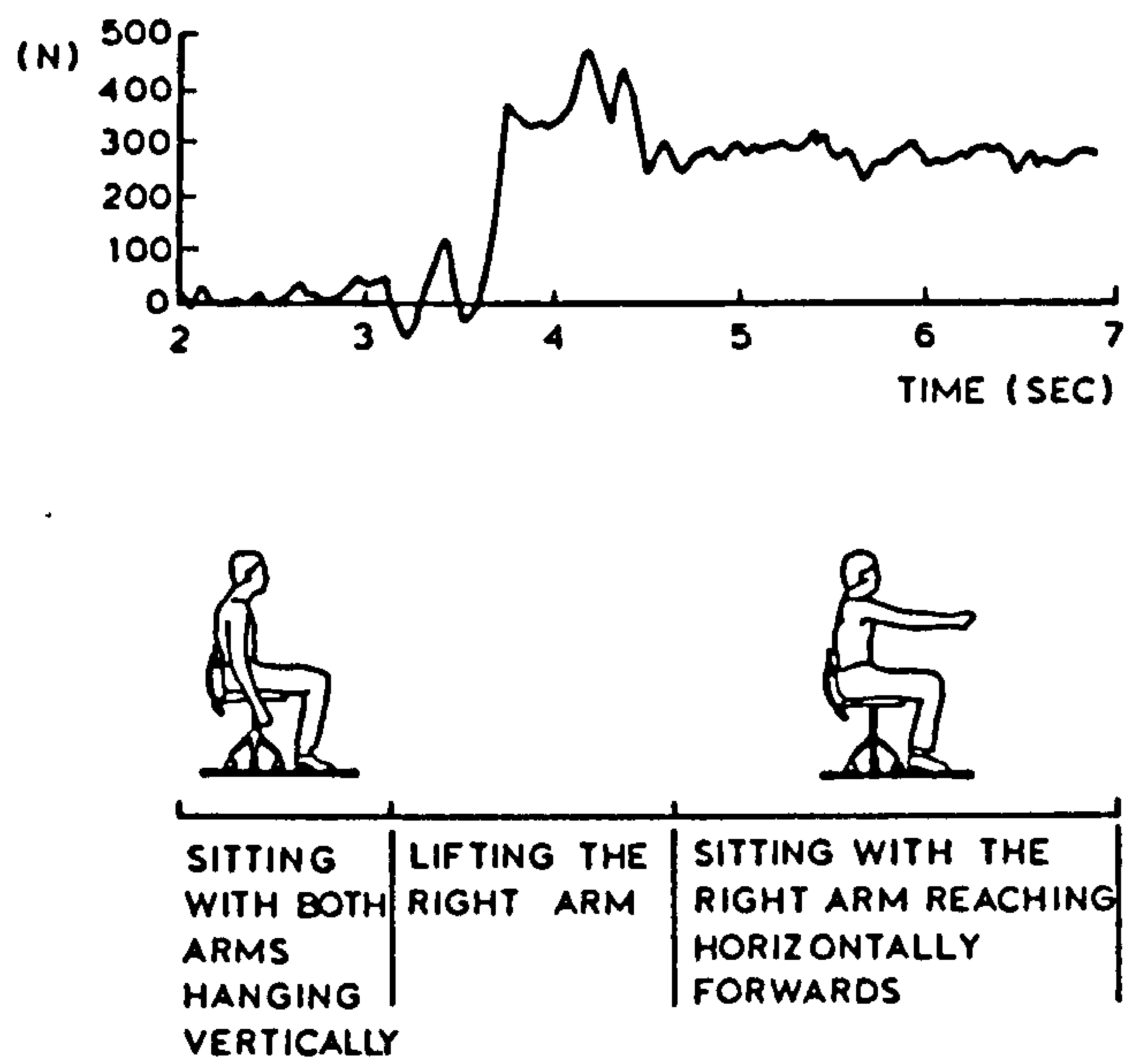


Figure 20. An example of the recordings obtained for each subject and experimental condition. Reproduced from Ergonomics (see Appendix 1).

Acceleration forces due to movements of body segments were seen, especially when the movements were performed rapidly. It was assumed that the weight of the body segments above the L3 level was 55% of the total body weight. The biomechanical load on the L3 disc was then calculated to 372 N on average when the subjects sat upright in their initial posture observed. The mean biomechanical loads on the L3 disc for the experimental conditions were thereafter calculated for the six subjects and presented in Table 8.

Table 8. Recorded mean loads compared with observed mean loads for the conditions tested. The complete set of data can be found in Appendix 1.

Condition	Biomechanical load on the L3 disc (N)		
	Observed	Recorded	Standard deviation of individual differences
A Right arm lifted forwards	580	571	42
B Right arm lifted sideways	454	423	43
C Right arm lifted forwards, no trunk movements	585	558	35
D Right arm lifted sideways, no trunk movements	475	454	28
E Bending head 45° forwards	444	447	14
F Bending trunk forwards	1089	1051	71
G Bending trunk sideways	743	791	79
H Right foot 30 cm forwards	534	558	25
I Slumping 5 cm forwards	694	726	116
J 2 kg dumb-bell at 20 cm	552	555	51
K 2 kg dumb-bell at 40 cm	779	835	61
L 2 kg dumb-bell at 50 cm	959	1040	107
M 4 kg dumb-bell at 20 cm	695	732	43
N 4 kg dumb-bell at 40 cm	1039	1120	101
O 4 kg dumb-bell at 50 cm	1393	1417	107

The results showed that the load was a function of the posture, the force exerted, and the task. It was clear from conditions B and D that some subjects compensated the extension of the arm to the right by leaning the trunk to the left, and thereby decreased the load on the lumbar spine. When reaching to fixed positions in order to lift objects, the opposite occurred, namely that the trunk was bent in the same direction as the arm. There was a tendency for the arm to be not fully extended, which could be due to the fairly high shoulder loads in conditions J–O. By this mechanism, the high load on the shoulder would be decreased, and the load on the lumbar spine increased without becoming high in relation to its maximum capability. The biomechanical spinal loads were low in relation to peak level, but the levels must by judged differently if held for long periods of time.

The resulting errors, due to the manual measurements of the body segment displacements, could be in the magnitude of 70 N. The errors from the recording and computer evaluation were shown to be smaller, given that movements of the lower body were prevented. Observations were found to be particularly difficult when spinal flexion and shoulder movements were involved. The conditions H and I tested the possible errors due to movements of the lower body, which showed the necessity to control these movements during measurements. Other sources of error were the presence of horizontal forces, inaccurately estimated position of L3 in relation to the force platform and inaccurate data used for body segment masses and muscle lever arms.

Discussion and conclusions

The force platform method was demonstrated to be suitable for the fast recording of biomechanical lumbar spinal loads in seated tasks, especially for complex postures, and to enable aspects of the temporal pattern of the loads to be evaluated. Also, the method is suitable for studying postural compensation mechanisms, such as leaning the body in the opposite direction when an arm is extended, or the effects of trunk flexion as a replacement for full arm extension when reaching to a fixed position in front of the body. The method has a good precision and accuracy, and the sources of error can be controlled. However, the biomechanical model used takes no account of the increased load which results from a less lordotic lumbar posture. The peak loads were relatively low in the tasks recorded. The individual loads arising from the tasks varied mainly between 400 N and 1500 N.

In this study, a method was developed for measuring the load on the lumbar spine in sitting, and it was evaluated in laboratory experiments. The results confirmed hypothesis 1, namely that different tasks give rise to different body loads.

Study II. A biomechanical model for assessment of spinal loads in seated tasks, using an instrumented chair

The aims of the study were to develop a comprehensive model to assess compressive, shear, and momental spinal loads at any spinal level on the individual when using work seats, and to evaluate the model and the equipment in a laboratory study. The study was performed in order to test hypothesis 1; different tasks give rise to different loads.

The experiments

This biomechanical model, developed for the calculation of compressive, shear and momental spinal loads (see Methods and Appedix 2), was evaluated in an experimental laboratory study. The subjects performed three tasks each, sitting on the instrumented experimental chair. The tasks can be seen in Figure 21.

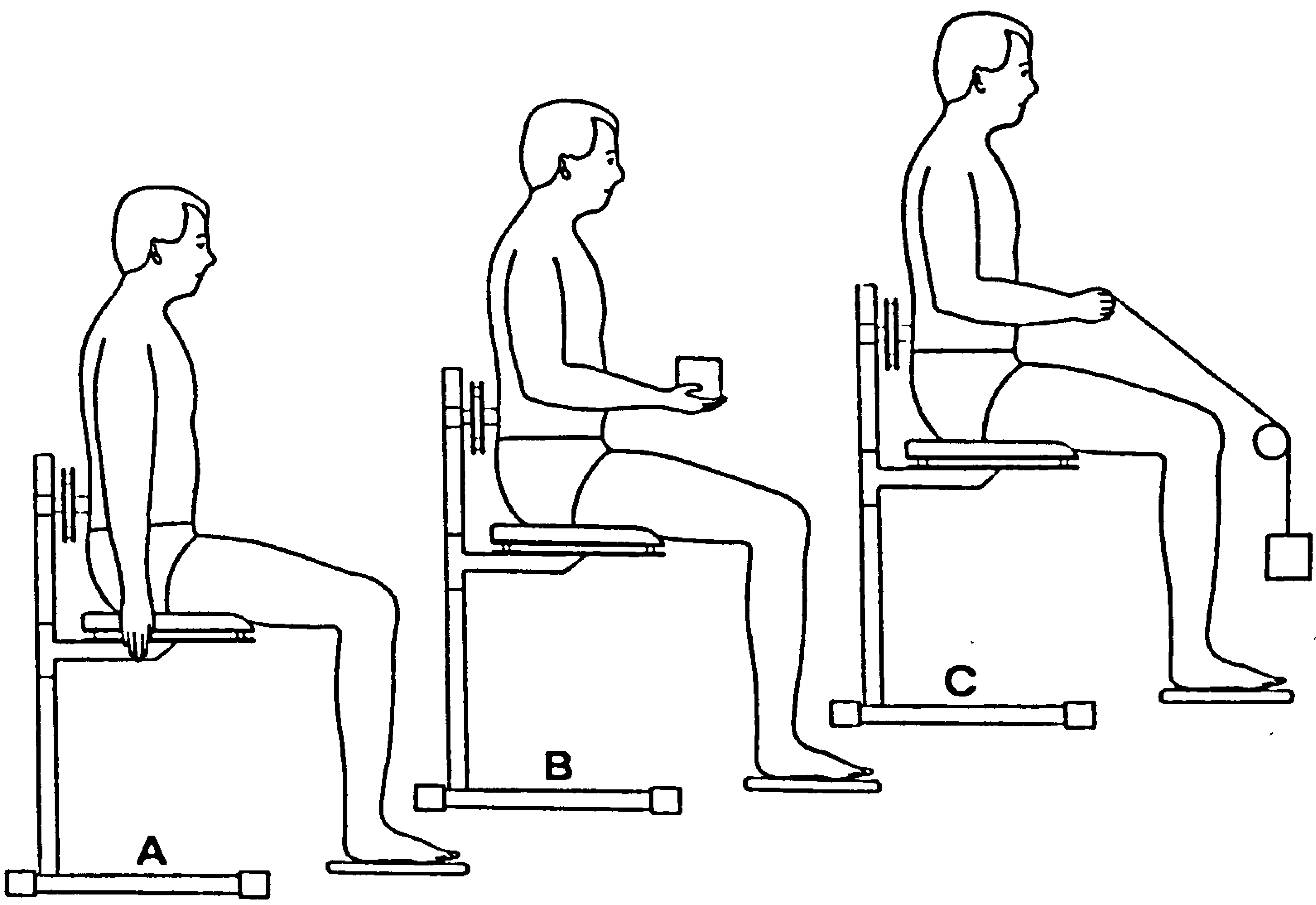


Figure 21. The three tasks performed by the subjects.
A. Sitting straight, looking forwards with hanging arms.
B. Sitting straight, holding a 5 kg weight in their hands.
C. Pulling a rope upwards and backwards, with a force of 49 N.

These tasks and postures were held for two minutes each. The strain gauge equipped experimental chair had a padded seat pan 44 cm wide and 40 cm deep, and a square bar 35 × 4 × 4 cm, with a thin padding, as backrest. It swivelled freely around a horizontal axis. The arrangement allowed measurements of the horizontal and vertical reaction forces of the seat and the backrest. These reaction forces and the vertical force transmitted from the feet to an adjustable footrest were measured during the time period the subjects held their postures. At the same time, a photograph was taken in the sagittal plane.

The subjects were dressed in swimming trunks. Before the experiment, dark marks were placed to represent the rotational axes of the shoulder joint, the elbow joint, the ulnar styloid, the hip joint, the knee joint, and the ankle joint. The coordinates of these axes in the sagittal plane were digitized manually. These coordinates, the measured forces, and the weights of the subjects were fed into a computer for calculation of the results according to the model. Masses of body segments were taken from Dempster (1955). It was assumed that the weight of the head, neck and trunk above the L4 plane was 40% of the body weight.

Seven subjects participated in the study. Their mean age was 35 years (range 33–36 years), their mean height 172 cm (range 152–188 cm) and their mean weight 63 kg (range 49-81 kg).

Results

The vertical forces acting on the body were calculated separately for downwards acting forces and upwards acting forces. The downwards acting forces were gravitational forces from the five body segments, the weight lifted in task B, and the vertical force component from the rope in task C. The upwards acting forces were the vertical components of the reaction forces from the floor, the seat and the backrest. These should equal one another, and the differences express errors, including measurement errors. The upwards and the downwards acting forces, i.e. the measured and the known forces, were plotted against one another in Figure 22. All 21 values show a good agreement between these forces, and the coefficient of correlation was 0.998.

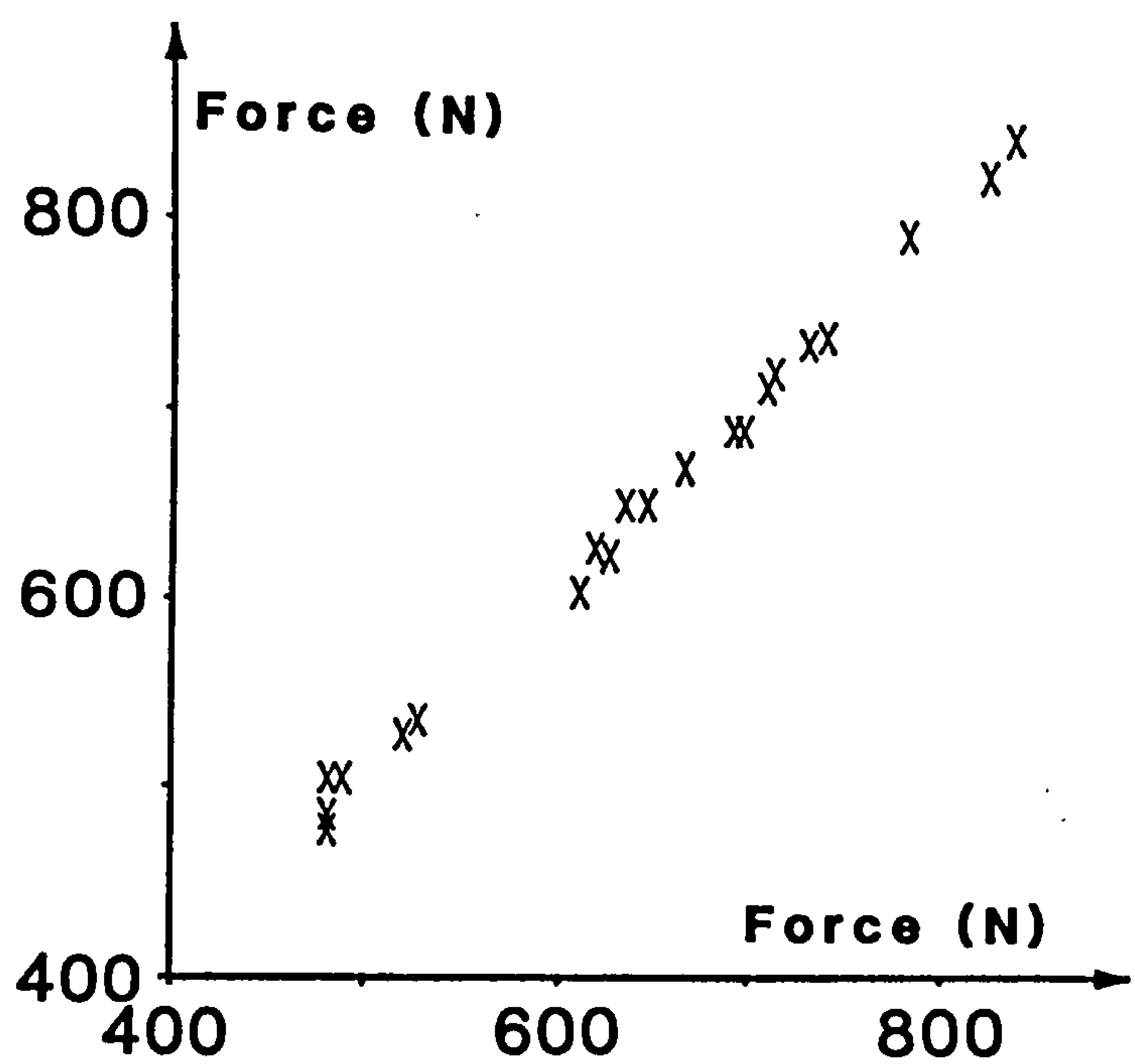


Figure 22. Postitive vertical forces plotted against negative vertical forces acting on the bodies of the subjects.

In the planning of the study, it was assumed that there was no horizontal force component acting on the feet. The horizontal backrest force and the horizontal component of the force from the rope in task C acted in the positive direction, and the friction force from the seat acted in the negative direction. The agreement between these horizontal forces was not as good as for the vertical forces. The coefficient of correlation was

0.789. The differences obtained were judged to be due to the horizontal component of the reaction force acting on the feet, which was not measured.

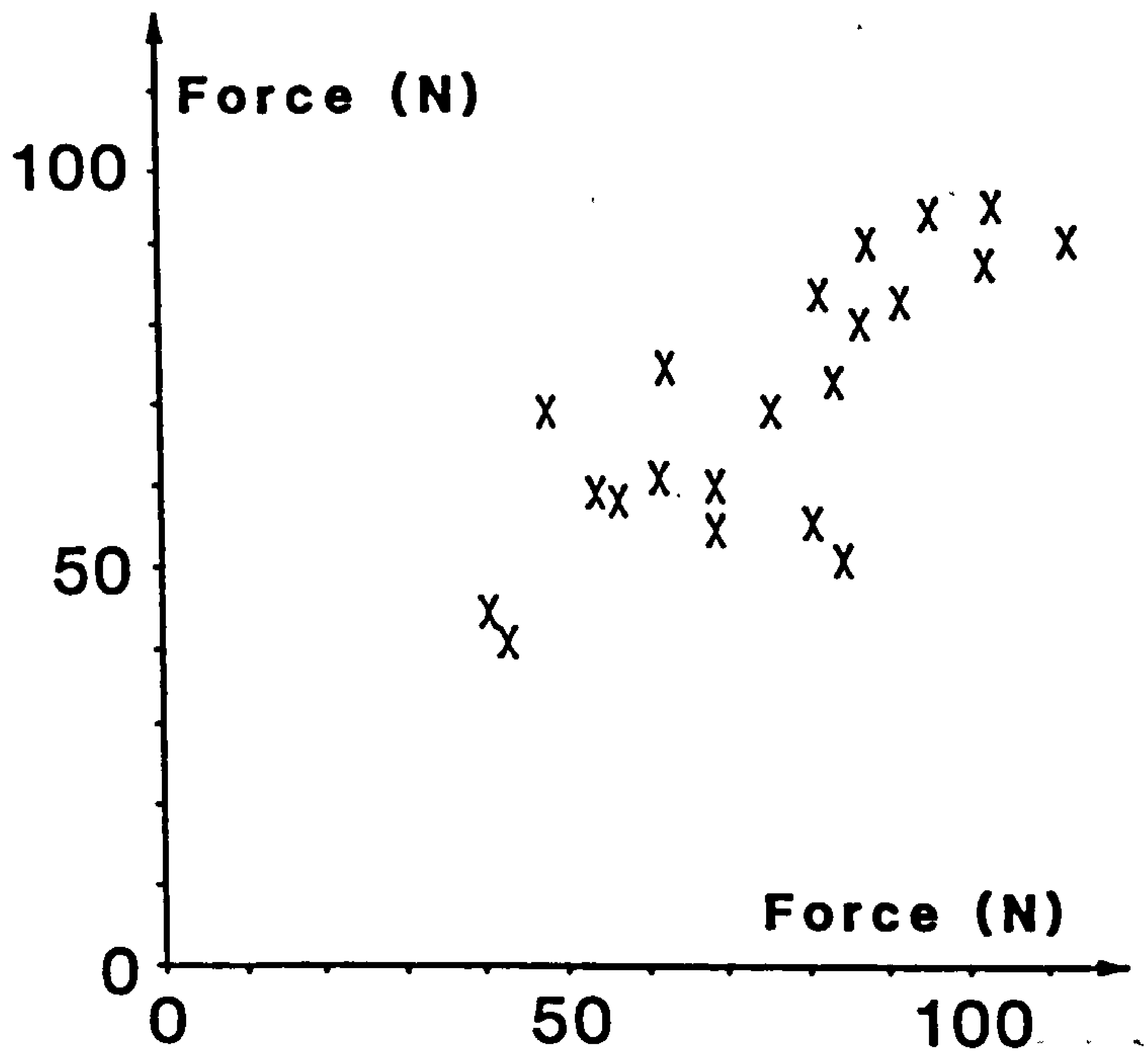


Figure 23. Positive horizontal forces plotted against negative horizontal forces acting on the body of the subjects.

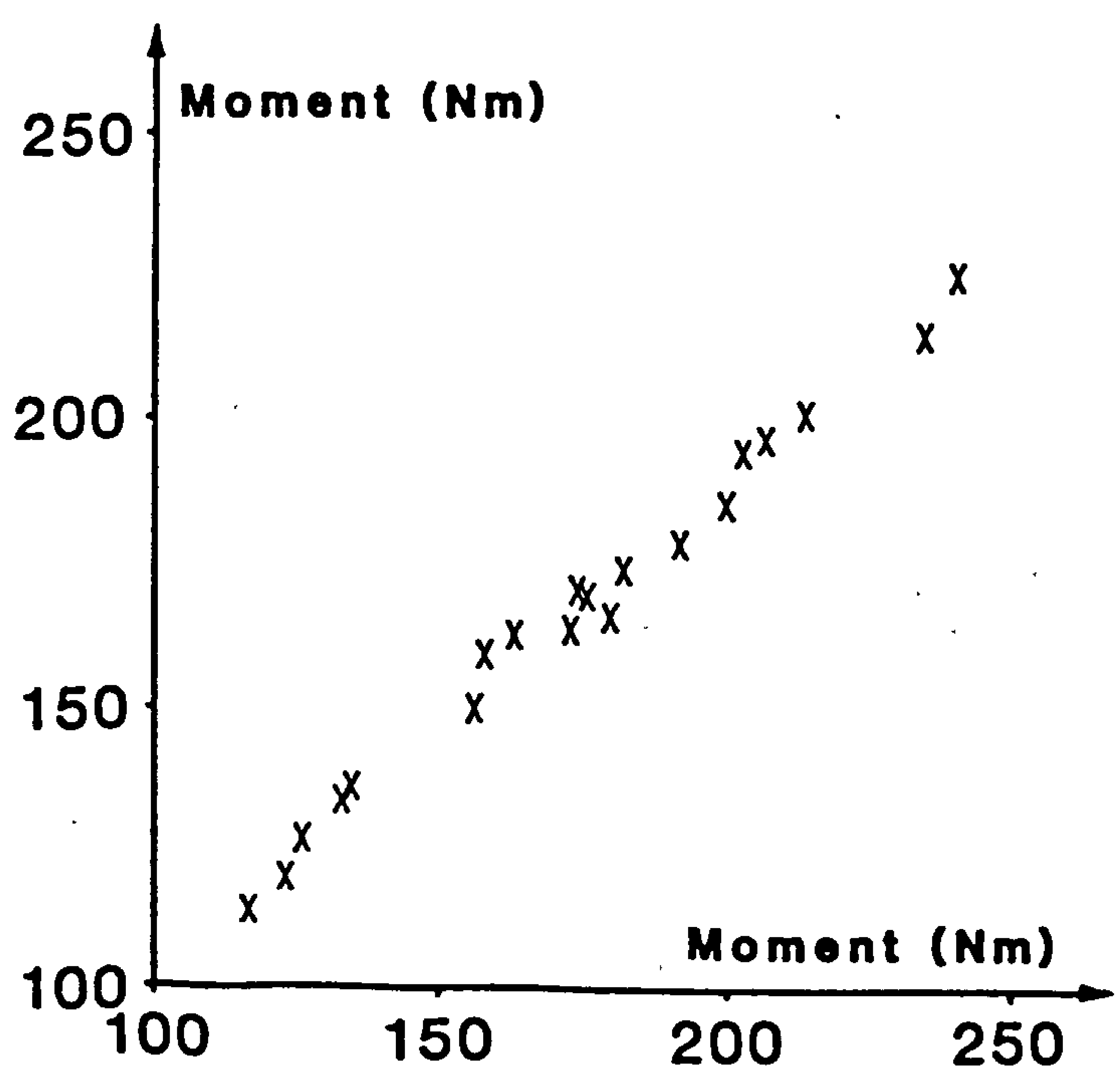


Figure 24. The total positive moment plotted against the total negative moment of forces acting on the body segments of the subjects.

The sum of the positive moment factors agreed well with the sum of the negative moment factors, which can be seen in Figure 24. The coefficient of correlation was 0.994.

The calculations of spinal loads were carried out at the L4 level, using a free-body diagram. The results showed that the compressive forces in the horizontal plane through the trunk at the L4 level increased during weight lifting and upwards force exertion. The shear force in this plane, just below the backrest, was dependent on the backrest force and the external forces. The backrest force, and therefore also the shear force, was lower in the lifting task. The forward bending moment around the L4 disc was higher in the lifting task. This also resulted in a higher compressive load on the L4 disc, which was calculated from the compressive load in the plane and the forward bending moment.

Table 9. Computed mean biomechanical loads, followed by the standard deviation, for the seven subjects in the three tasks.

	Hanging arm	Holding 5 kg	Pulling 49 N
Compressive force in L4 plane (N)	288 (68)	347 (65)	325 (69)
Shear force in L4 plane (N)	84 (19)	56 (15)	88 (9)
Moment around L4 (Nm)	25 (7)	41 (11)	33 (14)
Calculated spinal load on L4 (N)	785 (202)	1168 (269)	985 (342)

In addition, calculations were made of the moment from the upper body, acting around a horizontal axis through the hip joints. For this particular calculation it was assumed that the upper body was undeformable and hinged around this axis. The results showed that the backrest force was higher than would be expected to only support an undeformable trunk freely hinged around the hip joint axis. Hence, the assumption above was shown to be inappropriate. Parts of the backrest force consequently resisted an internally generated moment around the hip axis. The internal moment was judged to be due to leg muscle forces and gravitational forces, causing a pelvic tilt. This could also be expressed in another way, that a part of the backrest force created a lumbar lordosis, or rather decreased the lumbar kyphosis and the pelvic tilt. In task A, this part of the backrest force was calculated to be 39 N on average, but it must be noted that trunk and leg muscle activity affects this value.

Discussion and conclusions

In this evaluation study of the model, it was shown that the model and the equipment were suitable for the intention. It was also shown that horizontal reaction forces from the feet can be present. The model permits three unknown factors to be calculated instead of measured. It is often easier to measure the reaction forces and their positions than the external force acting on the hands, when applying the model in industrial tasks. In this study, the horizontal reaction force from the feet could be calculated, since it was the only force not measured or known. However, the demands on the measurement equipment are higher if small forces are to be mathematically determined from measurements of larger forces.

The calculated compressive load on the L4 disc in task A, 785 N, was relatively high, which depended on the postures assumed by the subjects in the experiment.

The spine can be loaded with compressive forces, anterior-posterior shear forces, lateral shear forces, forward-backward bending moments, lateral bending moments, and torsion moments, These loadings stress different substructures of the spine. Better knowledge is needed about how these various loading conditions arise from industrial tasks, in order to find relationships with the occurrence of discomfort, pain and disease of the back. The model presented enables calculations of compressive, shear, and momental loads on the spine in the sagittal plane to be done. It can be used at any chosen level of the spine. The model is suitable for the comparison of loads, chairs, and workplace equipment in relation to the task. It was shown to be quick and inexpensive in its computerized version.

The free-body diagram calculations can be applied to the upper body part only, or to the lower body part only. The concept of the model can be used for relative comparisons between two loading situations without performing all of the outlined calculations. It is also possible to use only parts of the model in certain circumstances.

The result from this study confirmed hypothesis 1, namely that different tasks give rise to different body loads.

Study III. Shrinkage as a measure of the effect of loads on the spine

It was noted in the literature review that reduction in stature over the day is a well recognized phenomenon, and that changes in stature have been related to changes in body loadings. In the Methods chapter, a device for the precise measurement of stature was described. The experiments were performed in order to define more precise relationships between spinal loads and stature changes, and to test if these changes could be used as a measure in the investigation of industrial seating. The aims of the study were thus to develop the method of using body height shrinkage as a measure of the effect of spinal loads on the individual when using work seats, and to evaluate the use of the method in laboratory experiments.

The study was also performed in order to test hypotheses 1, 2 and 3, namely that different tasks give different loads on the body, that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and their effects.

The experiments

The eight experiments described below were performed using, as the dependent variable, body height shrinkage. Each experiment incorporated one, two, or three spinal loading conditions. In all but two of the experiments, four subjects participated. Their body heights were measured in the rig described in Appendix 3, using the procedure developed for this purpose. Body height was determined from five consecutive measurements. The standard deviation obtained with the height measurements was less than 1 mm. All subjects learned the measurement procedure within half an hour. A set of five height readings usually took 3–4 minutes. The equipment and procedure used are described in detail in Appendix 3. Several modifications to the procedure and the equipment were introduced after this study and before Study IV, which were reported in the Methods chapter.

The eight experiments were:

Experiment A. Measurements of height were made every three hours throughout an ordinary working day with sedentary activity.

Experiment B. Measurements were taken every half hour, with subjects lying down between the measurements. The experiment started in late afternoon and continued for 1.5 hours.

Experiment C. Measurements were taken every 12 minutes during one hour, with the subject standing between the measurements. The experiment was performed around mid-day.

Experiment D. Measurements were taken before and after one hour of sedentary activity. This was repeated another day with corresponding activity but with a 14 kg shoulder load. The time between getting up in the morning and the start of the experiments was held constant.

Experiment E. Measurements were taken before and after each of the three following activities: 1 hour of standing, followed by 30 minutes of standing and carrying a 14 kg bag in one hand (11 kg for women), followed by 15 minutes of lying down. The subjects were allowed to change hands in the carrying task when they experienced too much discomfort. The experiment was performed in the morning.

Experiment F. In this experiment, only three subjects participated. Each subject sat for 1.5 hours on each of three chairs during one day, doing ordinary sedentary work. Two sessions were performed in the morning and one in the afternoon. The three chairs were a stool, an office chair with a lumbar support, and an easy chair with a full-size backrest, inclined 110° and with a 4 cm deep lumbar support. The order of the chairs was different for each subject.

Experiment G. Measurements were taken before, between and after two half-hour experiments. The sitting subject pushed one of two levers forward, exerting 25 N alternately with the left and right hands. One lever was placed on each side, approximately 40 cm to the side, 35 cm forward, and 25 cm above L3. For one half-hour period, a chair with a full-size backrest was used, and for the other period,the same chair without the backrest was used. For two subjects, the order of the chairs was reversed. In addition, the subjects rated their discomfort and related it to body parts, as described in the Methods chapter. They also performed maximal voluntary push forces in both chairs. The sitting posture was upright, in other words horizontal thighs and vertical trunk.

Experiment H. Measurements of the height of one subject were performed throughout one working day, with sedentary activity.

Several subjects participated in more than one experiment. In total there were 15 subjects, five of whom were women. Their mean age was 27 years (range 22–39 years), and their mean height was 173 cm (range 157–189 cm).

Results

The standard deviation of the body height measurements, based on all sets of readings, was 0.63 mm. The individual values varied between 0.37 and 0.87 mm.

The results from experiment A in Figure 25 show how the body height decreased during a working day with sedentary activity. The rate of the shrinkage was decreasing throughout the day. The body height increase during lying down in experiment B took place at a high rate in the beginning, but it also decreased with time. Since people spend less time lying in bed than in other activities, the rate of the recovery must be faster than the rate of shrinkage, which also is indicated in Figure 25. Both the shrinkage curve and the recovery curve have similarities with exponential curves.

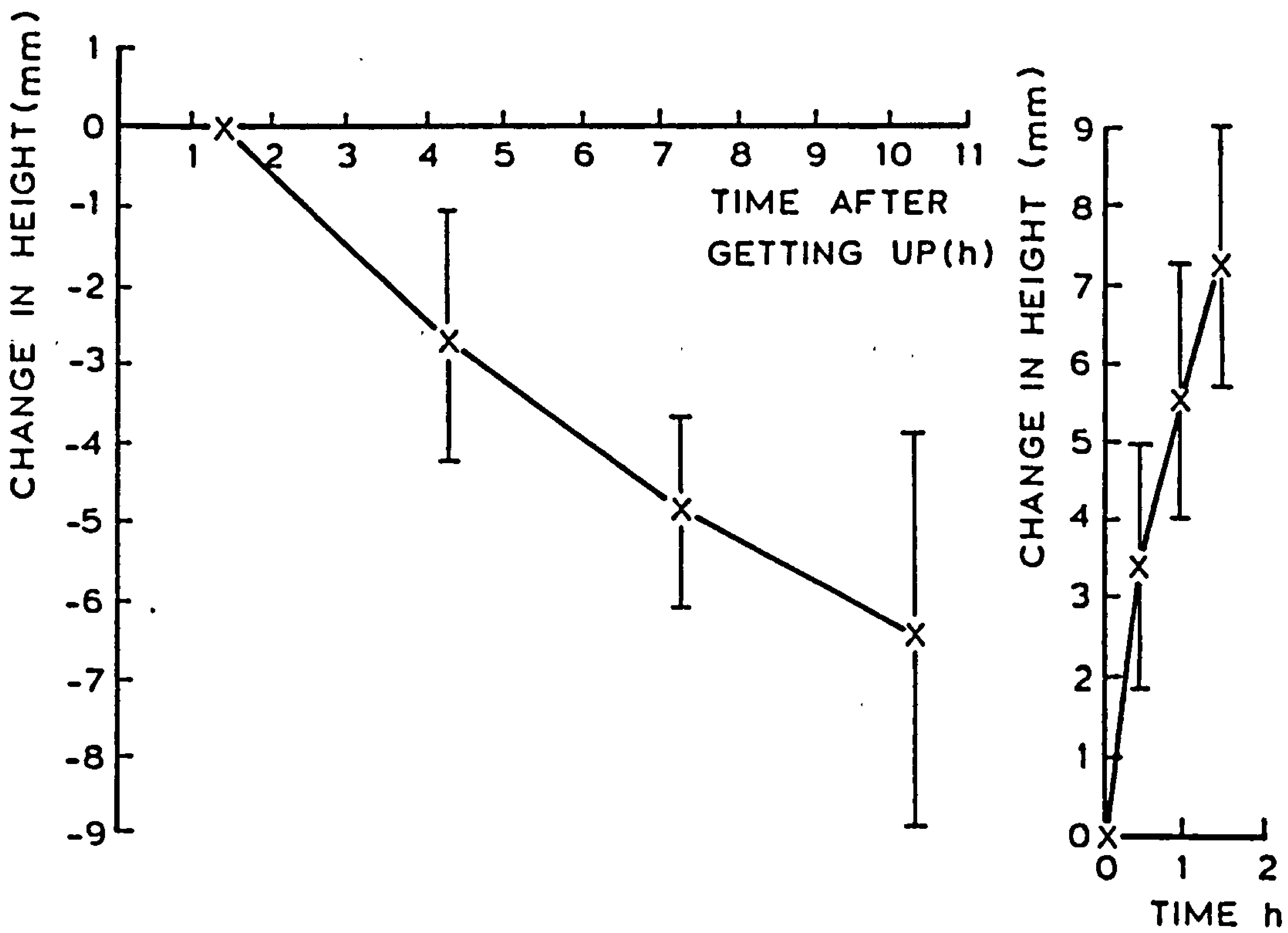


Figure 25. The decrease in height during an ordinary working day with sedentary activity (left) and recovery during lying down (right) from experiments A and B. The means of the four subjects and the standard deviations across the subjects are marked. Reproduced from Spine (see Appendix 3).

Experiment C was evaluated by determining a regresson line for the means, and then calculating the standard deviation of the means around the regression line. A linear decrease of body height would not be expected, but the results from experiment A indicated that such an approximation would not cause too large errors if used on the data from experiment C. The data from the experiment confirmed this assumption.

Table 10. A comparison between standard deviations from experiment C.

Subject	Standard deviation over the 6 sets of measurements (mm)	Standard deviation of the means s.d./$\sqrt{5}$ (mm)	Standard deviation of the means around the regression line (mm)
1	0.60	0.27	0.39
2	0.87	0.39	0.67
3	0.37	0.17	0.38
4	0.45	0.20	0.29
All subjects	0.60	0.27	0.46

It is shown in Table 10 that the standard deviation around the regression line was higher than the standard deviation of the means. However, the standard deviation of the measurements was clearly below 1 mm, which was due to the rigorous control of the posture and of the measurement procedure.

Experiment D demonstrated the increased rate of shrinkage when the load on the spine was increased. The conditions were identical for the subjects on the two days, apart from the weight, which was applied directly on the shoulders during one experimental session by using a waistcoat.

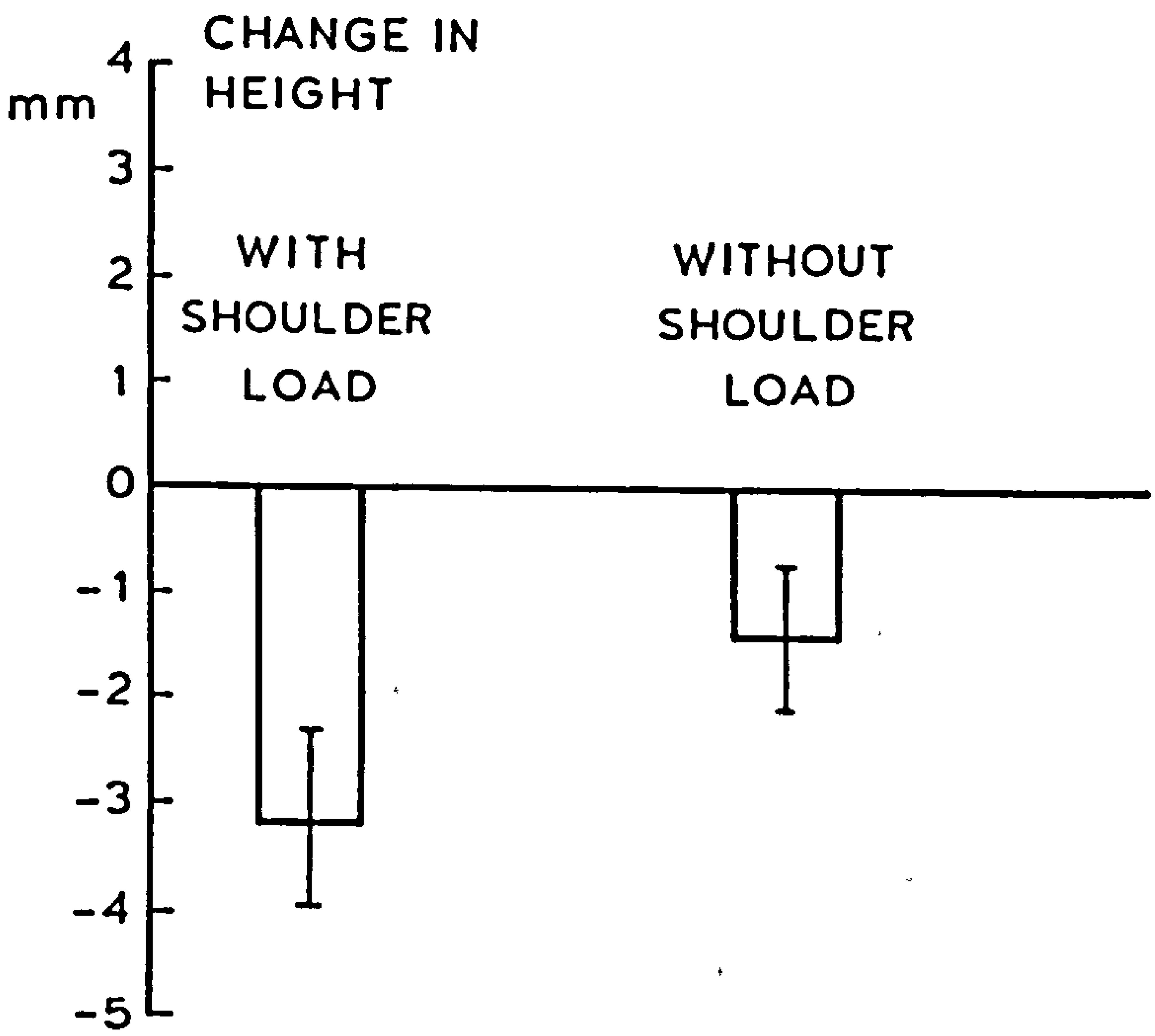


Figure 26. Shrinkage during one hour with and one hour without a shoulder load of 14 kg, on separate days, from experiment D. The activities were office work in each case, i.e. seated at a desk and moving about the office. The means of the four subjects and the standard deviations across the subjects are marked. Reproduced from Spine (see Appendix 3).

Experiment E shows how the body height changed as a function of the loads imposed on the spine. When the activities changed, the body height changed according to the loads imposed by those activities, and even recovery occurred. The very fast rate of shrinkage when carrying a load with one arm should be noted.

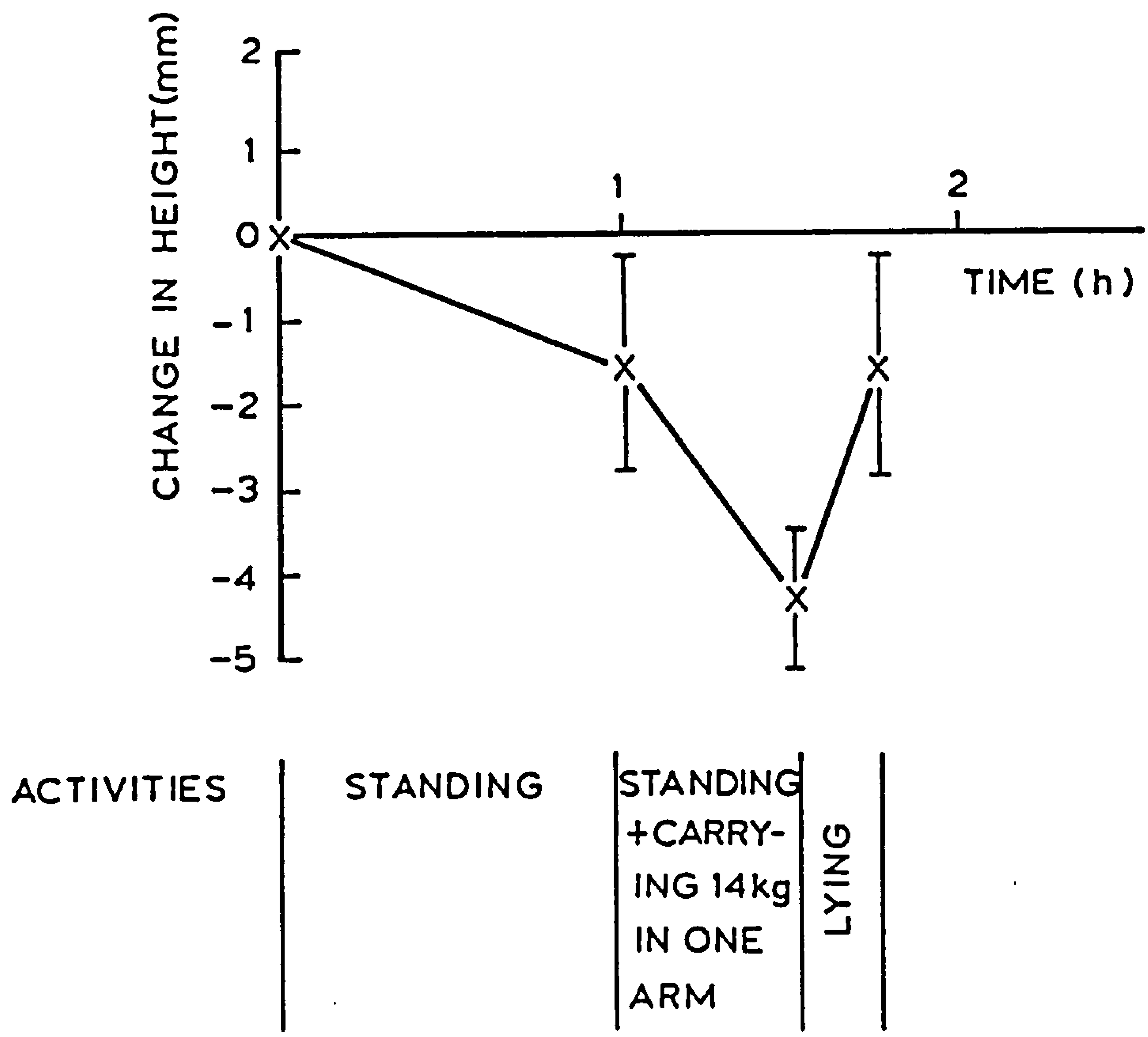


Figure 27. The effect of different successive loading conditions on body height from experiment E. The means of the four subjects and the standard deviations across the subjects are marked. Reproduced from Spine (see Appendix 3).

Experiment F demonstrated the differences in shrinkage when sitting on chairs of different designs. Figure 28 shows the shrinkage, which was highest for the stool and lowest for the easy chair. The difference between the office chair and the easy chair was however not significant.

The greater variability in this experiment was judged to be because the experimental condition was performed at different times of the day, which means that the discs had been subjected to a different loading history.

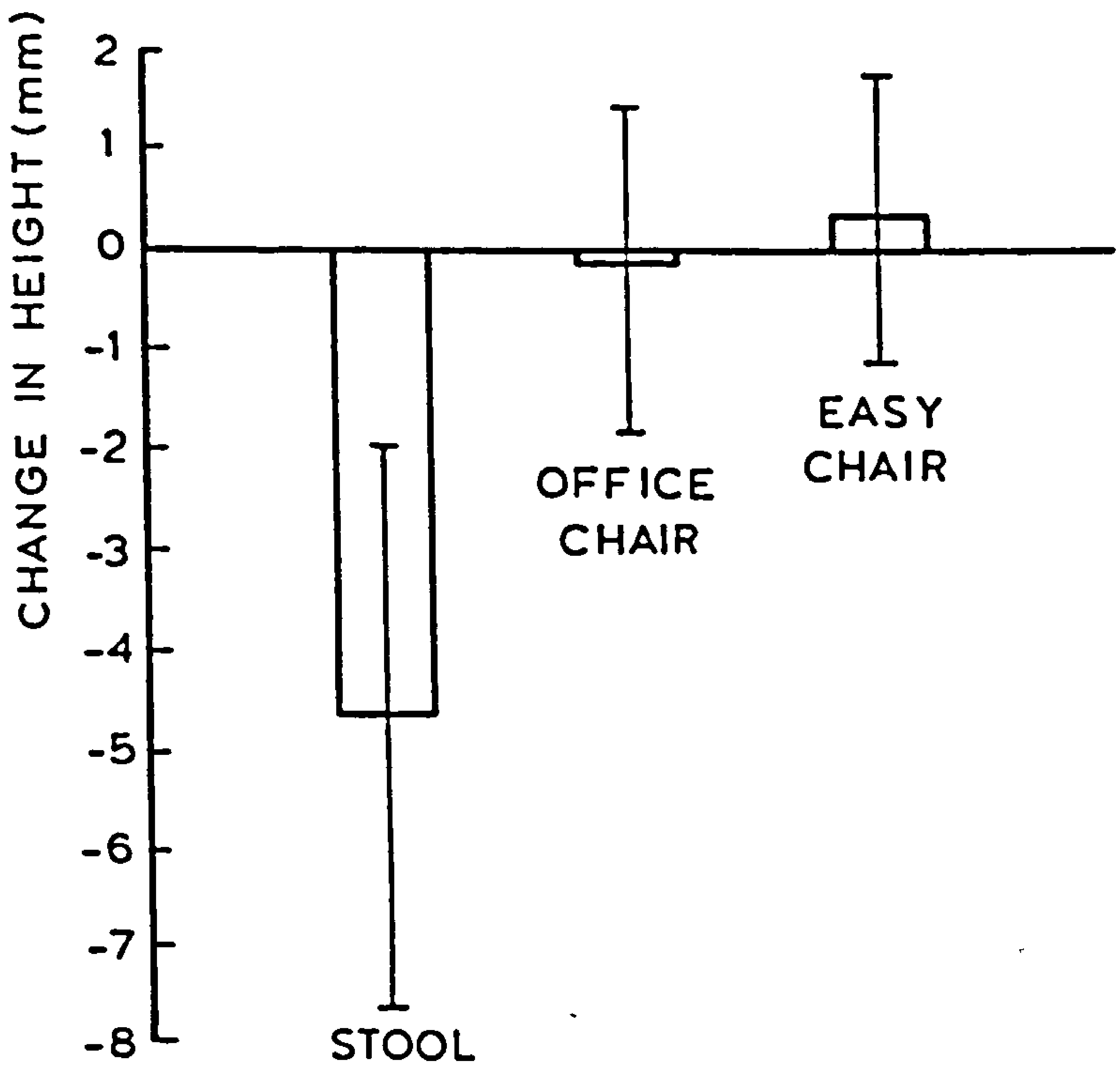


Figure 28. Shrinkage after 1.5 hours of sitting on each of the three chairs from experiment F. The means of the three subjects and the standard deviations across the subjects are marked. Reproduced from Spine (see Appendix 3).

Experiment G compared two chair designs for a push task. In Figure 29 it can be seen that the tasks caused an increase in body height when using the chair with a full-size backrest. The stool caused shrinkage. The subjects experienced more intensive discomfort, and discomfort from more body parts, when using the stool. They also performed a lower maximum push force when using the stool. All results confirmed that the full-size backrest chair was more effective than the stool. In addition to discomfort from the arms, shoulders, and back, the subjects felt discomfort from the thigh and abdominal regions. This was more pronounced for the stool, and simultaneously the force upon the feet decreased and the trunk was bent more forward.

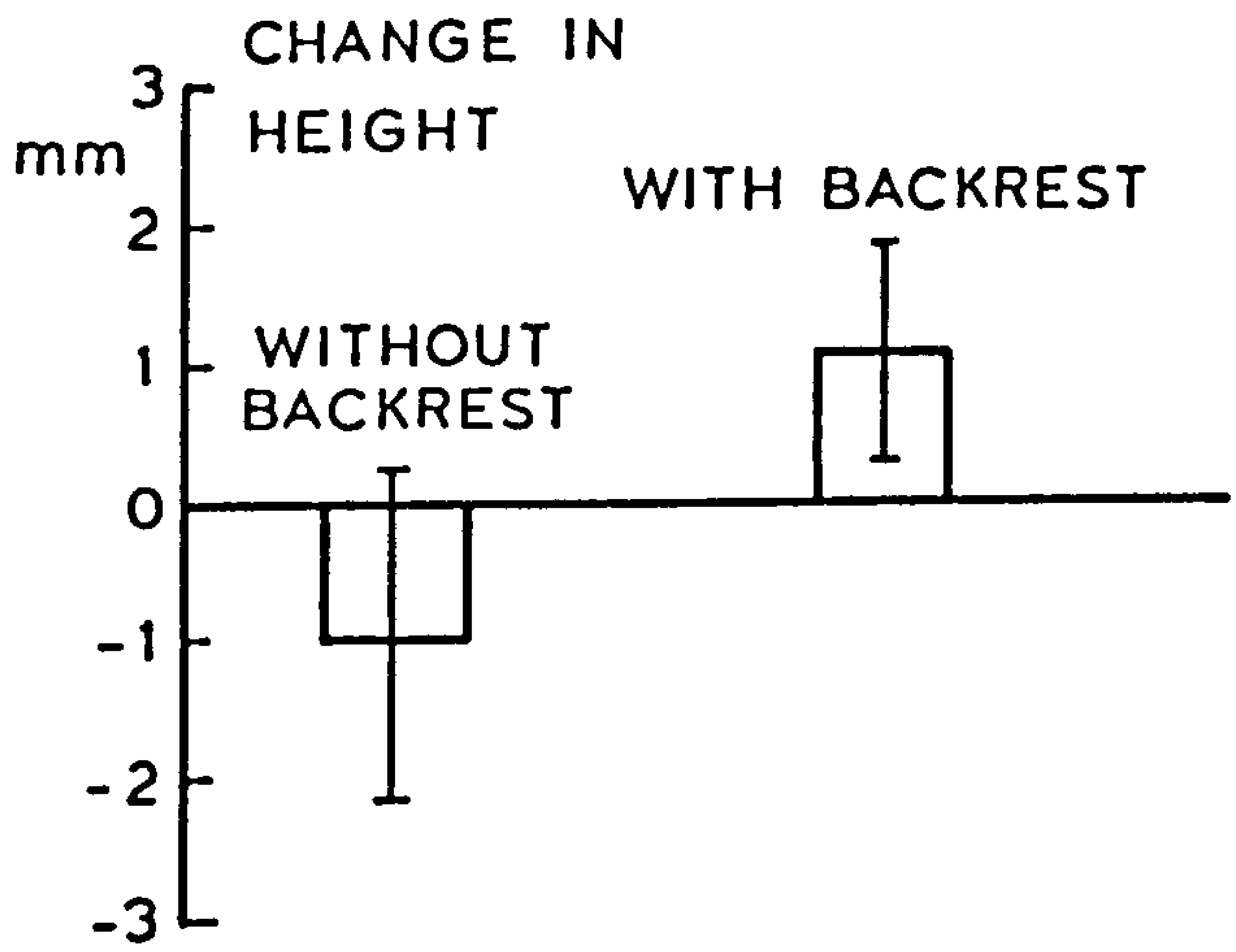


Figure 29. Shrinkage from experiment G, after performing a push task sitting on a chair with and on a chair without a full-size backrest. The means of the four subjects and the standard deviation across the subjects are marked. Reproduced from Spine (see Appendix 3).

In experiment H, the height measurements were repeated 13 times during one day with one subject, and the results are presented in Figure 30. The activity was sedentary and as uniform as possible.

The results showed a good agreement with an exponential curve. The equation of the curve was expressed according to the results of Burns and Kaleps (1980). After having solved the constants, the equation was expressed as

$$H(t) = 1876.5 + 14.1e^{-0.186t}$$

where $H(t)$ is body height in mm as a function of time, and t is time in hours from getting up in the morning.

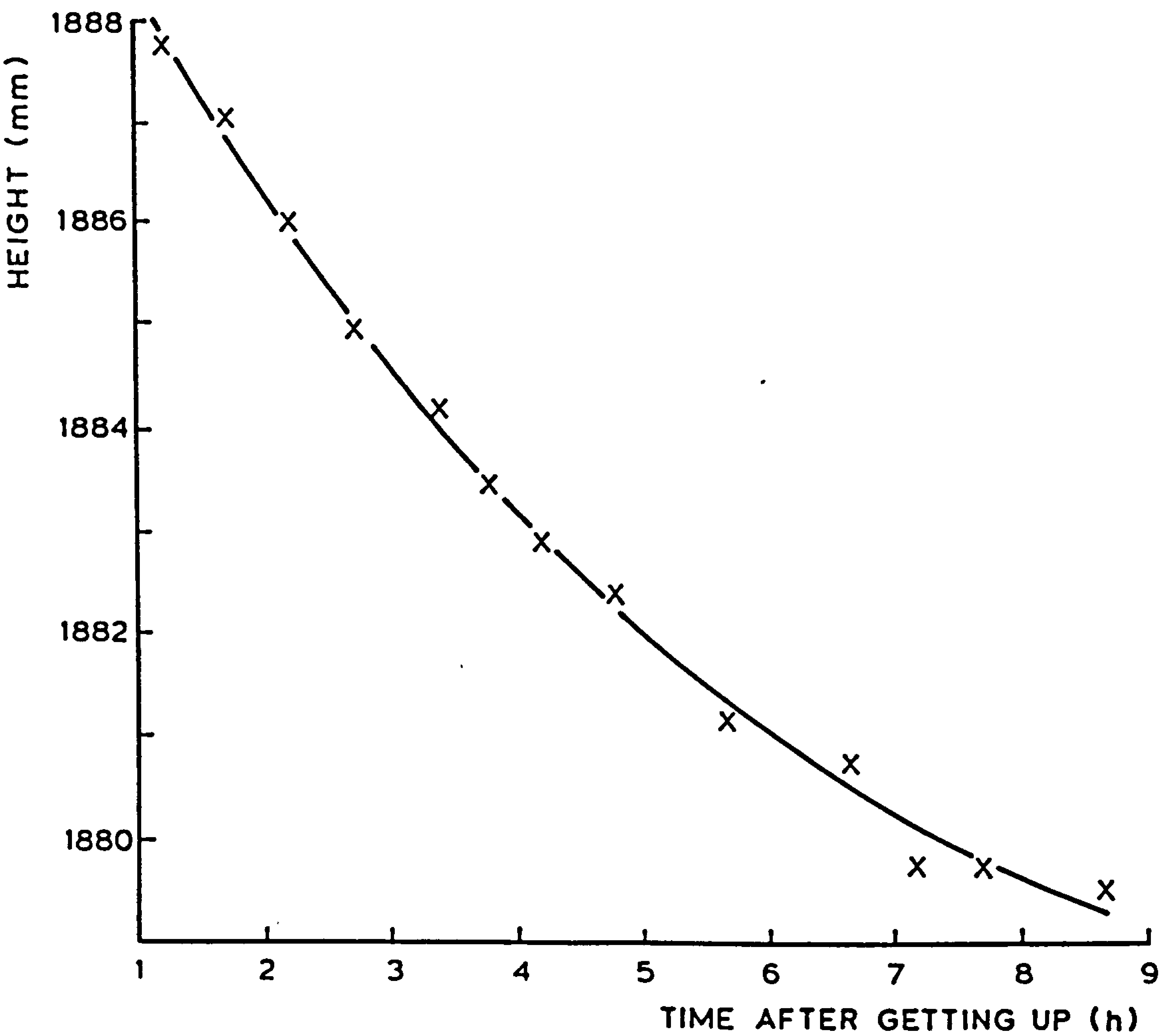


Figure 30. The height of one subject over a day is marked with (x). The line is the solution to the Kelvin unit model, used to describe the time dependent body height. Reproduced from Spine (see Appendix 3).

The loads on the L3 disc in the experimental situations B–F were estimated from disc pressure measurements performed in similar situations and reported in the literature. (Andersson et al 1974 b, Nachemson and Elfström 1970, Nachemson 1981). Also, biomechanical calculations were used for the estimation. It was assumed that lying gave 250 N load on the L3 disc, sitting in the easy chair 400 N, standing 500 N, sedentary activity such as sitting on an office chair 500 N, standing and carrying 14 kg shoulder load 640 N, standing and carrying 14 kg in one hand 920 N. These figures were plotted against their corresponding rates of body height changes. The relationship is shown in Figure 31. In this comparison, the time of the day, the subjects participating, the previously experienced spinal loadings, and the length of the time periods for the experiments varied. Thus a valid comparison was not possible, but a relationship was indicated.

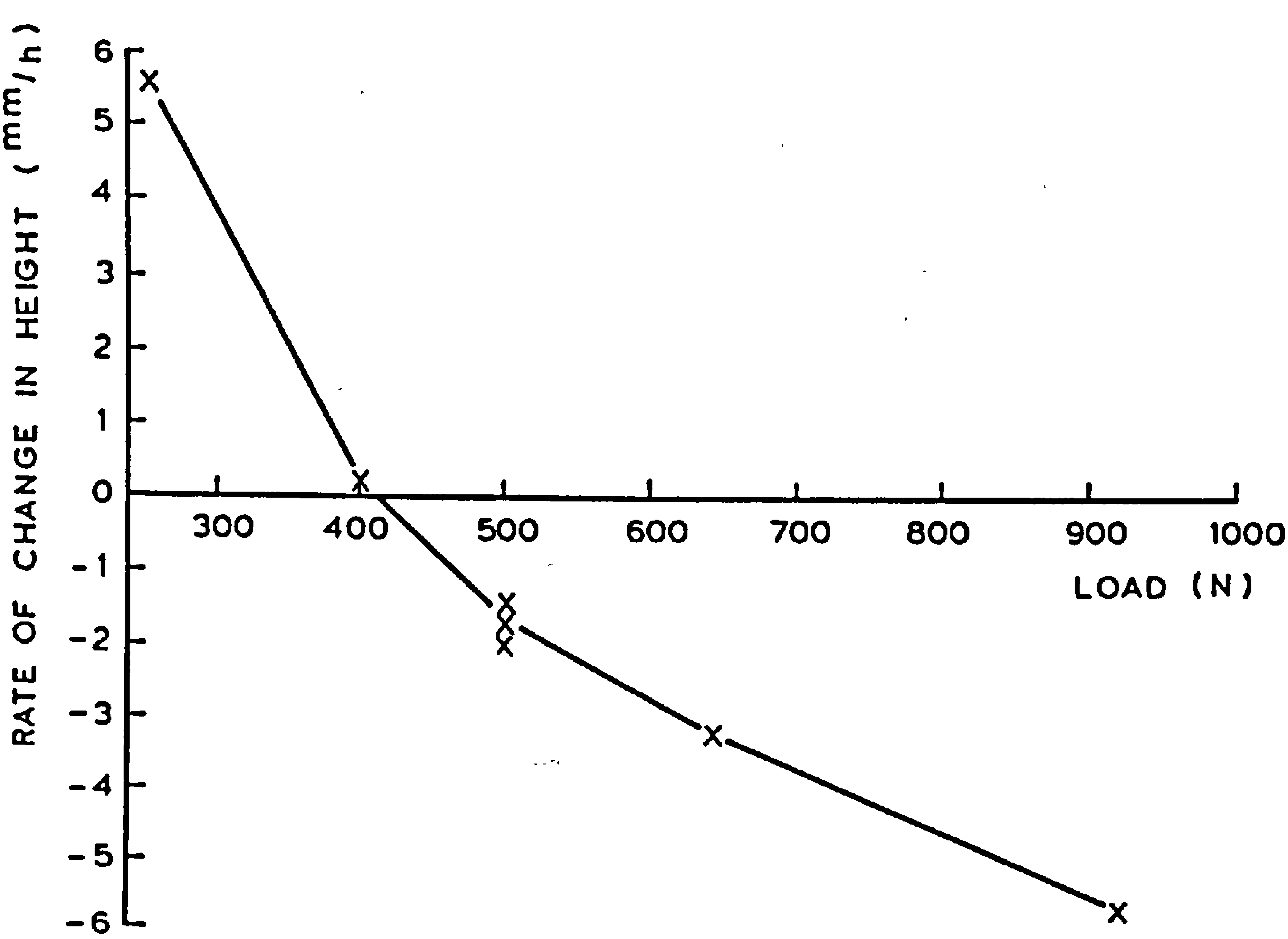


Figure 31. Shrinkage from experiments B, C, D, E and F, plotted as a function of estimated load on L3. Reproduced from Spine (see Appendix 3).

Discussion and conclusions

The results from these experiments showed that body height changes can be measured with sufficient precision to be used as a measure of the effect of loads on the spine, or as a measure of the load itself. The measurement equipment and procedures were developed so that the sensitivity of the method was good enough to differentiate between spinal loads in the magnitude of 100 N. The results were in good agreement with disc pressure measurements reported in the literature. However, several sources of errors have to be controlled, such as the duration of the experimental load, individual differences, loadings before the experiment begins, getting up time, and hours of sleep in the previous night. One possible experimental design, when comparing shrinkage for two loading situations, is to perform the activities on different days but with a control of the time and loadings before the experiment. This was done in experiment D. Another possible method is to perform the experiments after one another but in a permutated order, which was done in experiment F. There is as yet not enough knowledge about individual differences, so every subject has to be used as his own control.

Advantages of the method are that it is non-invasive, and does not require expensive equipment or specially educated personnel. It can be used in laboratory studies and in field studies in difficult environments. Therefore it can be of great value in ergonomic evaluations of workplaces, work tasks and equipment. It is one of the few methods suitable also for the evaluation of long term static loads imposed on the body.

It is not possible to detect if certain parts of the spine have borne a higher load than others, and therefore suffered more shrinkage. The variablity of the height readings necessitates the use of repeated measurements, which gives a possibility to determine not only the mean value, but also the variance. There was a clear difference between individuals regarding the variability of the height measurements performed. Factors of importance for this were probably motivation, stress, ability to concentrate and body awareness.

The study demonstrated the quick recovery which took place when the spine was unloaded. This emphasizes the importance of taking the temporal pattern of the spinal loads into account. It is also implied that several short periods of unloading the spine in a heavy job can allow a substantial recovery to take place and thereby decrease the total disc compression and shrinkage. The very high rate of shrinkage when carrying a load with one arm should also be noted. Further, the adverse influence of static postures and loads and the benefits of dynamic work can be argued not only for muscles but also for the spine.

The method can in the future be used to evaluate manual handling situations, the effects of vibrations, rest pauses, sports training methods and even to assess response characteristics of the spine to standardized loading situations in individuals. Further work on improving the measurement procedure and also the mathematical modelling of the spine's behaviour under loadings is needed.

This study has demonstrated that body height shrinkage can be used as a method to measure the effect of loads on the spine. It can also be used to evaluate industrial seating. The results have supported hypotheses 1, 2 and 3, namely that different tasks give different body loads, that changed chair design cause changed loads, and that the effectiveness of a seat can be assessed with this method.

Study IV. The relationship between shrinkage and loadings on the back

This experimental laboratory study was performed to examine the relationship between shrinkage and spinal loads in more detail. It was also considered of interest to investigate the relationship between shrinkage and discomfort. Further, it was needed to identify and control sources of errors and influences on the experimental procedures and results, such as age, height, individual differences, control of loadings before experiments, and training of subjects. The equipment also had to be modified for use in future field studies. The aim of the study was thus to improve the shrinkage method so that it would be suitable for ergonomic evaluations.

The experiments

In this study, the resulting rate of shrinkage due to loadings on the back was investigated. Loadings on the back were attained by draping a waistcoat, with pockets for lead weights, over the shoulders of the subjects. They were standing during the whole experiment. Five loading situations were given, of which four used shoulder loads, namely 0, 10, 20 and 25 kg. The weights were divided symmetrically between the participant's front and rear sides. In this way, the increase in weight caused an equal increase of the biomechanical lumbar load. The fifth loading situation meant that a padded belt was strapped around the chest immediately under the arms. The belt was then exposed to a lifting force of 98 N (10 kp), evenly divided between the front and the back. This was arranged by using a rope over a pulley in the ceiling, a 10 kg weight at one end and four strings at the other, attached to the belt. This situation of unloading the back, or exerting traction forces in the standing position, was named "-10 kg". During all five experiments, the subjects stood for 45 minutes, but they were allowed to move a little and take some steps at will. Body height measurements were taken immediately before and after each experimental session, and discomfort ratings were taken after the sessions. One experiment was performed per day, which meant five different days for each subject. The activities of the subjects before the experiments were controlled by starting at the same time after getting up (75–90 minutes), and with instructions of comparable morning activities and hours of bed rest.

There were in total eight subjects participating, and two of these were women. Their mean age was 30 years (range 18–34 years), and their mean height was 178 cm (range 166–189 cm). None of the subjects suffered from back, neck or shoulder pain before or after the study, with the exception of discomfort during the studies.

Statistical evaluations were made using analysis of variance for shrinkage values and the Wilcoxon test for discomfort ratings.

Results

Shrinkage showed a close relationship with loads on the back, when given as weights on the shoulders, and thus also with biomechancial loading. The analysis of variance is given in Table 11. There was a clear significant variation among subjects as well as a clear significant effect due to loads.

Table 11. Two-way analysis of variance of shrinkage results for loads on the shoulders.

Source of variation	SS	df	MS	F	P
Load	25.99	3	8.66	10.04	< 0.001
Subject	38.79	7	5.54	6.43	< 0.001
Residual	18.11	21	0.86		
Total	82.91	31			

Table 12 demonstrates that a linear regression can be used for the relationship between loads and shrinkage.

Table 12. Analysis of variance for linear regression of shrinkage results as a function of loads on the shoulders.

Source of variation	SS	df	MS	F	P
Due regression	25.47	1	25.47	13.31	< 0.001
Deviation about regression	57.43	30	1.91		
Total	82.91	31			

The results from these experiments are shown in Figure 32 together with the regression line.

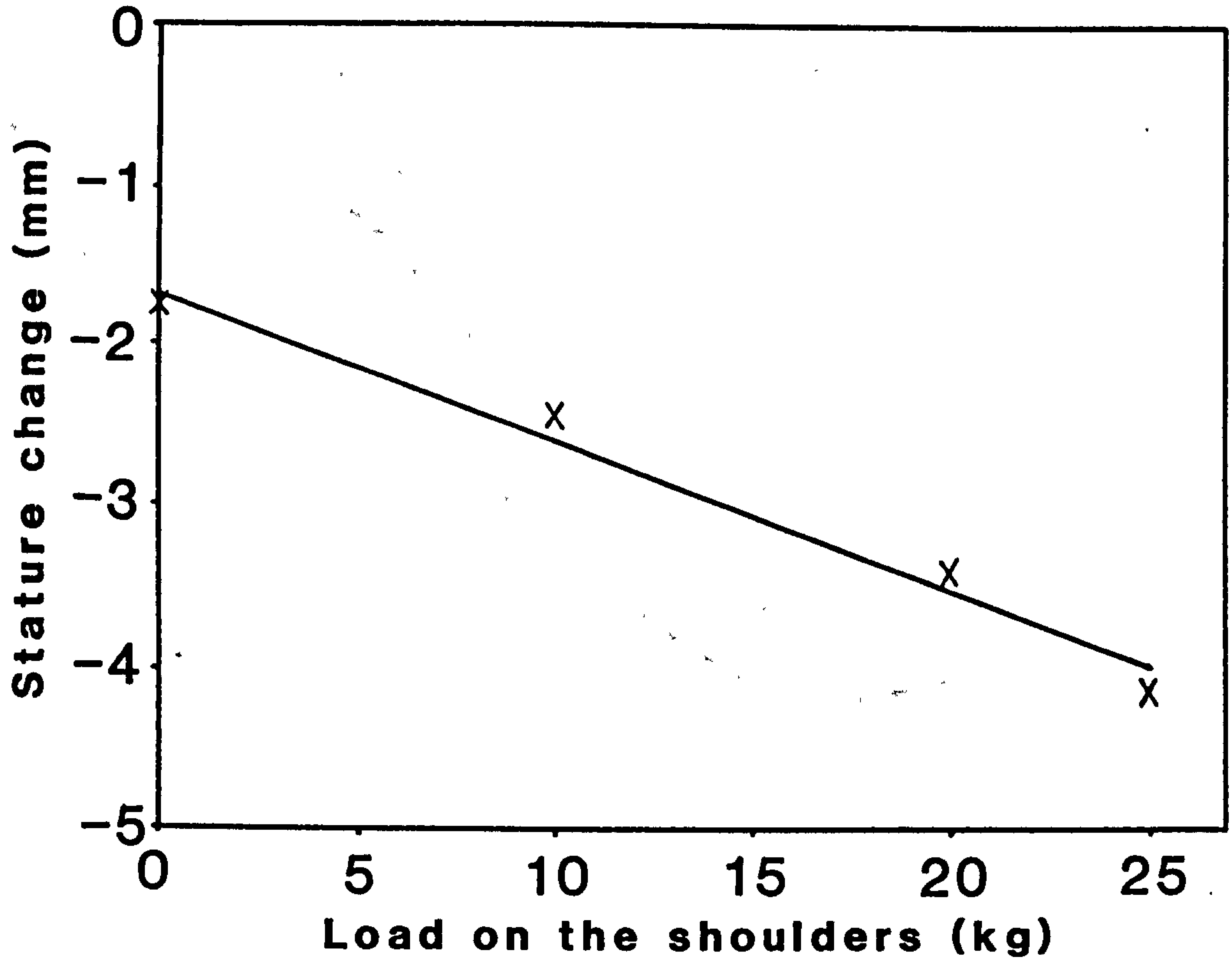


Figure 32. Changes in body height, shown as means for the eight subjects, expressed as a function of loads on the back. The regression line is included.

The equation of the regression line can be written as:

$$H = -0.093 \cdot L - 1.68$$

where H is body height change in mm and L is load on the back in kg ($r = 0.55$). The standard deviation for the eight subjects' shrinkage values, based on each of the four loading situations, was 1.43 mm. This figure expresses the individual differences.

The results from the discomfort ratings and the shrinkage from all five experimental situations are shown in Figure 33.

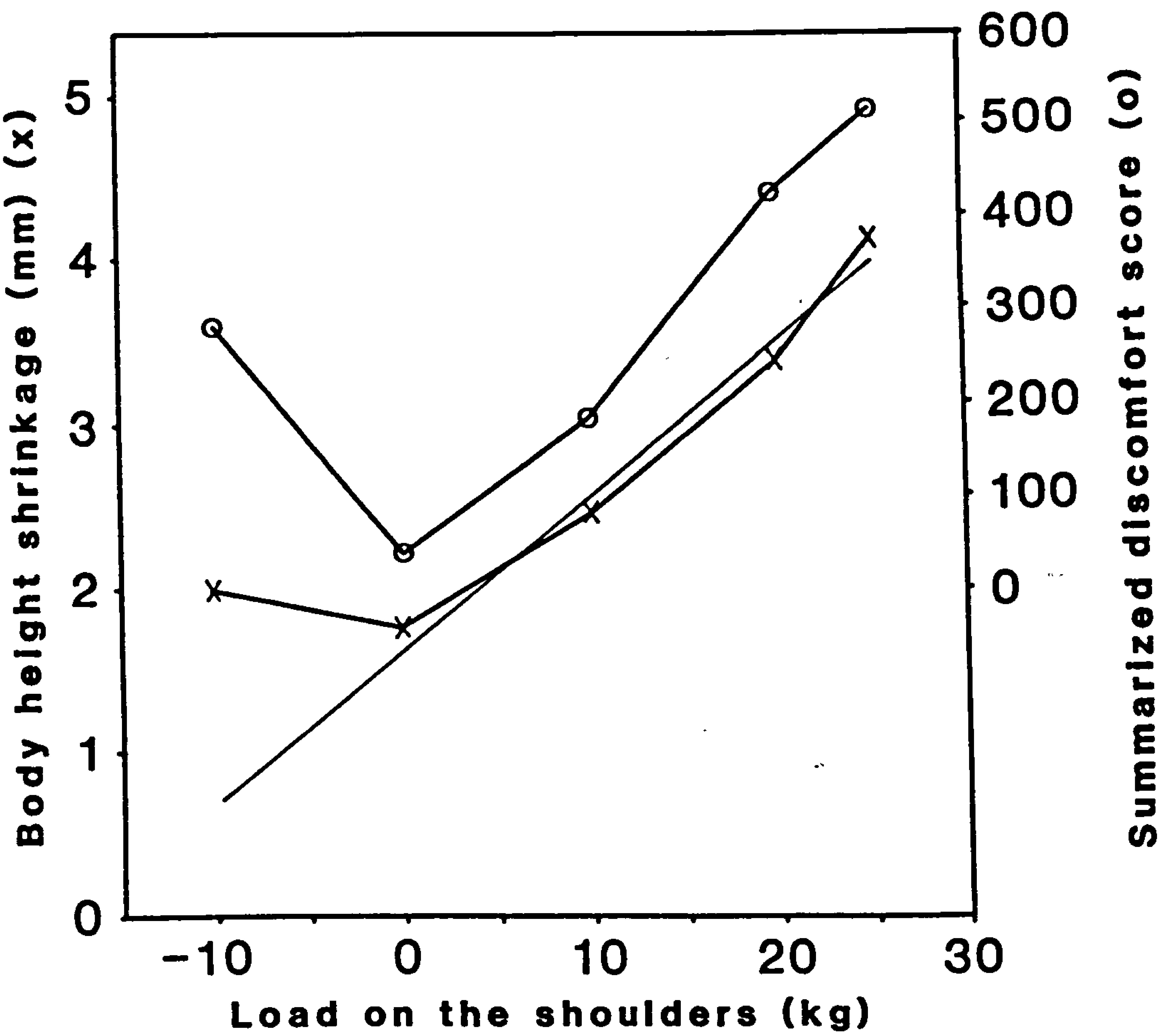


Figure 33. Summarized discomfort ratings and average shrinkage for the eight subjects as a function of loads on the back. The thin line marks the regression line based on the situations with loads on the shoulders.

The situation with traction forces, i.e. "-10 kg", caused significantly more discomfort than the situation "0 kg" (evaluated at the 5 per cent level of significance). At the same time, the subjects lost more body height than expected from the biomechanical point of view. For the four situations with loads on the shoulders, those resulting in more shrinkage also caused more discomfort, and the agreement was good. The results therefore demonstrated a relationship between shrinkage and discomfort in two ways.

The traction situation caused more variation between the subjects for both the shrinkage results and the discomfort ratings, than particularly the "0 kg" and the "10 kg" situations.

The standard deviation of the measurements was 0.62 mm, with the subjects individual values ranging from 0.43 to 0.73 mm. This demonstrates the relatively large individual differences in the ability to perform repeatable height measurements. No relationship could be seen between the standard deviation and the subject's age or height.

The standard deviations for the measurements of each of the five loading situations were compared, without finding any significant differences. When the standard deviations from the individuals' first sessions were compared with those from the second, third, fourth and fifth sessions, there was a weak tendency for a decreased standard deviation with increased number of experimental sessions performed. This probably implies that with increased training of the subjects, a better result can be obtained, i.e. a decreased spread of the height measurements.

The experiment involved totally 80 sets of five height measurements. The fifth measure was lower than the first in most sets and the difference was significant. This shows that shrinkage takes place during measurement, and this variation is included in the standard deviation measure.

By comparing every subject's individual body height in the mornings, before the experiments began, a control measure of the loading history of the discs was attained. This difference was judged to be mainly due to the time of bed rest, the time between getting up and the start of the experiment, and the patterns of spinal loading in the morning before the experiment. The control measure is by no means complete. If the body height for example was the same on two mornings, it would not be possible to draw the conclusion that the loading patterns had been identical. However, a height difference reflects differences in the loading patterns, so it was considered that the measure is important in displaying one aspect of the quality of the control of the subjects' loading patterns. The difference between the highest and the lowest body height in the five mornings before the experiments was 3.34 mm on average for the eight subjects. The standard deviation of the five body heights was on average 1.56 mm. These figures express a quality measure of the study. The measure is perhaps more important to use on an individual basis for each of the participating subjects. In this study no subject was excluded, but a too large height difference might be used as a basis for that in the future. It should also be observed that these figures include variations caused by the adjustments of the supports, which always was done in the morning before the first measurement.

The effect of age upon shrinkage was tested by calculating each subject's mean shrinkage during all the loading experiments, and then relating these values to the subject's age.

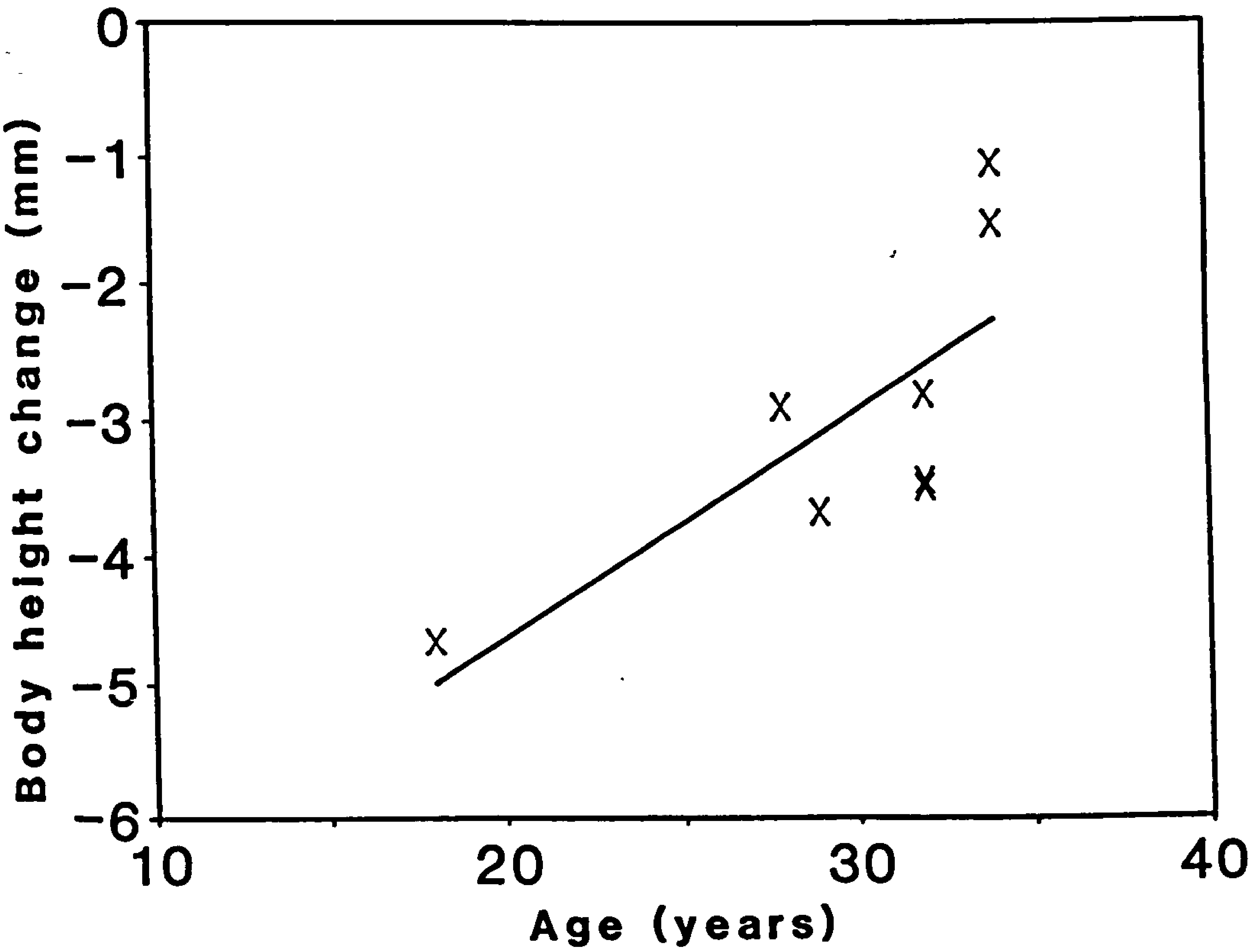


Figure 34. The mean shrinkage during all loading experiments as a function of the subject's age, and the resulting regression line.

The regression line in Figure 34 has the equation:

$$H = 0.17 \cdot A - 8.0$$

where A is age in years and H is height change in mm ($r = 0.75$). The age effect was found to be significant, but the age distribution was unfavourable. The slope of the regression line was interpreted in the way that peoples ability to shrink due to loadings on the back decreases with age. No conclusion could be made regarding an association between shrinkage and body height in this material. Consequently, there were large individual differences remaining, which could not be explained with age, height or any other factor registered.

Discussion and conclusions

The shrinkage method is easy to apply, and the results from it are reliable. It is suitable for comparisons of situations with different loadings on the back, but a control of the loading history of the subjects before the experiments is necessary. This control should incorporate the time of bed rest in the night before the experiments, time between getting up from bed and start of the experiment, and the activities or loadings during that period. The sensitivity of the method is good, which can be exemplified by the fact that it gives significant differences in a comparison between two loading situations for a group of eight subjects when the loads on the backs differ 100 N. The equipment and measurement procedure have been improved, but there are still several possibilities to improve the method further. A decrease of the variability of the measures would be beneficial, since it would decrease the number of subjects needed.

The shrinkage measure has been shown to correlate well with loads on the back and thus also with biomechanical loads. This opens many fields of application for the evaluation of loadings on the back at work. Shrinkage has also been shown to be related with the perception of discomfort. This is very noteworthy and promising for the use of the method in the future.

The reason why the traction force increased the shrinkage in relation to no traction, was judged to be due to an increase in trunk muscle tension, because of the uncomfortable experimental situation. This may also be expressed differently: the traction forces did not reach the spine due to trunk muscle forces of the same magnitude as, or slightly greater than, the traction force. Nachemson and Elfström (1970) showed that the disc pressure decreased during traction, and Andersson et al (1983 a) showed that the disc pressure increased during auto-traction treatment. This study emphasize that discomfort can influence the spinal load in traction.

The relationship between shrinkage and load on the back was described with a linear function (regression line). This is not the most accurate description since a non-linear relation would be expected, as single disc specimens have shown such properties (Markolf and Morris 1974). However, the rate of disc creep decreases with time, similar to an exponential curve, as shown in the literature review. Also, the range of lumbar disc loads was small in this experiment, which means that a linear relationship can be a reasonable approximation.

As mentioned earlier, the standard deviation between the subjects' shrinkage values, based on each of the loading situations, was 1.43 mm. This value was substantially higher than the standard deviation of the individual height measurements (within the subjects), which reflects individual differences, for example age, in the response to the same loading situations. To a certain extent, differences in bed rest time, time between getting up and the start of the experiment, and loadings before the experiment were probably also reflected in this measure.

This study has made contributions to the development of the shrinkage method and has created possibilities to use it in studies of chair design and other ergonomic evaluations.

Study V. Laboratory study of chairs in a forward directed force development task

The methods devised in the previous chapter were used simultaneously in this study, which gave opportunities to evaluate not only chair design and work task influences, but also the suitability of the methods used. The aims were to evaluate the use of the methods of measurement, to evaluate influences of backrest design in a forward force development task, and to relate the results to the industrial seat model.

The study was performed in order to test hypotheses 2 and 3, namely that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and responses to these loads. Also, another hypothesis was that a higher backrest would be beneficial in comparison to a low lumbar support in a forward force development task.

The experiments

The task was designed so that the seated subjects applied a force to a metal plate by pressing a handle against it. The handle was so constructed as to allow it to be gripped and held with both hands without any particular wrist flexion or deviation. The force upon the plate was measured continuously and displayed digitally so that it could be read by the subject and the experimenter. The subjects were instructed to hold the force at 25 N, with an allowable variation of ± 2 N. The force was directed 15° below the horizontal plane, which meant that the gravitational force from the handle was approximately compensated for. The metal plate was placed approximately 50 cm over and 10 cm forward of the front edge of the chair for all of the subjects. That position resulted in a 30–35 cm visual distance and a slightly forward bent head. The subjects exerted the force for 105 seconds and were then given 15 seconds of rest, when they could put the hands in their lap and relax. This schedule was maintained throughout the whole experimental session.

The instrumented experimental chairs had horizontal seats, padded and covered with upholstery with a high degree of friction. One chair had an 18 cm high and 35 cm wide backrest, and the other had a 38 cm high and 41 cm wide backrest. The upper edges of the backrests were 31 cm and 43 cm above the seat pan respectively. Both backrests were padded and upholstered. A footrest was used to adjust the thighs to an approximately horizontal level.

Eight subjects participated, two of them being women. Their mean age was 31 years (range 24–35 years), and their mean height was 178 (range 161–191 cm). None of the subjects had any back, neck or shoulder complaints at the time when the study was conducted, except for the discomfort during the experimental sessions.

To compare the two chair designs, each subject performed the experimental sessions on two separate days. The tasks were performed for 45 minutes, and they started in the morning, 75–90 minutes after the subjects got up from bed.

Measures of shrinkage, forces, postures, and subjective ratings were taken during the sessions. Body height was measured immediately before and after each experiment. The reaction forces from the seat, backrest, and floor were measured in sequence during ten periods of 15 seconds each while the force was exerted. These forces were also measured during one 15 second period just before the pushing started and another 15 second period just after the pushing finished, while the subjects did not exert any force with the handle and sat upright in the chair against the backrest. At the very beginning of the experiment, photographs were taken of the subjects in the sagittal plane when they performed the push task. This was repeated once again at the middle of the experiment and once more just before the end. Discomfort ratings were also performed three times during the experiment, the first at the beginning, the second at the middle and the third just before the end. After the subjects had carried out the experiments on the second day, they made an additional comparative rating and evaluation of the two chairs. They were also interviewed about their experiences.

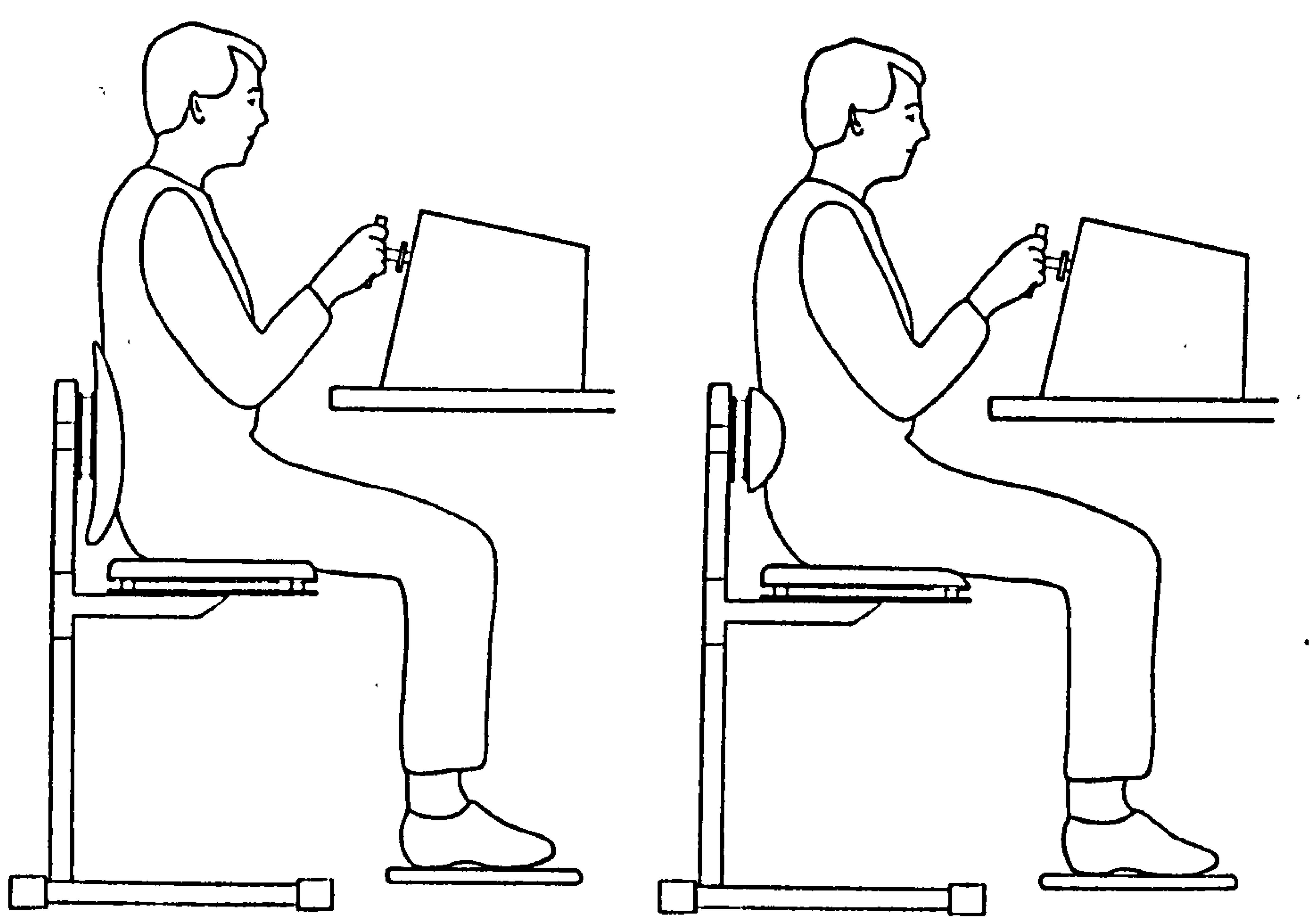


Figure 35. The working posture and the equipment used in the forward force development task. The chair with the high backrest on the left, and the chair with the low backrest on the right.

In summary, the task demands were static forward force development with lifted hands. The methods of measurement chosen were shrinkage, biomechanical evaluations, posture analysis, and subjective evaluations.

Statistical evaluations were made at the 5 per cent level of significance (one-tailed test). The Wilcoxon test and the Sign test were used for evaluation of discomfort ratings and preferences respectively. The paired t-test was used for all other data.

Results

In this forward force development task, the shrinkage of the subjects was 0.66 mm on average when using the chair with the high backrest. This corresponds to a relatively low load on the spine. The chair with the low lumbar support caused 1.37 mm shrinkage on average. The difference was significant, and six of the eight subjects shrank more with the low backrest. The standard deviation of all sets of height measurements was 0.55 mm. The difference in body height between the start of the two experiments in the two mornings were calculated for all eight subjects. On average, that difference was found to be 1.11 mm.

The backrest force at rest was 35 N higher for the low lumbar support compared to the high backrest, as shown in Table 13. This difference also was significant. In a corresponding manner, there was a 35 N higher force on the low backrest during the period when the force was exerted. This differance too, was significant. All eight subjects showed the same pattern, both at rest and at work. The force on the two backrests increased significantly from the resting situation to the work situations. The increase was in both cases 16 N, which meant that a large proportion of the 25 N forward directed force was transmitted to the backrest. The centre of pressure of the backrest force was situated significantly higher above the seat pan for the high backrest compared to the low one. This was the case in both the rest and the work situations, and also for all eight subjects. The centre of pressure was situated significantly higher during work compared to the rest situation for the high backrest.

The forces on the feet were significantly lower during work than during rest, for both backrests. This was the case for seven of the eight subjects. However, there was no difference between the force on the feet when a comparison was made between the two backrests. Most of the subjects tended to have a more forward bent working posture when using the low lumbar support, compared to the high backrest. The tendency for higher forces on the feet with the low lumbar support was probably due to the slightly more forward bent posture.

The moment around the hip joint, caused by the backrest force, was calculated, i.e. the product between the backrest force and the perpendicular distance between the force and the hip joint. This moment was approximately the same for the two backrests in the rest situation, and the moment was approximately the same for the two backrests at work.

According to the biomechanical model, the shear forces in the lower lumbar back were higher for the low lumbar support than for the high backrest. There also existed a greater moment upon the back in the region just above the upper edge of the low lumbar support, according to the model. This moment increased the compression forces on the discs.

*Table 13. Results from the forward directed force development task. The measurement results from shrinkage and reaction forces are given as means, followed by the standard deviation. The ratings are given as the total sum of discomfort score for the eight subjects. Significant differences are marked with *.*

	Low backrest	High backrest	Standard deviation of individual differences
Shrinkage (mm)	1.37 (1.09)	0.66 (0.85)	1.03*
Backrest force at rest (N)	139 (24)	104 (25)	16*
Backrest force at work (N)	155 (23)	120 (16)	18*
Force upon feet at rest (N)	160 (29)	156 (31)	19
Force upon feet at work (N)	155 (29)	152 (30)	22
Position of backrest force above seat at rest (mm)	209 (13)	237 (12)	16*
Position of backrest force above seat at work (mm)	212 (15)	244 (12)	13*
Increase in discomfort score for the worst body part	326	206	
Sum of overall discomfort score	344	229	*
Number of discomfort statements	30	25	
Preference	0	7	*

The discomfort from the lower and upper arms were dominant in this task, and comparable for the two backrests. Thereafter the lower back was named, with five statements of discomfort for the low lumbar support and three statements for the high backrest. The neck followed next, with a total of four statements of discomfort for the low lumbar support and two from the high backrest. The overall discomfort, recorded just before the end of the experiments, showed significantly more discomfort for the low lumbar support situation. Only one subject showed more discomfort for the high backrest. Further, six out of the eight subjects experienced that the increase in the discomfort from the worst body part was more pronounced for the low lumbar support, but the difference was not significant. The total number of discomfort statements reported were also greater with the low lumbar support. Seven of the eight subjects preferred the high backrest, and one felt that the two backrests were equal.

It can be noted that the two subjects who were least in favour of the high backrest were the only subjects who shrank more for the high backrest.

Discussion and conclusions

The results from all the methods were in agreement, confirming the advantages of having a high backrest in tasks requiring forward force development.

As reported in Study III, more discomfort was experienced in the thigh and abdominal regions and less forward directed force could be exerted when using a seat without a backrest, compared to a chair with a high backrest. Simultaneously there was a decrease in the force upon the feet, and the trunk was bent more forwards. Also, more static muscle load was judged to be needed to maintain the stability while the horizontal forces were transmitted to other contact areas of the body. These results were interpreted as showing that the most effective transmission of forward force development takes place with a high backrest. Inappropriate chair design in that task might lead to compensation mechanisms, such as a forward bent working posture or decreased force upon the feet. The slightly more forward bent posture, which could be seen when using the low lumbar support in this study, was probably a result of such a compensation mechanism.

The relatively high levels of the discomfort experienced from the upper arms and the region near the shoulders, emphasize the importance of working near the body. A high backrest would not compensate for the hands having to be held too far away from the body. In this study, the discomfort was experienced from an area near the border line between the body parts upper arms and shoulders in the body map. This caused difficulties for the subjects to choose. A modification of the body map should be considered in similar situations. The final comparative ratings very much agreed with the ratings during the experiments.

It was considered that the methods chosen were relevant to the problem, and that they all contributed to the evaluation.

Several measures displayed large differences between individuals, for example the shrinkage method and force measurements. Some of the differences can be related to the characteristics of the individual. Pared comparisons were therefore used.

As shown in Table 13, the force upon the lumbar support was 140–155 N and the force upon the seat was around 490 N. According to the biomechanical model, the seat took up approximately 140 N as friction force. The friction coefficient of seats should be substantially higher than $140 : 490 \approx 0.29$, so that the sitters would not slide forwards on the seat. There must be a safety margin so that sliding does not occur due to movements in the seat, force exertion or materials handling activities. Work chairs with varnished wooden seats are consequently inappropriate because the friction force necessary to prevent sliding cannot be built up. As a result, the user's buttocks will slide forwards on the seat, the lumbar back will receive an increased kyphosis and a decreased backrest force, which will cause an increased load on the lumbar spine.

The study confirmed the hypotheses tested, namely that changed chair design can cause changed loads, that the effectiveness of a seat can be assessed from body loads and responses of these loads, and that a high backrest is beneficial in comparison with a low lumbar support in a forward force development task.

Study VI. Laboratory study of chairs in assembly work with limited knee-room

This study was performed in order to extend Study V by incorporating another situation. It was designed similarily, but with another task and a different chair. The aims were to evaluate the use of the methods of measurement, to evaluate influences of chair design in an assembly task with restricted knee-room, and to relate the results to the industrial seat model.

The study tested hypotheses 2 and 3, namely that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and responses to these loads. Also, it was hypothesized that a sit-stand seat would be beneficial in comparison to a conventional chair in this task with restricted knee-room.

The experiments

The task involved picking up 10 cm long screws, mounting them through pre-bored holes in a vertical plate, and screwing a nut and a wing-nut on to every screw. The subjects were told to work at their own pace, i.e. not to work unnecessarily slow or fast. There were in total 25 screws, nuts, wing-nuts and holes. When they had been assembled, the subjects were asked to dismantle them, and thereafter begin to reassemble them again. The performance was recorded, i.e. the number of assembled and dismantled screws and the subjects were aware of their results. The boxes holding the screws and nuts were placed on the table top, approximately 40 cm above the seat surface. The plate with holes was also placed on the table, above the surface restricting the knee-room. This geometry of the work area meant that the subjects would have to work with almost straight and outstretched arms, or with a slightly forward leaning trunk. One rest period of 1 minute was allowed during the experiment.

The experimental chairs were instrumented. One was a conventional chair with a horizontal seat surface and an 18 cm high and 35 cm wide lumbar support, whilst the other was a sit-stand seat with an 18 cm high and 35 cm wide lumbar support. The upper edges of the lumbar supports were 31 cm above the seat. Both seats and backrests were padded and upholstered. A footrest was used to adjust the height of the feet so that the thighs were approximately horizontal for the conventional chair, and sloped approximately 30° downward from the horizontal plane for the sit-stand seat. Thus, the sit-stand seat could be placed a few centimetres closer to the table, because of the reduction in needed knee-room. The working positions were otherwise of the same geometry, as was the table height in relation to the elbow height.

Eight subjects participated, three of them being women. Their mean age was 31 years (range 24–42 years), and their mean height was 177 cm (range 152–191 cm). None of the subjects had any back, neck or shoulder complaints at the time the study was conducted, except for the discomfort during the experimental sessions.

For the comparison of seat designs, each subject performed the two experimental sessions on separate days. The tasks were performed for 45 minutes, and they started in the morning, 75–90 minutes after the subjects got up from bed.

Measures of shrinkage, reaction forces, postures, and subjective ratings were taken during the sessions. Body height was measured immediately before and after each experiment. The reaction forces from the seat, backrest, and floor were measured in sequence during ten periods of 15 seconds each while the assembly work was carried out. The reaction forces from the seat and the backrest were also measured during one 15 second period just before the assembly started and another 15 second period just after it had finished, while the subjects sat upright on the seats against the backrest without any work activity. At the beginning of the experiment, photographs were taken of the subjects in the sagittal plane when they performed the assembly task. This was repeated once again at the middle of the experiments and once more just before the end. Discomfort ratings were also performed three times during the experiment, the first at the beginning, the second at the middle and the third just before the end. After the subjects had carried out the experiments on the second day, they made an additional comparative rating and evaluation of the two seats, and they were also interviewed about their experiences.

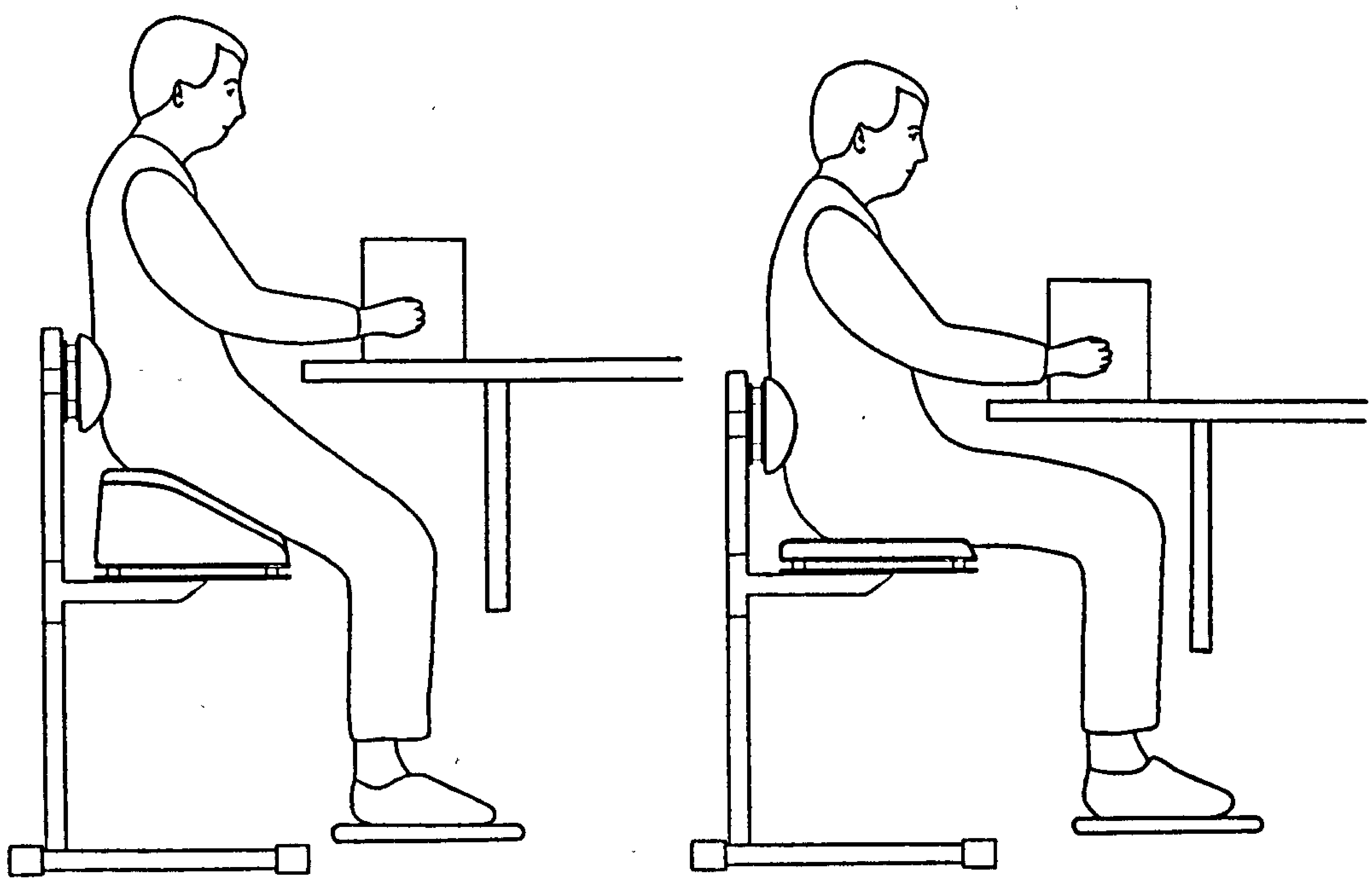


Figure 36. The working posture and the equipment used in the assembly task with restricted knee-room. The sit-stand seat on the left, and the conventional chair on the right.

In summary, the task demands were assembly of screws and nuts, with both arms lifted, and at a workplace with restricted knee-room. The methods of measurement chosen were shrinkage, biomechanical evaluations, posture analysis and subjective evaluations.

Statistical evaluations were made at the 5 per cent level of significance (one-tailed test). The Wilcoxon test and the Sign test were used for evaluation of discomfort ratings and preferences respectively. The paired t-test was used for all other data.

Results

The work task resulted in an average body height shrinkage of 2.41 mm for the conventional chair with a low lumbar support, and an average shrinkage of 0.92 mm for the sit-stand seat. Seven of the eight subjects experienced more shrinkage when they used the sit-stand seat. The difference was statistically significant, which is shown in Table 14. The standard deviation of all sets of height measurements was 0.57 mm. The individual difference in body height between the start of the two experiments, was 2.53 mm on average.

The forces on the lumbar supports were significantly lower for the sit-stand seat than for the conventional chair, while sitting upright and being at rest. This was the case for all eight subjects. The lumbar support on the conventional chair was only used intermittently during short periods in the work situation. The subjects hardly used the lumbar support on the sit-stand seat at all. The positions of the centre of pressure for the backrest forces were completely comparable for the two chairs, as shown in Table 14.

The forces upon the seat pans were comparable for the two chairs. At the same time, there were no particular differences between the two chairs regarding the forces upon the feet. These forces were not measured during the periods of rest before and after the task, but calculations according to the biomechanical model confirmed that there were no particular differences between the chairs in this respect.

It was possible for the subjects to perform the task and at the same time lean against the backrest. However, they chose to lean the trunk forward and thus lost contact with the backrest. By this action, they reduced the load upon the shoulders but increased the load on the back. A difference between the postures of the two chairs was that the subjects could come 3-4 cm closer to the work task with the sit-stand seat, which was due to the forward tilt of the thighs so that the knees did not hinder as much as with the conventional chair. The subjects attained a somewhat more forward leaning trunk when they used the conventional chair. The curvature of the lower back could not be accurately estimated, since the subjects wore their ordinary clothing during the experiment. The impression was that the sit-stand seat caused less kyphotic lumbar backs than the conventional chair. Kyphotic lumbar backs were seen in most of the subjects during the experiments.

According to the biomechanical model, the shear forces in the lower lumbar back were higher for the conventional chair than for the sit-stand seat. The forward bending moment in the lumbar region also tended to be higher for the conventional chair compared to the sit-stand seat, which resulted in an increased compression force on the lumbar discs.

The discomfort from the upper arms and the shoulders were dominant in this task. Thereafter followed the lower back with six statements of discomfort for the conventional chair and zero statements for the sit-stand seat. It should also be noted that there were four statements of discomfort from the buttocks, i.e. the area in contact with the seat, for the sit-stand seat, while there were only two for the conventional chair. In total, six subjects gave more discomfort statements for the conventional chair than for the sit-stand seat. The overall discomfort, recorded just before the end of the experiments, showed more discomfort for the conventional chair, but the difference was not significant. The discomfort from the worst area of the body, experienced towards the end of the experiment, showed a significantly greater amount of discomfort when the subjects used the conventional chair compared to when they used the sit-stand seat. The same results were attained for the increase of discomfort from the worst body part for six of the eight subjects. In particular, there was significantly less discomfort from the lumbar region for the sit-stand seat. Seven subjects preferred the sit-stand seat and one subject preferred the conventional chair, as shown in Table 14.

*Table 14. Results from the assembly task with restricted knee-room. The measurement results from shrinkage and reaction forces are given as means, followed by the standard deviation. The ratings are given as the total sum of discomfort score for the eight subjects. Significant differences are marked with *.*

	Conventional chair	Sit-stand seat	Standard deviation of individual differences
Shrinkage (mm)	2.41 (1.20)	0.93 (0.71)	0.80*
Backrest force at rest (N)	109 (36)	61 (25)	20*
Backrest force at work (N)	8 (7)	—	—
Force upon feet at work (N)	131 (23)	136 (39)	28
Position of backrest force above seat at rest (mm)	210 (12)	209 (15)	9
Increase in discomfort score for the worst body part	381	262	*
Sum of overall discomfort score	357	279	
Number of discomfort statements	33	26	
Performance (screws)	83	81	
Preference	1	7	*

The performance was measured by the number of screws assembled and dismantled. As can be seen in the Table 14, this measure was nearly idential for both of the chairs.

Discussion and conclusions

All the methods used showed or indicated that the sit-stand seat gave less loads and discomfort from the back than the conventional chair. The results also showed that it is not necessary for the force upon the feet to be higher when sitting on a sit-stand seat compared to a conventional seat. The forces upon the feet were to a great extent dependent on the height of the chair, the design of the chair and also the posture.

The body height shrinkage was high for the conventional chair. Attempts were made to calculate to what degree the decrease in shrinkage with the sit-stand seat was caused by a shorter distance to the work surface (lower biomechanical loading), or by the less kyphotic lumbar posture. The relationship between shrinkage and biomechanical loads, established in Study IV, was used for this. These calculations were uncertain, because the work postures were not fully documented due to the clothing of the subjects. The results suggested that the decrease in shrinkage could only be partially explained by the shorter distance to the work surface. Even though the lumbar support of the sit-stand seat was hardly used at all, relatively moderate shrinkage occurred, and no discomfort from the lumbar region appeared. This demonstrated the advantages of a sit-stand seat, even if used without a backrest. The disadvantage with the sit-stand seat was the discomfort experienced from the buttocks, due to the seat surface. It should also be noted that the discomfort from the shoulders and the upper arms was relatively pronounced, which could have reduced the subjective impression of the discomfort experienced from the buttocks and the back, as well as reducing its recorded level. The subject who shrank more when using the sit-stand seat was not the same subject who preferred the conventional seat.

All the methods of measurement gave important information for the evaluation of seat design, and they were judged to function satisfactorily.

This study confirmed the hypotheses tested, namely that changed chair design causes changed loads, that the effectiveness of a seat can be assessed from body loads and responses to these loads, and that a sit-stand seat is beneficial in comparison with a conventional chair in an assembly task with restricted knee-room.

The most important action to take in tasks with restricted knee-room, is of course to improve the knee-room, not just to replace the chair.

Study VII. Laboratory study of chairs in a task demanding vision to the side

This study was an extension of Studies V and VI, with a similar design but with another task and different chairs. The aims were to further evaluate the use of the methods of measurement, to evaluate influences of chair design in a task demanding vision to the side, and to relate the results to the industrial seat model. The study tested hypotheses 2 and 3, namely that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and responses to these loads. It was also hypothesized that a chair with a high backrest would be disadvantageous in comparison to a chair with a low backrest in this task, where vision to the side is required.

The experiments

The task was looking at a TV screen, which was placed 90° to the left of the subjects. The subjects were required to watch a video film during the whole experiment. They were not allowed any rest from watching, neither were they allowed to position their buttocks and thighs sideways on the seat during the experiment. No other tasks were included. The arms of the subjects were resting in their laps.

One of the instrumented experimental chairs incorporated a 30 cm high and 46 cm wide backrest, and the other experimental chair had a 47 cm high and 47 cm wide backrest. The upper edges of the backrests were 35 and 52 cm above the seat pan respectively. The backrests were adjusted to an upright sitting posture, approximately 95° between thighs and trunk. Both of the chairs had seats which were horizontal. The seats and the backrests were padded and upholstered. A footrest was used to adjust the thighs to an approximately horizontal level.

Eight subjects participated, three of them being women. Their mean age was 30 years (range 24–33 years), and their mean height was 175 cm (range 152–191 cm). None of the subjects had any back, neck or shoulder complaints at the time the study was conducted, except for the discomfort during the experimental sessions.

To compare the two chair designs, each subject performed the experimental sessions on two separate days. The tasks were performed for 45 minutes, and they started in the morning, 75–90 minutes after the subjects got up from bed.

Measures of shrinkage, reaction forces, postures, and subjective ratings were taken during the sessions. Body height was measured immediately before and after each experiment. The reaction forces from the seat, backrest, and floor were measured in sequence during ten periods of 15 seconds each, while the task was performed. The measurements of the reaction forces also allowed the torque around a vertical axis through the backrest to be calculated. The reaction forces from the seat and the backrest were also measured in rest during one 15 second period just before the task started and another 15 second period just after it had finished, while the subjects looked forwards and sat upright against the backrest. At the beginning of the experiment, photographs were taken of the subjects, one in the sagittal plane and another in the frontal plane, when they performed the task. This was repeated once again at the middle of the experiment and once more just before the end. The entire experimental session was recorded on video tape from above. Marks were attached to the shoulders and the head in order to evaluate shoulder and head rotation from the film. Discomfort ratings were also performed three times during the experiments, the first at the beginning, the second at the middle, and the third just before the end. After the subjects had carried out the experiments on the second day, they made an additional comparative rating and evaluation of the two chairs, and they were also interviewed about their experiences.

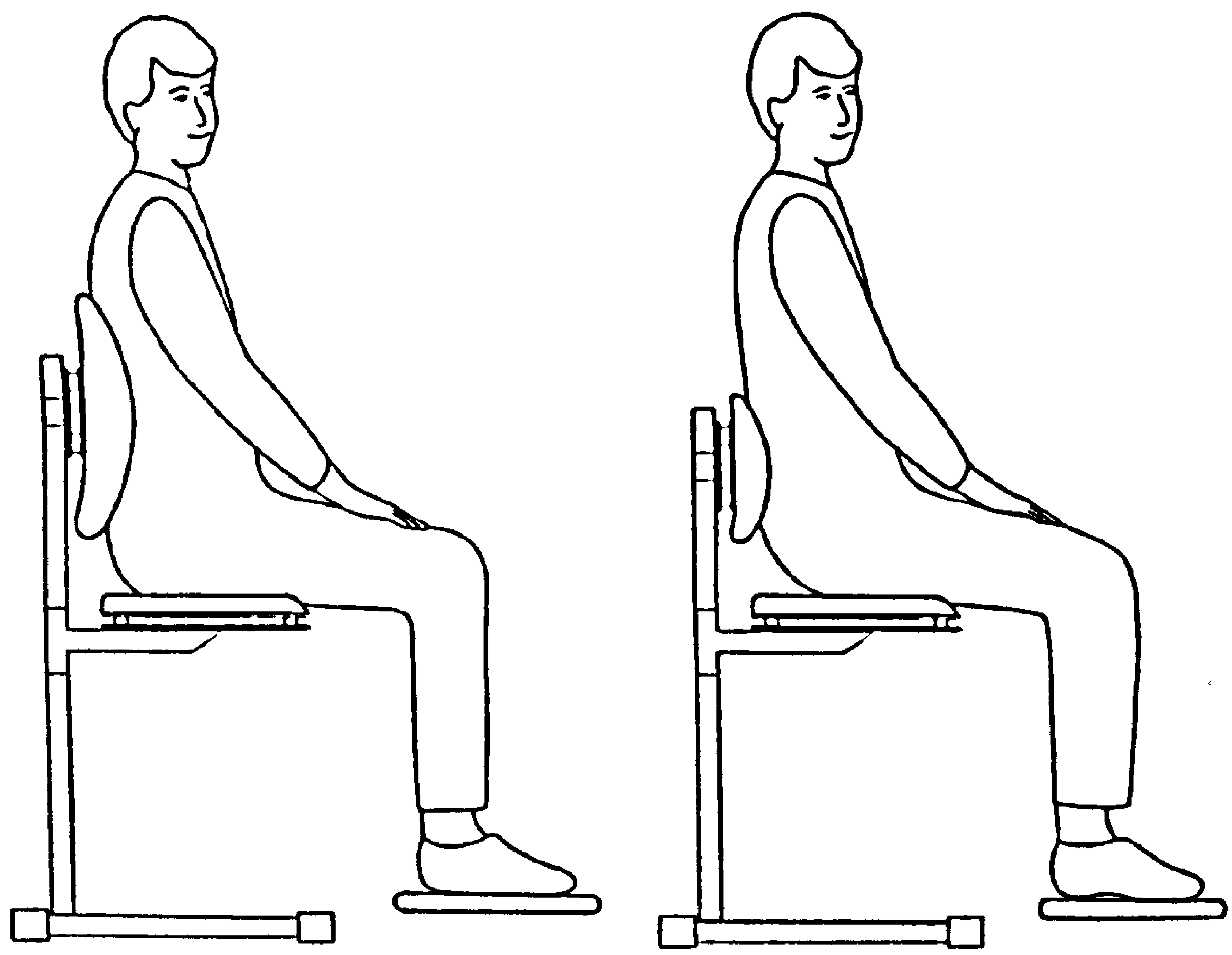


Figure 37. The working posture and the equipment used in the task demanding vision to one side. The chair with the high backrest on the left and the chair with the low backrest on the right.

In summary, the task demands were continuous viewing sideways with no demands on arm or hand movements. The methods of measurement chosen were shrinkage, biomechanical evaluations, posture analysis, and subjective evaluations.

Statistical evaluations were made at the 5 per cent level of significance (one-tailed test). The Wilcoxon test and the Sign test were used for evaluation of discomfort ratings and preferences respectively. The paired t-test was used for all other data.

Results

In this sideways viewing tasks, the low backrest caused 0.88 mm shrinkage and the high backrest caused 1.44 mm. Four subjects experienced more shrinkage when they used the low backrest and four subjects experienced less. The difference was not significant. The standard deviation of all sets of height measurements was 0.65 mm. The individual difference in body height between the start of the two experiments, was 1.85 mm on average.

The force measurements showed that at rest, the force on the high backrest was significantly lower than the force on the low backrest. The same thing occurred when the work task was performed, as shown in Table 15. This was the case for all of the eight subjects. The centre of pressure of the backrest force showed no systematic difference in position between the low and the high backrest or between rest and work. The forces upon the feet were equal for the two supports.

An attempt was made to calculate the torque acting on the backrest around a vertical axis in the centre of the back. These calculations were difficult to conduct, because the task not only involved a rotation of the back, but also a simultaneous lateral movement, especially of the upper portion of the back. The results pointed to a higher torque for the high backrest, compared to the low one.

The work task defined a rotation angle of the head, which was in principle equal for each individual when using either back support. The shoulders were on average twisted more when using the low backrest than when using the high one. Rotation of the neck was defined as the difference between head rotation and shoulder rotation. This meant that the neck was rotated an average of four degrees more with the high backrest than with the low one, as shown in Table 15. It could also be noted that the rotation of the shoulders increased on average throughout the experiment. The three subjects who used glasses had to rotate their heads more than the others, in order to see the TV-screen.

The discomfort from the neck dominated totally during this task. The increase in discomfort for the worst body part during the experiment was significantly higher for the high backrest than for the low one, which was the case for seven of the eight subjects. On the whole, the high backrest received a greater number of discomfort statements, overall discomfort to a higher degree, and also more overall discomfort from six of the eight subjects, but the differences were not significant. Large individual differences came out of the evaluation of discomfort, even though the task demands were idential. One person completed the task without any discomfort at all. The three subjects who used glasses, experienced more discomfort than the others. One of them was very close to dropping out of the experiment due to intensive discomfort. Six out of the eight subjects preferred the low backrest, while two preferred the high backrest, as shown in Table 15.

*Table 15. Results from the task demanding vision to the side. The measurement results from shrinkage, reaction forces, and angles are given as means, followed by the standard deviation. The subjective ratings are given as the total sum of discomfort score for the eight subjects. Significant differences are marked with *.*

	Low backrest	High backrest	Standard deviation of individual differences
Shrinkage (mm)	0.88 (1.70)	1.44 (0.77)	1.80
Backrest force at rest (N)	128 (39)	97 (21)	23*
Backrest force at work (N)	127 (39)	93 (22)	25*
Force upon feet at work (N)	156 (21)	155 (20)	6
Shoulder rotation (°)	12 (4)	9 (5)	6
Neck rotation (°)	54 (6)	58 (4)	6
Increase in discomfort score for the worst body part	129	369	*
Sum of overall discomfort score	256	399	
Number of discomfort statements	15	20	
Preference	6	2	

Discussion and conclusions

All the methods indicated that a low backrest is advantageous in tasks demanding vision to the side, even though there were few significant results in this study. The low backrest allowed a greater degree of freedom to move the upper back and shoulders, and allowed rotation of the shoulders and the shoulder blades to take place more easily without being restricted, compared to the higher backrest.

The two subjects who preferred the high backrest, and two other subjects, considered that the backrests were very similar when they made their choice of preference. This was judged to be connected with the decreased anterior-posterior trunk stability for the low backrest.

The biomechanical calculations of the torque exerted on the backrests implied that higher trunk muscle activity was needed in order to press one side of the back and one shoulder into the high backrest, compared to the muscle activity needed when using the low backrest. At the same time, increased thoracic rotation meant decreased neck rotation, and in this situation, also less discomfort was recorded. These results pointed to the benefit of a low backrest in tasks demanding vision to the side.

A difficulty with the torque measurements on the backrests was that the backrests used were curved horizontally. This meant that the distribution of pressure on the backrest, and therefore also the torque, did not change to such a large extent as it would have done for a backrest without a horizontal curve. In this respect, a horizontally curved backrest can be regarded as beneficial in tasks involving trunk rotation. In other words, a horizontally concave backrest increases the stability and the support for the sitter.

The relationship between neck rotation and discomfort from the neck was emphasized in several ways. More discomfort was experienced for the high backrest, which caused more neck rotation than the low backrest, and for the users of glasses, who were forced to rotate their necks more. Also, the subjects decreased their neck rotation during the experiment, in order to decrease the neck discomfort. The resulting decrease in shrinkage for the low backrest may have been a result of a decrease in muscle activity of the trunk and neck muscles.

The methods used worked satisfactorily for the evaluation of the appropriateness of chair design. However, biomechanical calculations according to the models presented, were not relevant for use in tasks involving spinal rotation.

The study confirmed the hypotheses tested, namely that changed chair design cause changed loads, that the effectiveness of a seat can be assessed from body loads and responses to these loads, and that a high backrest is disadvantageous, compared to a low one, in a task demanding vision to the side.

Study VIII. Field study of chairs in grinding work

This study was performed to assess if the results from the laboratory studies were supported in the field. The aims were to evaluate the use of the methods devised in a field study, to evaluate influences of chair design in grinding work, and to relate the results to the industrial seat model. The study tested hypotheses 2 and 3, namely that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and responses to these loads. Also, it was hypothesized that a chair with a high backrest would be beneficial compared to a chair with a low backrest in forward force exertion when grinding.

The experiments

The task included grinding and burring workpieces by hand, using a single stationary grinding machine. It was performed in a Swedish mechanical workshop. The workpieces varied in weight from 0.02 kg up to 5 kg. Their largest dimensions varied approximately from 5 cm to 35 cm. In some cases only the sharp edges were ground, in others cubic centimetres of material were removed. The forces exerted on the sanding belt of the grinding machine could not be measured, but simulations showed that the horizontal force component varied from under 10 N to approximately 150 N. Some workpieces were ground on only one side, while others needed to be twisted and turned in order to be ground on all the edges. The workpieces were taken from a pallet on one side, and after the grinding was finished, they were laid on a pallet on the other side.

The stationary grinding machine was equipped with a box for collecting burrs. This box encroached upon the leg-room for sitting operators, which created problems to obtain a desirable sitting posture.

One instrumented experimental chair had an 18 cm high and 35 cm wide lumbar support and a horizontal seat. The other experimental chair had a 38 cm high and 41 cm wide backrest and a horizontal seat. The upper edges of the backrests were 31 cm and 43 cm above the seat pan respectively. Both seats and backrests were padded and upholstered. The height of the chair and its distance from the grinding machine was tested and decided by the operators themselves.

Eight people, who in their work conducted or had conducted this grinding work, took part in the experiments. They were instructed to work at their own normal pace. All of them were men. Their mean age was 33 years (range 24–42 years), their mean height was 181 cm (range 178–187 cm), and their mean weight was 79 kg (range 72–90 kg).

Each operator participated in the two experimental sessions on two separate days. The grinding task was performed for 45 minutes both days, starting in the morning, about 75–90 minutes after the participants got up from bed.

Body height shrinkage, reaction forces, postures, and subjective ratings were assessed during the experiments. The participant's body height was measured immediately before and after each experimental session. The reaction forces from the backrest, seat, and floor were measured in sequence during five periods of 15 seconds each, while the grinding task was performed. These measurement periods were adjusted in starting time in order to get as representative grinding activity as possible. The reaction forces were also measured during one period before and one period after the grinding was conducted, in upright sitting against the backrest without work activity. Photographs were taken of the grinders in the sagittal plane when working, at the beginning, at the middle, and just before the end of all experiments. Discomfort ratings were also performed three times, at the beginning, at the middle, and just before the end of the experiments. After the second day, the grinders made an additional comparative rating and evaluation of the two seats, and they were also interviewed about their experiences.

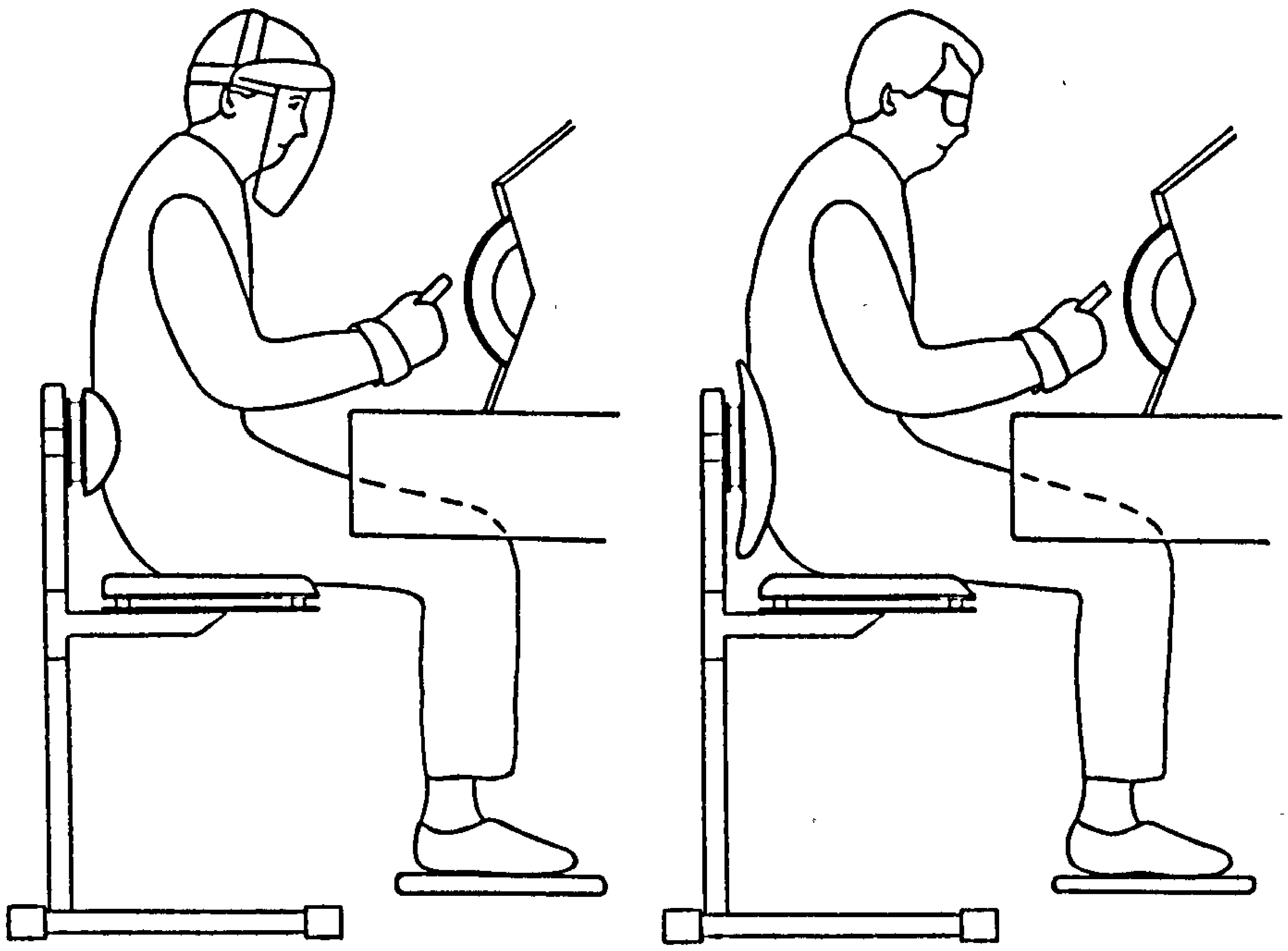


Figure 38. Typical work postures, the experimental chairs, and the grinding machine. The chair with the low backrest on the left, and the chair with the high backrest on the right.

In summary, the task demands were grinding, exerting forwards and upwards directed force, and picking up workpieces from the side. The methods of measurement chosen were shrinkage, biomechanical evaluations, posture analysis, and subjective evaluations.

Statistical evaluations were made at the 5 per cent level of significance (one-tailed test). The Wilcoxon test and the Sign test were used for evaluation of discomfort ratings and preferences respectively. The paired t-test was used for all other data.

Results

A considerable variability between the conditions of the experimental sessions was noticed. Disruptions and changes in the production occurred due to adjustment of sanding belt tension, adjustment of belt position, belt replacement, reorganization of workpieces, changing fuses, and adjustment of lighting. Also, there was a variation of the picking and unloading zones, due to the fact that different workpieces were used during the different experimental sessions.

The chair with the low back support caused 2.81 mm shrinkage and the chair with the high backrest caused 2.54 mm. Four of the grinders shrank more when they used the low lumbar support, and the other four shrank more when they used the high backrest. The difference was not significant, as shown in Table 16. The standard deviation of all sets of height measurements was calculated as 0.52 mm. The individual difference in body height between the start of the two experiments, was 2.85 mm on average.

The force upon the high backrest was significantly lower than the force upon the low backrest, when measured at rest. Six of the eight subjects had lower forces upon the high backrest than upon the low one. There was also a similar tendency of lower force upon the high backrest during work. The force on the backrest was, at the same time, less at work than while resting for both chairs. The positions of the centre of pressure of these forces were significantly higher above the seat pan for the high backrest than for the low one, both at rest and at work. The force on the feet was lower during work compared to rest, for both chairs.

Because different workpieces were ground during the experimental sessions, a variation in the angle of the grinding force was recorded. It varied between 5° and 35° above the horizontal plane, i.e. a forwards and upwards directed force was exerted. There were also friction forces from the sanding belt, which had to be resisted with upwards directed forces. However, the upwards directed forces were sometimes resisted by one hand being supported against the edge of the box for collecting burrs. There was no systematic difference seen in the direction of the grinding force between the two backrests.

The photographs showed that the chair was placed by the grinders at the same distance from the grinding machine for both the high and the low backrest. The distance from the backrest to the sanding belt was approximately 50 cm on average. The height of the seat pan of the chair was adjusted with the height of the sanding belt in mind rather than the length of the subject's lower legs. This meant that the angle between the upper side of the thighs and the horizontal plane was 15–20°, with the thighs sloping forward. No systematic difference was seen in the thigh angles between the high and the low backrests. There was a tendency among the grinders to lean the trunk more forward when using the low backrest.

Calculations according to the biomechanical model were difficult to perform due to difficulties to determine the posture from the photographs, and due to the movements which occurred when the task was performed. However, the tendency was that the high backrest caused less shear force upon the lower part of the lumbar spine. The moments of the backrest force around the hip joints were found to be higher for the high backrest than for the low one, which was interpreted as meaning that the higher backrest was more effective.

The dominating discomfort experienced during the grinding work came from the shoulders. No significant differences were noticed between the two backrests for any of the discomfort ratings which were performed. Five of the grinders experienced more discomfort from the low backrest. Further, the low backrest received two more discomfort statements from the lumbar back, and the high backrest was given two more discomfort statements from the shoulders. Five of the grinders preferred the high backrest and three preferred the low backrest, as seen in Table 16. Two of the three grinders who preferred the low backrest stated that the reason for their choice was that the high backrest was too wide and thus allowed too little elbow-room.

*Table 16. Results from the grinding work. The measurement results from shrinkage and reaction forces are given as means, followed by the standard deviation. The ratings are given as the total sum of discomfort score for the eight participants. Significant differences are marked with *.*

	Low backrest	High backrest	Standard deviation of individual differences
Shrinkage (mm)	2.81 (2.01)	2.54 (1.68)	1.83
Backrest force at rest (N)	97 (22)	75 (22)	17*
Backrest force at work (N)	72 (33)	62 (19)	23
Force upon feet at rest (N)	137 (35)	147 (38)	41
Force upon feet at work (N)	132 (42)	143 (27)	33
Position of backrest force above seat at rest (mm)	214 (15)	277 (19)	19*
Position of backrest force above seat at work (mm)	224 (13)	281 (42)	47*
Increase in discomfort score for the worst body part	139	152	
Sum of overall discomfort score	196	184	
Number of discomfort statements	18	21	
Preference	3	5	

Discussion and conclusions

The results supported the previously shown results, that a high backrest is advantageous in tasks demanding forward force exertion. However, other conditions were present at the same time in the grinding task, which decreased the advantages with the high backrest used. These were the trunk movements necessary in order to reach and pick up the workpieces, and inadequate elbow-room when picking up and grinding large workpieces. It is important to recognize that a high backrest can be disadvantageous in tasks which demand large movements of the trunk or movements of the arms rearwards. Also, a wide backrest can be disadvantageous in tasks demanding movements of the arms and the elbows, which is of great importance, since high backrests almost always have been made wide at the same time.

The variability of the grinding task caused an increased random variation of the results, which was judged to be another reason for the few significant differences obtained.

The shrinkage method was applied in industry without any problems. All grinders learned the procedure in less than the 30 minute training session, and they performed height measurements with a relatively small standard deviation. The posture assessment, using photographs of the grinders in the sagittal plane, caused difficulties mainly due to lack of space for the camera, and due to the protective clothing which concealed body parts. The discomfort ratings gave valuable information, however, and could be performed without problems.

As pointed out earlier, the grinders on average decreased the force on the backrest when grinding. Two of them showed a clear increase of the force upon the backrests while grinding, and they pointed to the special advantage of getting better support, which the high backrest gave. Two of the grinders noticeably decreaced their force upon the backrests when they started to grind. This could be observed during the experiments as different individual strategies. The latter two grinders leaned forward when they applied the force on to the sanding belt. It should be noted that in the instructions given before the experiment, nothing was mentioned of how to use the chairs. The grinders had no previous experience of chairs with high backrests. It is possible that the grinders, who did not make full use of the high backrest, would have learned to do so if they were given more training or experience of using it. Another possible cause of the decrease in force upon the backrest when grinding, could have been that the grinders needed to see the work process thoroughly, and because of that took a somewhat forward leaning posture. There was no clear relationship found between the individuals who shrank more and the forces they exerted on the chairs or the discomfort they experienced.

The study supported the hypotheses tested, namely that changed chair design can change the loads, that the effectiveness of a seat can be assessed from body loads and responses to these loads, and that a high backrest is advantageous, compared to a low one, in forward force exertion when grinding.

The study also demonstrated that if arm movements are involved, the width of the backrest must be designed to give necessary clearance. Further, it was also indicated that a too high backrest can be disadvantageous in tasks demanding trunk movements and arm movements.

Study IX. Field study of chairs in punch press work

This study was performed in order to gain further experience from applications in the field. The aims were to evaluate the use of the methods devised in a field study, to evaluate influences of chair design in punch press work, and to relate the results to the industrial seat model.

This study tested hypotheses 2 and 3, namely that changed chair design can cause changed loads, and that the effectiveness of a seat can be assessed from body loads and responses to these loads. It was also hypothesized that a sit-stand seat would be beneficial for the spine in punch press work compared to a conventional chair with a low backrest.

The experiments

The experiments took place in a Swedish mechanical workshop with a variety of manufacturing processes. The length of the batches of work varied under normal circumstances between 15 minutes and 2 days. Four different types of punch presses were used in the experiments. They all had limited knee-room for a sitting operator. Almost all of the experimental sessions involved different workpieces, varied lengths of batches, and varied tempo. The weight of the workpieces varied between 0.02 kg and 5 kg. Their largest dimension varied between 3 cm and 50 cm. Some tasks required high precision in fitting the workpiece into the tool, while others required hardly any precision. The presses were operated by light sensors, foot pedals or two-hand manoeuvred controls. The workpieces were taken from a pallet on one side, and after being finished, they were laid on a pallet on the other side. The pallets were adjustable in height and position. The operators normally worked both sitting and standing, depending upon the type of workpieces and tools involved. Workpieces weighing more than 3–5 kg were considered too heavy to lift in a sitting posture, which can be referred to the long lever arms involved in those lifts. When rods and other bulky raw materials were used, the work required walking a few steps once in a while, which meant that sitting was not practical. The experimental sessions only involved work suitable for sitting. There were no restrictions regarding the visual angle in any case.

One of the experimental chairs had an 18 cm high and 35 cm wide lumbar support and a horizontal seat. The other was a sit-stand seat, with an identical lumbar support. Both seats and lumbar supports were padded and upholstered. They were identical with those used in Study VI. The operators tested and decided upon the height of the seat and its distance from the punch press themselves.

Eight people took part in the experiments. They carried out tasks which were a regular part of their ordinary work, and they were instructed to work at their own normal pace. All of the operators were men. Two were immmigrants, one of whom had a very bad command of the Swedish language. The operators' mean age was 35 years (range 18–61 years), their mean height was 174 cm (range 160–185 cm), and their mean weight was 81 kg (range 53–102 kg).

Each operator participated in two experimental sessions on two different days. The task was performed for 45 minutes each day. For practical reasons, since the work in this workshop was mainly shift work, the experiment took place 4–7 hours after the participants got up from bed. It was tried to start both sessions for the same operator at similar times.

Body height shrinkage, reaction forces, postures, and subjective ratings were assessed during the experiments. Each participant's body height was measured immediately before and after the experimental sessions. The reaction forces from the backrest, seat, and floor were measured in sequence during five periods of 15 seconds each, during the punch press work. These measurement periods were adjusted in starting time in order to get as representative a coverage of the work activity as possible. The reaction forces were also measured during one period before and one period after the grinding was conducted, in upright sitting against the backrest without work activity. The reaction force between the floor and both feet was not possible to measure due to foot pedals and space restrictions, but the force from the foot which was not occupied with the foot pedal was measured. Since the force required for the foot pedal was low, it was considered in the analysis that the total reaction force on the feet was twice the force measured for one foot. Photographs were taken of the operators in the sagittal plane when fitting the workpiece into the tool. One photograph was taken at the beginning, one at the middle, and one just before the end of all experimental sessions. Discomfort ratings were also performed three times, at the beginning, at the middle, and just before the end of the session. After the second day, the operators made an additional comparative rating and evaluation of the two seats, and they were also interviewed about their experiences.

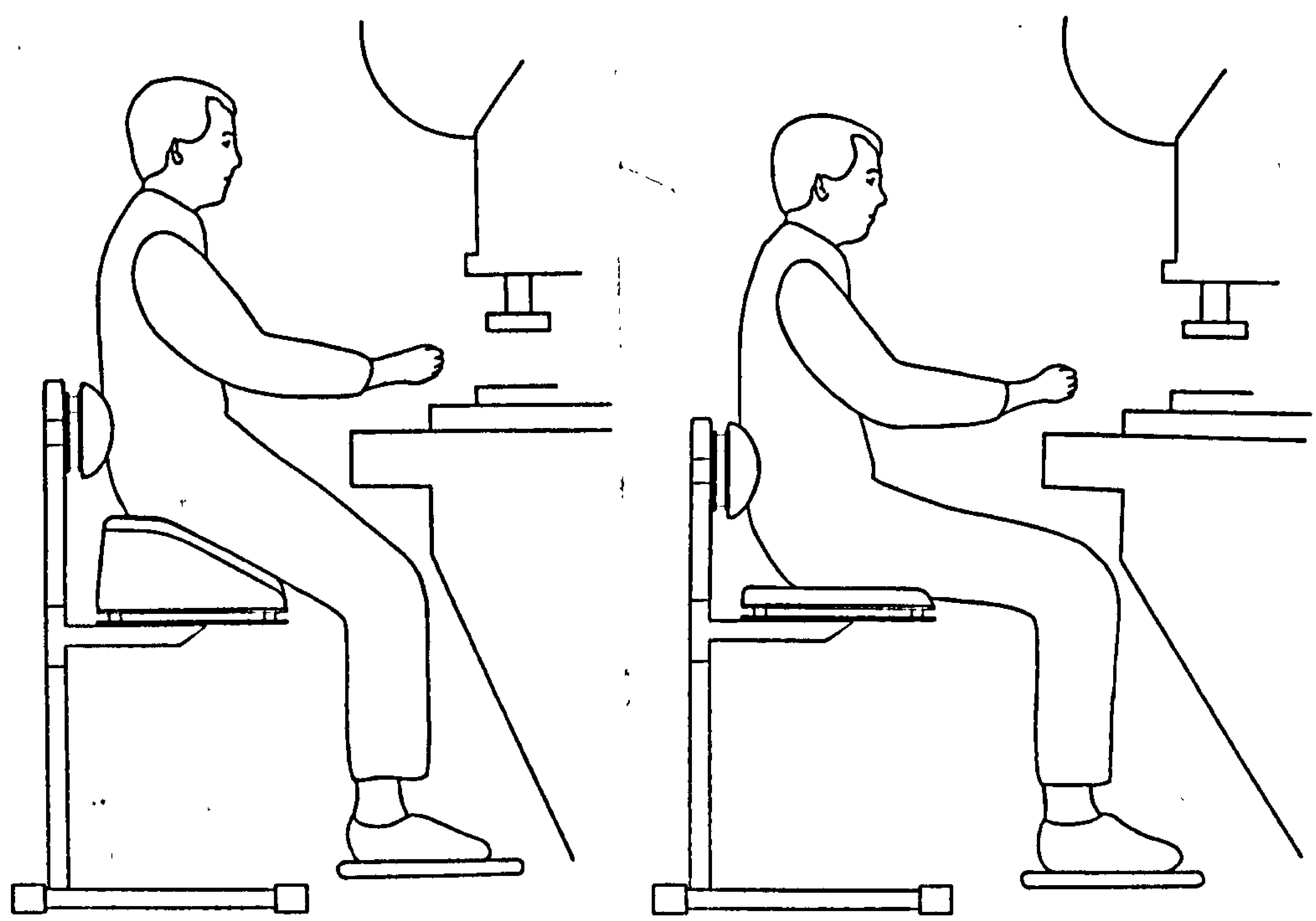


Figure 39. Typical work postures, the experimental chairs and a punch press. The sit-stand seat on the left and the conventional chair on the right.

In summary, the task demands were punch press work with restricted knee-room, involving handling workpieces into and out of the tool. The methods of measurement chosen were shrinkage, biomechanical evaluations, posture analysis, and subjective evaluations.

Statistical evaluations were made at the 5 per cent level of significance (one-tailed test). The Wilcoxon test and the Sign test were used for evaluation of discomfort ratings and preferences respectively. The paired t-test was used for all other data.

Results

As with the previous field study, there was a considerable variability between the conditions of the experimental sessions in this study too. Interruptions took place, such as workpieces getting stuck in the tool, tool readjustments, control measurements of the workpieces, manual lubrication with oil using brushes, and running out of work.

The measurements of body height showed that the operators on average obtained an increase in body height of 0.19 mm for the conventional chair and an increase of 0.48 mm for the sit-stand seat. Four of the operators experienced more height increase for the conventional chair, and the other four experienced more height increase for the sit-stand seat. The difference was not significant, as shown in Table 17. The increase in body height pointed to the load on the back being relatively low during the work, but such conclusions should not be pushed too far, since the starting time of this experiment, and the loadings before it, were not controlled. The margin of error should for that reason be larger than for the other shrinkage studies reported. The standard deviation of all sets of height measurements was calculated to be 0.58 mm. The individual difference in body height between the start of the two experiments, was 2.04 mm on average.

The force upon the backrests was higher for the conventional chair than for the sit-stand seat, both at rest and at work. This was the case for all eight subjects at rest and seven of the eight subjects at work. The difference was significant. No difference in the centre of pressure of the backrest forces was seen. The force upon the feet was significantly higher for the sit-stand seat compared to the conventional chair, and this was the case for seven of the eight operators. These force values were based on measurements of the force from one foot, as previously described. This observation was also confirmed by a lower force on the seat for the sit-stand seat, compared to the conventional seat. There was a variability in the weight of the workpieces and the frequency with which they were handled. Also the height of the punch press tool and its horizontal distance from the front of the press varied. On average, the operators adjusted the seat height of the conventional chair so that the upper side of the thighs sloped 25° downward. The corresponding angle for the sit-stand seat was 36°. The operators hence used both chairs as high seats and increased the angle between the trunk and the thighs. The distance between the tool (the working surface) and the seat was on average 45 cm for the conventional chair and 32 cm for the sit-stand seat. The operators adjusted the seat and arranged a compromise between the demands of the working height in relation to the shoulders or elbows and the seat height in relation to the lower leg length. The neck was, because of the higher seat adjustment, tilted significantly more forward for the sit-stand seat. Also, the sit-stand seat was placed significantly closer to the press than was the conventional chair. Hence, the arms needed neither to be lifted so high, nor to be stretched so far forward when the sit-stand seat was used.

Calculations according to the biomechanical model indicated a decreased shear load on the lower lumbar spine for the sit-stand seat, compared to the conventional chair.

Discomfort from the shoulders and upper arms dominated in the experiments. No significant differences were seen between the two seats regarding any discomfort measure. Three of the subjects experienced more discomfort for the conventional chair. The discomfort experienced when using the sit-stand seat originated from the shoulders, the upper arms, and the buttocks. When using the conventional seat, the discomfort arose from the thoracic and lumbar back, shoulders, and upper arms. Three of the operators preferred the sit-stand seat, while five preferred the conventional one, as can be seen in Table 17. The people who preferred the sit-stand seat mentioned a better working posture for the arms and the back as a reason for their choice. In total, six people complained of sliding off the sit-stand seat or said that it felt unstable, unsafe, or uncomfortable for the buttocks. These were the main reasons why five operators preferred the conventional chair.

*Table 17. Results from the punch press work. The measurement results from shrinkage, reaction forces, and angles are given as means, followed by the standard deviation. The ratings are given as the total sum of discomfort score for the eight participants. Significant differences are marked with *.*

	Conventional chair	Sit-stand seat	Standard deviation of individual difference
Shrinkage (mm)	−0.19 (1.20)	−0.48 (1.28)	1.62
Backrest force at rest (N)	96 (15)	59 (23)	13*
Backrest force at work (N)	57 (32)	33 (24)	17*
Force upon feet at rest (N)	131 (61)	192 (57)	49*
Force upon feet at work (N)	132 (62)	189 (70)	61*
Position of backrest force above seat at rest (mm)	221 (15)	227 (20)	21
Position of backrest force above seat at work (mm)	219 (15)	212 (40)	31
Thigh angle (°)	25 (6)	36 (6)	5
Increase in discomfort score for the worst body part	81	79	
Sum of overall discomfort score	130	164	
Number of discomfort statements	24	27	
Preference	5	3	

Discussion and conclusions

The results showed that in punch press work, the sit-stand seat was advantageous for the spine, but also that it caused major disadvantages, primarily concerning discomfort from the seat surface and poor stability. These problems were perceived to such an extent that a majority of the participants preferred the conventional chair.

As mentioned earlier, the operators chose to adjust the conventional chair to such a height that it was already used to some extent as a sit-stand seat. Hence, the punch press workers already had adapted the height of the seat to the working surface and moved the chair closer to the punch press. This decreased the difference between the two seats. It also showed that the operators spontaneously adjusted the seat in a way which decreased the loads on the arms, shoulders and back by allowing them to sit closer to the work and not lifting the arms so high. The sit-stand seat decreased these loads to a greater extent. The reasons for the subjects not preferring the sit-stand seat was, as previously mentioned, discomfort from the buttocks and also that the operators felt that they slid off the seat. This was also confirmed by the increased force upon the feet. A probable reason why this problem became so obvious in this study, but not in Study VI in the laboratory, was that the work involved movements when picking and handling workpieces from pallets on the sides. The operators had to bend and rotate a little every time, and presumably slid slightly forwards each time on the seat. The higher force on the backrest in this study, compared to the laboratory study, also acted in the same direction, by "pushing" the operators off. The design of the seat surface of sit-stand seats needs to be improved in order to overcome the problems mentioned above.

The shrinkage method was also applied in industry in this study without any problems. The operators learned the procedure in less than the 30 minute training session, and performed the measurements with a relatively low standard deviation.

The movements caused problems in measuring representative reaction forces. Also the posture assessment, using photography, was difficult in industry, due to the reasons mentioned previously.

The discomfort ratings gave very valuable information and could be performed without any problems.

The study confirmed the hypotheses tested, namely that changed chair design can change the loads, that the effectiveness of a seat can be assessed from body loads and resonses to these loads, and that a sit-stand seat is beneficial regarding the spine, compared to a conventional chair in punch press work.

The study also demonstrated that trunk movements can cause forward sliding on a sit-stand seat, which gives rise to feelings of instability and discomfort.

Study X. Field study of seats in fork lift truck driving

This study was performed to assess if the results from the laboratory studies were supported in the field. The aims were to evaluate the use of discomfort assessments in a field study, to evaluate aspects of seat design in fork lift truck driving, and to relate the results to the seat model.

These aims relate to hypotheses 3 and 4, namely that the effectiveness of a seat can be assessed from the subjective responses to loads, and that the task is a major factor in the design of an effective chair. It was also hypothesized that a high backrest would be disadvantageous compared to a low backrest in a task demanding vision to the sides.

The experiments

The study was performed in a Swedish mechanical workshop. The tasks for the drivers were to transport pallets in the workshop and warehouse. The pallets were handled at high and low levels, including the floor level. The dominating level varied between the drivers, due to their tasks, as did the lift frequency and the distances travelled. The drivers normally worked more than four hours a day with truck driving.

The fork lift trucks were all battery powered, narrow aisle sit-down lift trucks, with a sideways sitting driver. Three backrests were tested, and a comparison was also made with a fourth backrest, originally mounted on the fork lifts. This original backrest was 47 cm high and 47 cm wide. The heights of the three backrests tested were 30, 36, and 42 cm. Their widths were 46, 44, and 47 cm respectively. The upper edges of the backrests were 35, 41 and 47 cm above the seat pan respectively. The upper edge of the original backrest was 52 cm above the seat pan. The seat pans were 42 cm deep and 45 cm wide for the three test seats, and 46 cm deep and 51 cm wide for the original seat.

A total of 18 truck drivers were chosen to take part in the experimental study. One of them dropped out because of long lasting work-related neck pain resulting in sick leave. Another person received changed work tasks, and a third person declined to complete the whole experiment. Of the 15 remaining drivers, six were women and eight were men. Their mean age was 40 years (range 22–62 years), their mean height was 172 cm (range 154–194 cm), and their mean weight was 70 kg (range 58-92 kg).

All 15 drivers used each seat for two working days, in their ordinary tasks. The original seat was used during the first two experimental days. The order of the other three seats was balanced.

In this study, subjective ratings, a questionnaire, and interviews were used for the evaluation. The drivers were trained to perform the discomfort ratings on the forms used in the other studies (see Appendix 7). This training took place on the first and second days, under the direction of the experimenter. While using the three test seats, the truck drivers performed the ratings themselves without supervision and then handed in the forms to the experimenter every day. The ratings were performed three times a day, about 15 minutes after work began, just before lunch, and 15 minutes before the end of the working day. When all the experiments had been completed, the drivers were interviewed and asked to answer a questionnaire about their patterns of exposure, their preferences related to the tasks, and their opinions about the experimental seats (see Appendix 8).

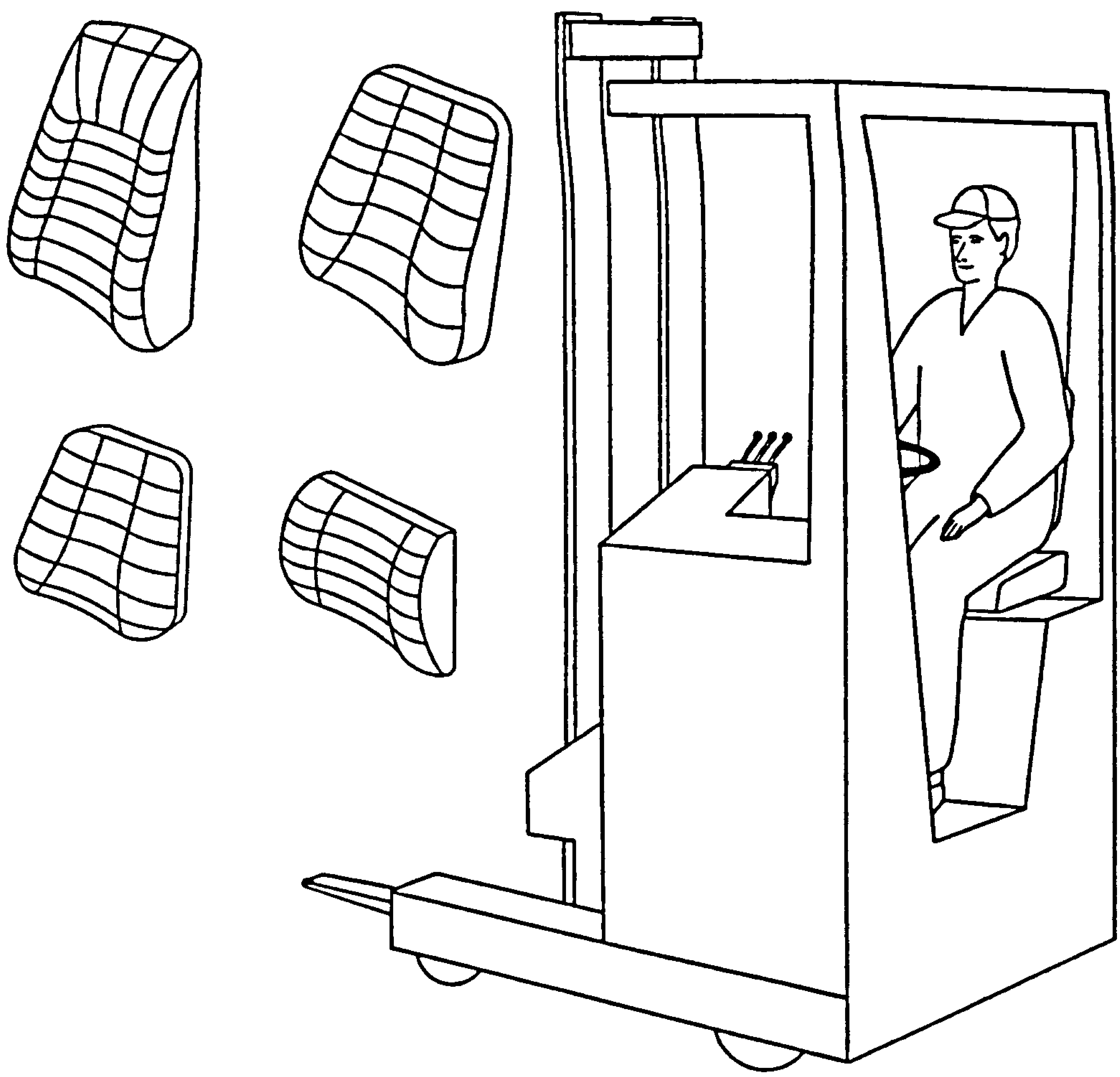


Figure 40. The four backrests used and a narrow aisle fork lift truck with a sideways sitting driver.

In summary, the task demands were fork lift truck driving, which included steering, accelerating, and decelerating the truck and visual control to the sides. Pallets were handled which demanded visual control to the side and upwards, and also lever control. The visual demands meant substantial movements of the trunk.

Statistical evaluations were made on the 5 per cent level of significance (one-tailed test), using the Wilcoxon test or the Sign test.

Results

The drivers estimated that they spent between 2–6.5 hours per day, or on average 4.7 hours per day sitting in their trucks. Driving distances over 100 metres were most common, but about half of the drivers had very variable driving distances. Some exposure to vibrations existed while driving, due to irregularities in the floor. The work was organized in such a way that it was necessary to step out of the truck quite often. Picking up or setting down pallets usually took less time than driving. The handling of pallets 5–6 metres above the floor involved a difficult posture, namely bending rearwards and rotating the trunk and neck and also bending sideways. Also, handling of pallets on the floor level involved a great deal of sideways bending and rotation. When handling pallets, unimpaired vision could only be attained by looking round the outside of the frame of the truck, when handling pallets. Particularly short drivers, who had their seats adjusted in a forward position, were forced into more extreme postures in this respect.

In total, discomfort from the lumbar back was most common, followed by discomfort from the neck and shoulders. The high backrest mainly caused discomfort from the neck, while the low one predominantly caused discomfort from the lumbar and thoracic regions. The medium-low backrest gave rise to the smallest number of discomfort statements, and it also received the largest number of preferences, as shown in Table 18. The differences were not significant. The medium-high backrest was comparable, and it received a lower overall discomfort score than the other backrests. The low backrest received significantly more overall discomfort than the medium-low and the medium-high backrests. This was the case for eleven drivers, but one driver made the opposite rating. The increase in discomfort for the worst body part was comparable for the two middle backrests, meaning that six drivers experienced more increased discomfort for one of the middle backrests and six drivers experienced more increased discomfort for the other one. These backrests received the lowest discomfort score of the four backrests, but the differences were not significant. Eight drivers experienced more increased discomfort for the low backrest compared to the two middle backrests, while only three drivers did the opposite. A majority of the truck drivers did not accept the low backrest at all. Several drivers expressed their discontent with this backrest strongly, and many of the drivers pointed out that the stability of the trunk was poor when using it. It was considered as difficult to twist or move the trunk when sitting on the seat with the high backrest, especially when pallets were handled high above the ground.

The operators' height, age, weight, or estimated time they spent sitting in the truck did not show any significant effect on the responses to the backrests. There was a slight trend that the taller drivers preferred higher backrests than the others. There was also a non-significant tendency that the taller and heavier drivers experienced more discomfort than the others.

Table 18. Results from the fork lift truck driving work. The ratings are given as the total sum of discomfort score obtained during all test days. Those test days with one or two ratings missing are omitted.

	Backrest			
	low (30 cm)	medium-low (36 cm)	medium-high (42 cm)	high (47 cm)
Increase in discomfort score for the worst body part /number of test days	360/27	223/30	219/30	130/12
Sum of overall discomfort score /number of test days	695/27	446/30	368/30	379/19
Number of discomfort statements /number of test days	113/27	89/30	99/30	63/19
Overall preference	2	7	6	—
Preference while lifting high above the floor	3	7	5	—
Preference while driving	2	6	7	—
Preference while sitting	1	8	6	—

Discussion and conclusions

The results confirmed that a high backrest is disadvantageous in a task demanding vision to the sides, rotation, and sideways and rearwards bending of the trunk. The result was unequivocal, even though the drivers had used the high backrest for a long time. Nearly all of them wanted to change their original high backrest to a medium backrest. It was also clearly stated by the drivers that the low backrest was inappropriate, due to lack of stability. This was judged to be mainly due to the acceleration forces present when driving. A higher backrest permits better relaxation of the trunk muscles than a low one. These observations demonstrate how the task influences the design of the chair. A suitable compromise between two conflicting demands in driving fork lifts of this type seems to be a medium size backrest, i.e. a height between 36 cm and 42 cm, which was accepted by most persons. Such a medium size backrest would give support to the thoracic spine, and at the same time allow movements and rotation to take place.

Another possible design of a backrest would be narrower at the top.

That could possibly provide both stability when leaning against it, and also provide freedom to move in the chair.

An important factor for the choice of preferred backrest was the sagittal curvature, i.e. the lumbar pad depth. Some of the truck drivers pointed out that the curvature of the medium-low backrest fitted their lumbar backs better and therefore gave a better support than the medium-high backrest, while other drivers preferred the opposite backrest using the same argument. An adjustable lumbar depth would therefore increase the number of drivers satisfied with their backrest.

Some of the taller drivers spontaneously pointed to the seat pan as being too short and some of the shorter drivers saw it as too deep. This complaint only appeared in this study of the truck drivers, and not in the other studies which included other tasks. It was judged that the acceleration forces due to starting, stopping and changing speed caused a sideways instability of the knees and legs, particularly because these forces acted in that direction on the sideways sitting driver. It is therefore important to have a relatively deep seat, in order to obtain good leg stability. The seat must, however, not be too deep, which was the case for the shorter drivers. The differences in thigh length between the operators thus necessitates an adjustable seat depth or possibilities to choose a suitable but fixed seat depth.

The subjective ratings gave a large amount of valuable information, and so did the questionnaire and the interviews. The drivers had clear opinions about the backrests, but it was often difficult for them to express and motivate these opinions. The question about preferences while performing the three work activities (see Table 18), is an example of this. The results from the comparison of these activities are therefore probably not too reliable.

The study confirmed the hypotheses tested, namely that the effectiveness of a seat can be assessed from measures of the responses to these loads, and that a high backrest is disadvantageous compared to a low backrest in tasks demanding vision to the sides. This study, in combination with Studies V, VII, and VIII supported hypothesis 4, namely that the task is a major influence on effective chair design.

It was also demonstrated in this study that a low backrest cannot provide sufficiently good stability for the trunk when acceleration forces are present.

Study XI. Head posture in fork lift truck driving

In this study, it was decided to examine the work task influences in relation to the postures. It was partly an extension of Study X, since the posture measurement equipment used was not available at that time. The aimes of the study were to evaluate how influences from the truck design, the work task, the seat, and the individual affected the truck drivers' head posture, to develop and use the equipment for measuring head posture and analyse the temporal pattern of the posture, to evaluate the method in the field, and to relate the results to the industrial seat model.

The study related to hypotheses 3 and 4, namely that the appropriateness of a seat can be assessed using methods to measure posture, and that the task is a major influence on effective chair design.

The experiments

The study was performed in four industries. Six fork lift truck drivers participated. One driver participated twice, using different seats, which meant that in total seven sessions were recorded. During the sessions, the drivers carried out their ordinary tasks while the head posture was recorded. Recording sessions A–D came from narrow aisle sit-down fork lift trucks with sideways sitting driver positions. These fork lifts were battery powered and used in the workshops and warehouses of two industries. The truck in session A had long transport distances, often over 100 metres, and about equal periods of transport and handling of goods. Sessions B and C utilized the same truck and the same driver. The backrest used in session B was 36 cm high and the backrest in session C was 42 cm high. The task was similar to the one described above. The work in sessions A, B, and C required mainly lifts between floor level and three metres above the floor. Both B and C sessions were comparable in terms of tasks and work intensity. The truck in session D was used mainly for handling of goods, which resulted in shorter periods and distances of transport, often less than 30 metres. Pallets were handled mainly up to three metres above floor level, but there were also lifts around five metres above the floor involved. The trucks in sessions E and F were large diesel powered counter-balanced lift trucks with the driver seated forwards, i.e. towards the forks. These were driven in a large warehouse. The task was to reorganize the storage of containers, so the transports were fairly short. The containers were handled from floor level up to five metres above the floor. The truck in session G was a truck for manual picking of custom orders of small pieces of goods in a warehouse. It was operated in a standing posture. The design however permitted the use of a sit- stand seat during transport driving.

Recordings of head posture, with the equipment described in the Methods chapter, were performed during the 40 minutes sessions. Before and after each driving session, reference postures were recorded. These were upright standing and looking straight ahead, maximal head rotation to the right and to the left, maximal neck flexion, and maximal neck extension. Large parts of the sessions were also video filmed in addition to taking notes about the tasks. The notes, the video film, and the sound recordings gave a documentation of the contents of the tasks, and also made it possible to identify single events, such as lifts.

The drivers of trucks A, D, E, and F were men and the other two drivers were consequently women. Their mean age was 38 years (range 29–47 years), and their mean height was 172 cm (range 156–198 cm). All had several years of experience in their jobs.

Results

There were mainly four influences on the head posture and its temporal pattern, namely the position of the driver seat, the task, the individual, and to some extent also the seat design. Clear differences were displayed between the situations recorded. It is obvious from Figure 41 that, on the whole, the temporal pattern was consistent and repetitive within each recording session.

The truck driver's job requires continuous combinations of neck flexion-extension and head rotation, but also lateral bending, which was omitted in this study. The task, relevant to the head posture, was looking at the forks when picking goods on a pallet, looking at the goods during handling, and looking at the traffic and obstructions when driving. The location of the goods when handled could be at any height from the floor up to over five metres above the floor. It was obvious that the head posture was mainly determined by the viewing angles. These were defined by the task in terms of where the pallets were placed, how much handling and driving was needed, and what combination of these factors the job demanded. Sideways sitting drivers had very different neck postures when looking at the goods and when driving, compared to those seated facing forward, i.e. towards the forks. Also, the truck design caused impaired sight lines at certain angles, which differed between trucks. The various drivers also behaved differently even when performing the same tasks.

Sideways sitting drivers (A–D) had their heads rotated to the left when driving and to the right when handling goods. Little time was spent with their heads straight, as can be seen in Figures 41, 43, and 44. Handling goods five metres above the floor involved a combination of extension and rotation of the neck. This posture was perceived by the drivers as the most strainful one. It should be noted that the driver of truck D had his head turned to the right most of the time, which was due to his task of mainly handling goods. Forwards sitting drivers, in trucks E and F, spent most of the time with their heads straight. However, they had also several short periods of pronounced rotation when they reversed the truck (see Figures 41, 43, and 44). Extension of the neck appeared when handling goods high up, otherwise the head was relatively little inclined. The driver of truck G spent most of the time with the head straight, but there were also short periods of rotation both to the right and to the left when looking at the warehouse shelves. Flexion occurred during several periods and in total for a longer period of time, because of lifting goods, looking at shelves, and reading from lists with article numbers. There were also short periods of extension when looking at shelves above eye level (see Figures 41–44). The noisier look of the flexion-extension signal in Figure 42 is due to the method of measurement, using a pendulum, which caused oscillations.

It could also be observed that some drivers rotated their heads more vigorously and more often when they reversed, compared to other drivers. Some drivers also made use of the possiblity to sit slightly diagonally in their seats, thereby decreasing the rotation of the neck.

In the comparison between the two backrests, subjects rotated the head 42.6° on average for backrest B and 43.1° for the slightly higher backrest C. The difference is very small and not significant.

One description of the temporal pattern of head rotations is made in Table 19. It can be seen that fork lift truck driving was shown to be an extremely repetitive task with respect to head rotations. More than 2000 rotations could be made in a working day, using as a definition that the rotations had to exceed 70% of the maximal range of voluntary rotation for the subject. The duration of the rotations were on average fairly short, only a few seconds, with the above-mentioned definition.

Table 19. Average frequency and average duration of neck rotations exceeding 70% of each driver's maximum, given as values for left rotation/right rotation.

	A sideways	B sideways	C sideways	D sideways	E forward	F forward	G picking
Frequency (1/hour)	90/50	270/280	290/270	30/370	30/220	120/180	50/190
Duration (s)	9/5	3/2	3/2	8/2	1/2	1/2	2/2

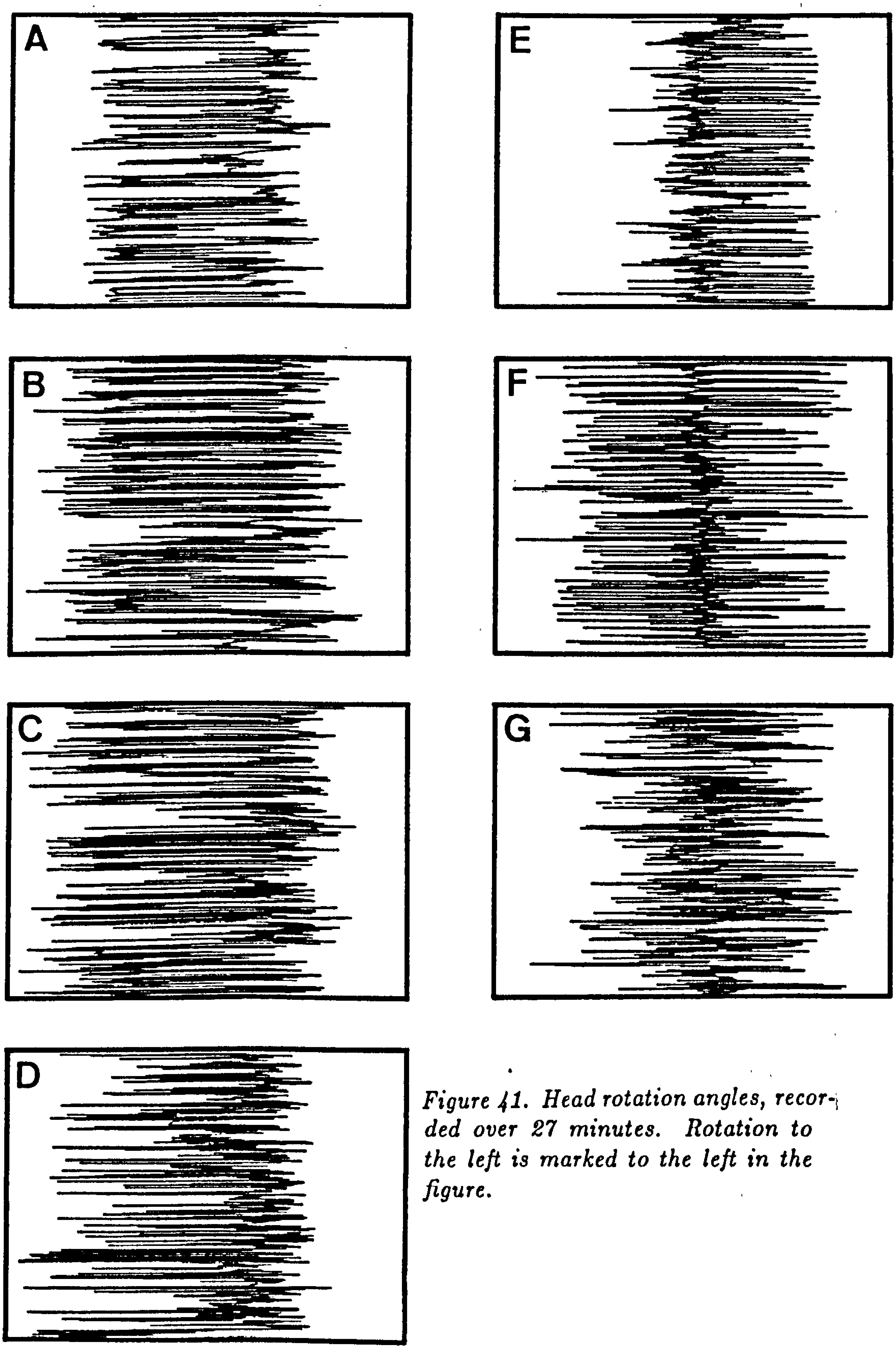


Figure 41. Head rotation angles, recorded over 27 minutes. Rotation to the left is marked to the left in the figure.

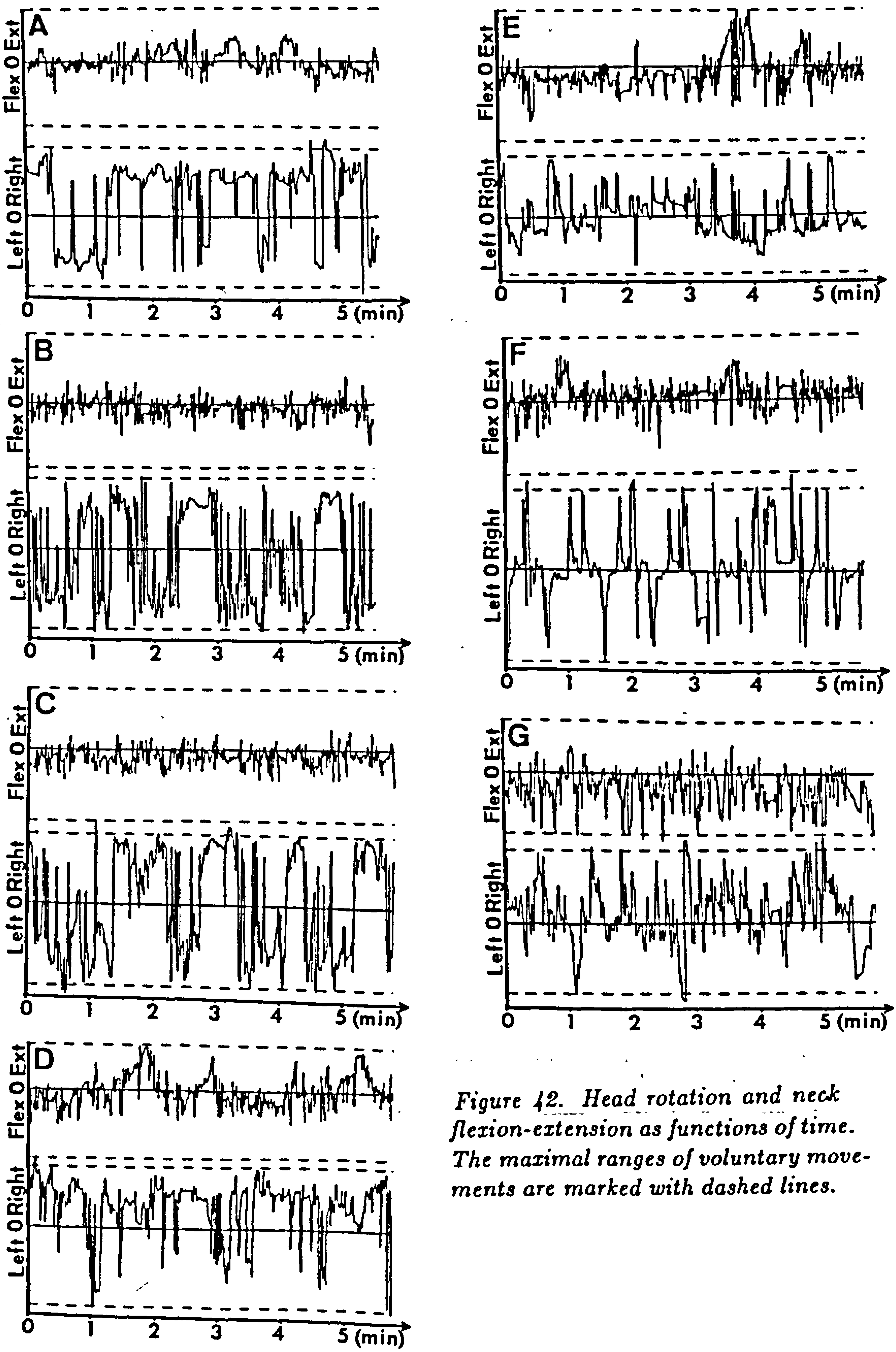
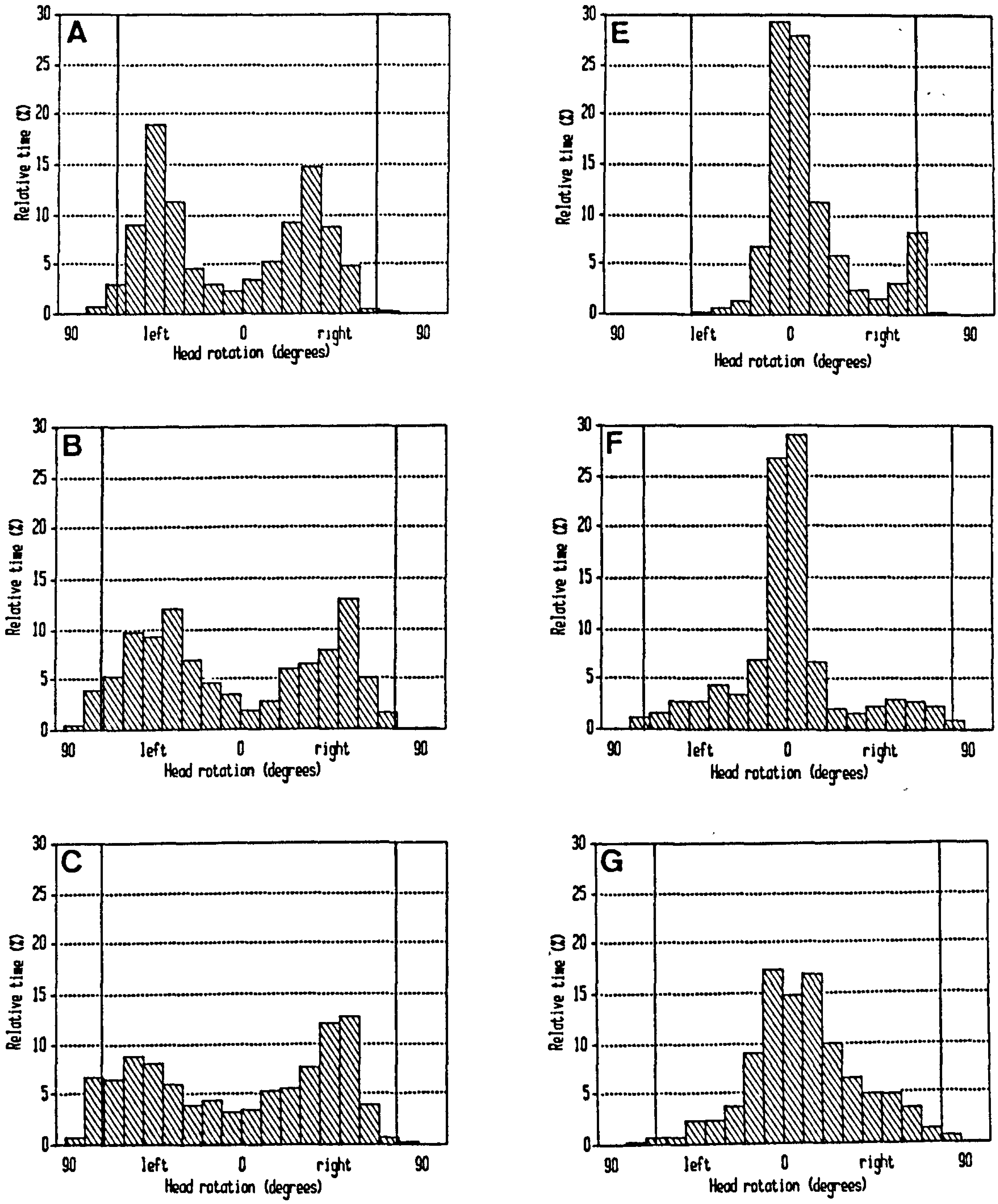


Figure 42. Head rotation and neck flexion-extension as functions of time. The maximal ranges of voluntary movements are marked with dashed lines.



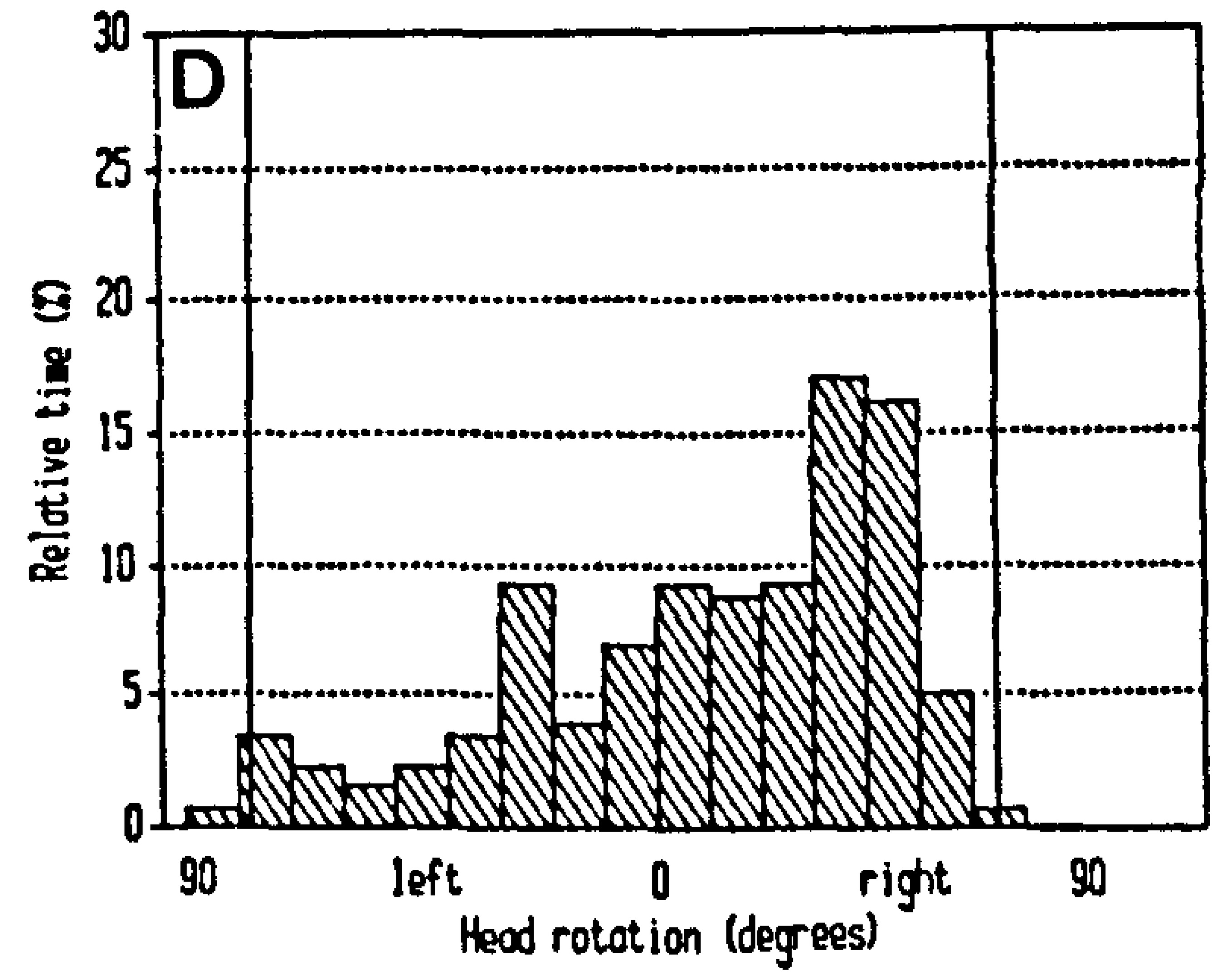
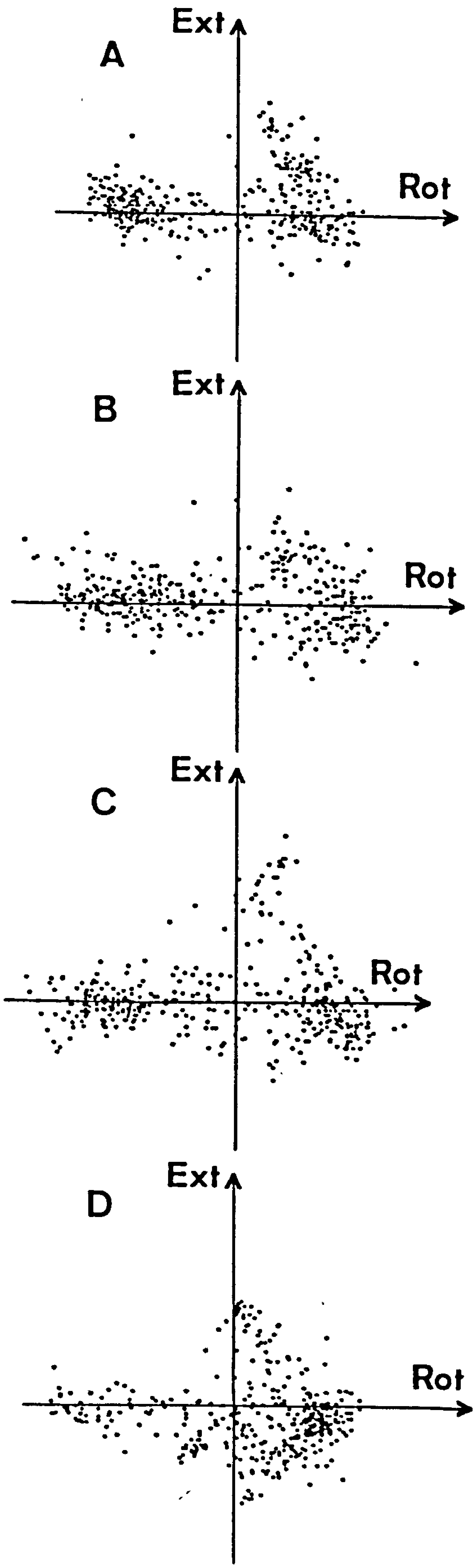


Figure 43. Amplitude histograms of head rotation. Solid lines mark the maximal range of voluntary rotation.



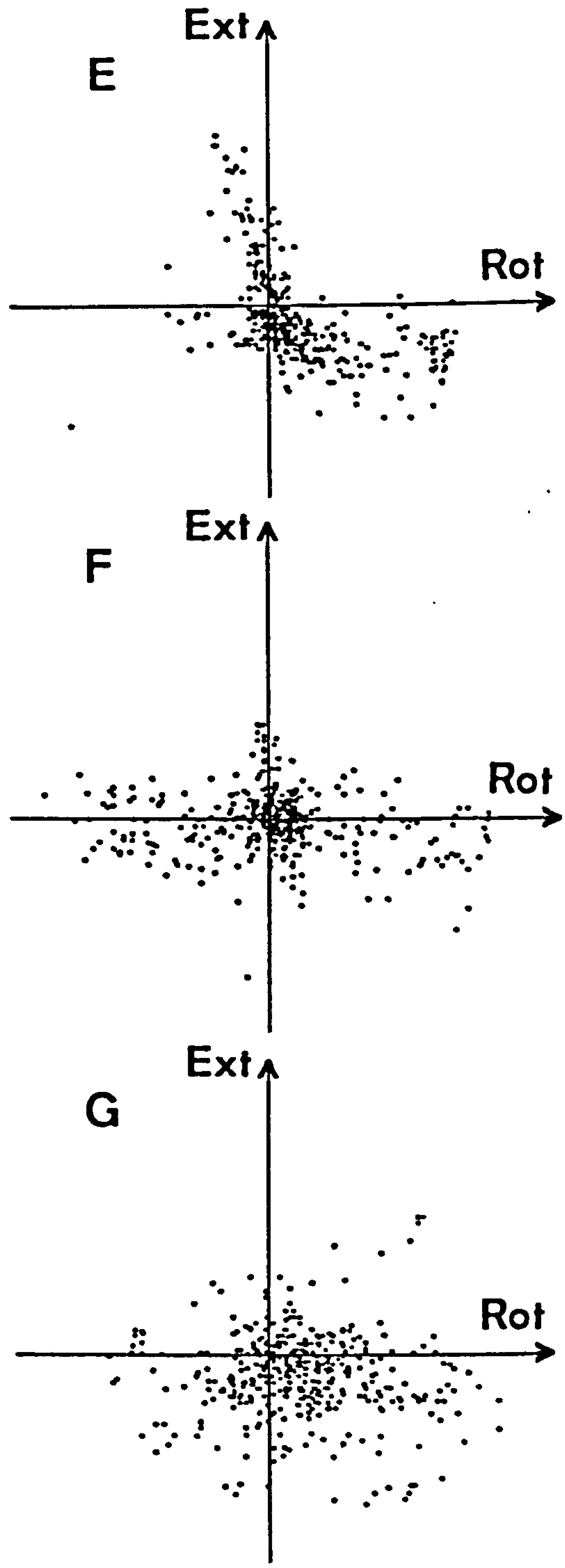


Figure 44. A sample of 400 postures during the recording period. Rotation to the right on the positive X-axis and extension on the positive Y-axis. An upright standing posture, is represented by zero values.

The time spent with the head in various angles of rotation was analysed in relation to "Model for evaluation of injuries of the neck and shoulders according to the work injury insurance" (Andersson et al 1983 b). It was considered, for the analysis, that the posture was dynamic.

Table 20. Relative time in %, spent in various angles of head rotation.

Session	Head rotation		
	< 15°	15–45°	> 45°
A (sideways)	10	58	32
B (sideways)	9	44	47
C (sideways)	11	38	51
D (sideways)	23	55	22
E (forward)	67	21	12
F (forward)	63	21	16
G (picking)	45	40	15
Injury criteria		> 80% of work time for dynamic postures	> 50% of work time

From Table 20, it can be seen that the insurance criterion was exceeded in sessions A, B, and C if the total time with rotation over 15° were considered for trucks A and B, but otherwise not. Sideways sitting trucks imposed a considerably higher risk on their drivers than other types of trucks according to this criterion. Forwards sitting trucks were well below the limits.

The temporal pattern of head posture was described in six ways, namely in Figures 41–44 and Tables 19 and 20. Figure 41 shows a long term recording of head rotation, suitable for monitoring the overall pattern of head rotation. The length and distribution of pauses can be seen and also differences as a result of the designs of trucks, as for example, recordings E and F are centered in the middle while recordings A–D are not.

Figure 42 gives a detailed view of head rotation and neck flexion-extension simultaneously, in relation to the maximal range of voluntary movement. The temporal pattern was confirmed, showing that sideways sitting drivers spent most of the time with their heads rotated to the left or to the right.

The amplitude histograms in Figure 43 give a more exact picture of the total time spent in different angles, but give no information about the length of the time periods in those angles.

In Figure 44, head rotation and neck flexion-extension are described simultaneously by a sample in an X–Y plane. Clusters of points respresent common postures taken. The maximal range of voluntary movement for combinations of rotation and flexion-extension could be described in the X–Y plane, as in Figure 45, but this was not measured in this stüdy. Postures involving combinations of these movements could therefore be substantially closer to the maximum range of motion than indicated by a one-dimensional analysis.

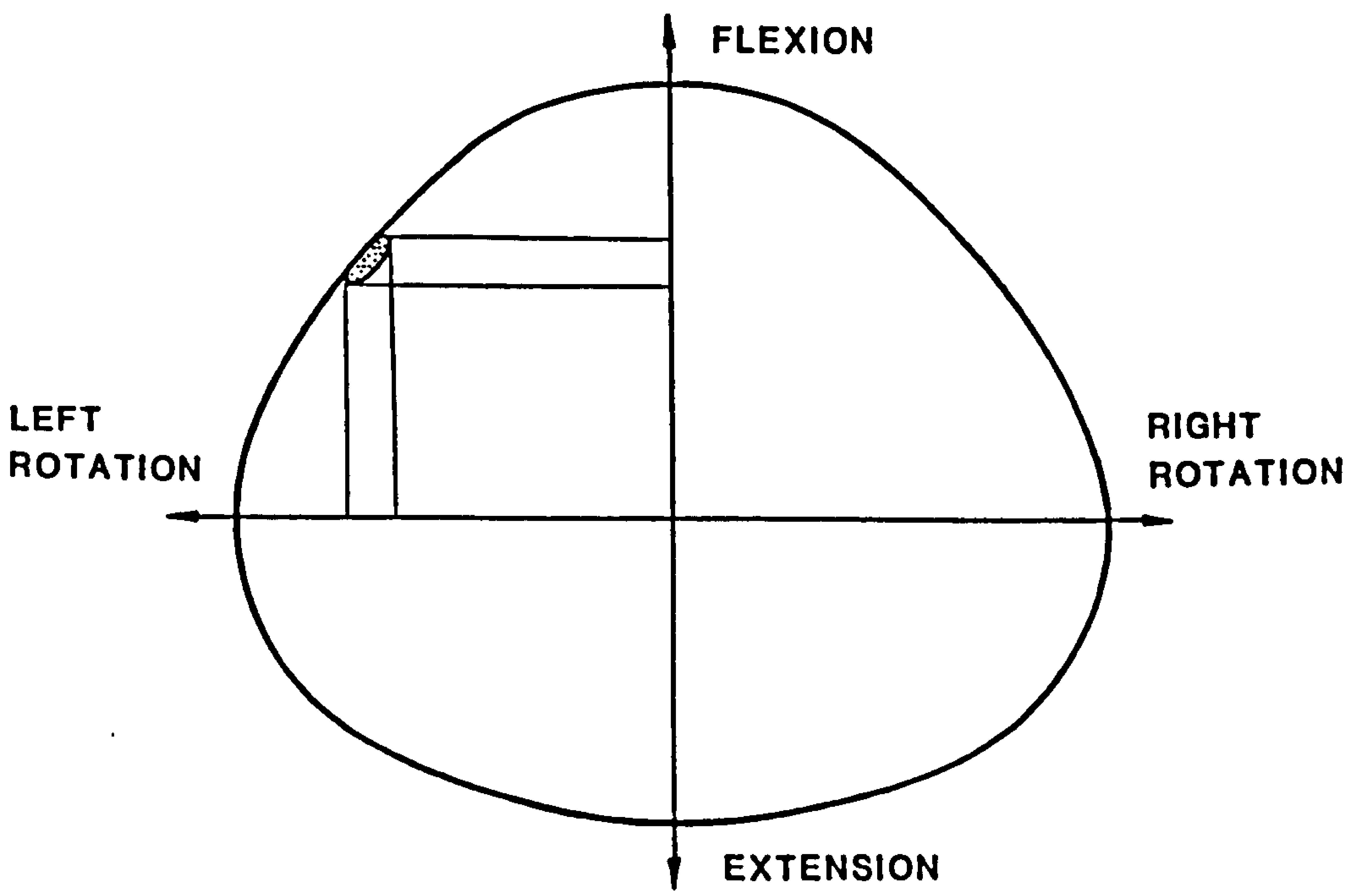


Figure 45. An example of maximal voluntary head rotation and flexion-extension of the neck in one person, described in two dimensions simulaneously.

The sample of postures shown in Figure 45 is very near the maximal range of voluntary movement, but one-dimensional analyses would indicate the opposite.

Table 19 shows an estimation of frequency and duration of head rotations exceeding 70% of the maximal range of voluntary movement. When other levels than 70% were chosen, changes of the frequency and duration measures appeared. If a level was chosen just below a commonly held posture, as for example when driving, the results were very different compared to when a level just above this posture was chosen.

Finally, the values in Table 20 were calculated from the amplitude histograms. The definitons of "near maximum joint motion", "static" and "dynamic" postures from Andersson et al (1983 b) were not further defined, giving a somewhat uncertain classification.

Discussion and conclusions

Fork lift truck drivers were shown to suffer from neck and back pain to a larger extent than others (Siktbehov för gaffeltruckar 1973). According to the Swedish national statistics on work injuries, lift truck drivers had a 2.5 times higher risk of getting neck injuries related to work, compared to the average of all occupations (Broberg 1984). These statistics referred to all types of trucks. Narrow aisle sit-down trucks were introduced some 20 years ago. That design allowed an increased space utilization in warehouses, which was of great economic importance. It was also recognized that conventional lift trucks imposed extreme rotations on the drivers' necks when reversing, and that there was an accident risk due to impaired sight when driving forwards. It was hoped that the new design, with a sideways sitting driver, would alleviate or abolish the problems (Stevens et al 1966). At present there are indications from occupational health centres in Sweden that sideways sitting fork lift truck drivers experience more neck pain than other fork lift truck drivers, and it is believed that the neck postures in sideways sitting trucks can be one reason.

It also seems as if the neck problems of fork lift truck drivers have increased and the back problems decreased during the last 10–20 years, even though no definite evidence of that exists. It is only possible to speculate about reasons for that. One reason could be that earlier on, people in industry with back pain could change jobs to become a truck driver, because it was considered as less heavy. Another possible reason can be that the truck seats have a better design for the back nowadays, i.e. lumbar support, lateral supports, and a higher and slightly rearward inclined backrest. A third possiblity can be that the sideways sitting trucks are particularly bad for the neck, and they have only been used in industries for 10–20 years. Not only the head posture, but also vibrations could then be a reason. It should be noted that the vibrations during driving occur when the neck is rotated for sideways sitting drivers, but when the neck is straight for the forwards sitting drivers. The transmission of vibrations from the seat to the head has been shown to increase when the head is rotated. Also, the design of the seat and the backrest has been shown to be of importance for the vibration transmission (Bjurvald et al 1973). It is clear that better knowledge is needed within this field.

It was shown in this study that the head posture is determined by the position of the seat, the task, the individual, and the seat design. The most important factor was the position of the seat, followed by the task. The loadings on the neck and its structures are to a large extent determined by the posture. It is also recognized that loadings on the shoulder muscles and arm activities affect the load on the neck. In the case of fork lift truck drivers, the tasks for the arms are handling levers and the steering wheel. The resulting loads on the shoulders in fork lift truck driving is little known. Lindbeck (1982, 1985) showed that work with levers caused shoulder muscle loads less than six per cent of MVC. Jonsson and Jonsson (1976) showed that the steering task in car driving caused some static shoulder muscle loads, probably due to elevated shoulders. These studies indicate that for fork lift truck drivers, the influence from the arm activity on neck loads is low or moderate. Studies of head posture and its temporal pattern are therefore important in the research of causes of truck drivers' neck pain.

The backrests used in sessions B and C were investigated in Studies VII and X, where the difference between these backrests was shown to be small. The reason why no significant difference appeared in this study was not judged to be that the method was insensitive. On the contrary, it is judged to be relatively sensitive. Longer recording periods and standardization of some well specified tasks would probably give significant differences. The study has, however, shown that there are other factors of greater importance than the backrest design, for example truck design, work organization, warehouse layout, goods flow planning, and perhaps also training/education of the drivers. There is a great need for international norms, regulating sufficent space for the drivers, and enabling accommodation of technical improvements. A driver's seat with the possiblity of limited swivel has a theoretical potential to improve the situation, but must be thoroughly evaluated first. It is also important to avoid small glasses for the drivers with their interference with peripheral vision. Contact lenses is a better alternative. Mirrors and TV monitors can improve the situation and decrease the demand for head rotations. Future studies of ergonomic improvements for fork lift truck drivers should emphasize these factors.

It must be noted that those criteria presented by Andersson et al (1983 b) were not intended to be used as ergonomic guidelines, but rather as a general approximation in the evaluation of patients with suspected work injuries, whether the work should be considered as having had an adverse influence on the work injury or not. Few jobs have been shown to exceed the limits in these criteria, and the angles and relative time should be set lower for ergonomic guidelines.

However, there is a shortage of methods for measuring head posture, and a great need for development in the field. The prototype equipment used caused several problems of handling and measurement errors. The transmission for rotation measurements showed non-linear characteristics and mechanical play. The inclinometer signals were affected by acceleration forces due to velocity changes of the truck and movements of the driver. These also caused oscillations, some delay in response time and overshoot. The errors were accounted for as much as possible by calibration and signal processing. The total error was estimated to be within the range of 5–10°. These problems with the equipment can be reduced by design modifications. This type of measurement looks promising indeed for the future.

In measurements of head and neck posture, difficulties arise with the definition of angles and planes of movements, and the position of the head, neck and trunk in relation to the gravity vector. The choice of reference points on the trunk, and the application of the measurement sensors are also difficult. This is related to the complicated structure of the neck, shoulders, and back, with a large number of degrees of freedom and changes of configuration. Further studies of the kinematics of the head, neck, shoulders, and back are therefore needed.

The instructions for the registration of maximal voluntary head movements have to be improved in future studies, because the results were not consistent within all drivers. In this study, the maximum value obtained was used in the evaluation, in an attempt to decrease this error. It would be of value to perform several measurements of maximal voluntary head movements in order to increase the reliability and to get a measure of the variability.

Improved methods for assessing the temporal pattern of posture open the field of epidemiological studies of the relation between posture and pain.

This study demonstrated the work task influences on the truck drivers' postures, and it also demonstrated the use of the measurement equipment. The results supported hypotheses 3 and 4, namely that the appropriateness of a seat can be assessed using methods to measure posture, and that the task is a major influence on effective chair design.

DISCUSSION

Methods of measurement

In this research, four groups of methods were used for chair design evaluations, namely body height shrinkage, biomechanical methods, subjective assessment and posture assessment. In Studies V–VIII, they were used in conjunction with one another. These studies showed that the results from the methods were in agreement, supporting one another. The methods were found suitable for evaluation of chair design features. They were also found to have limitations in different situations.

Body height shrinkage

The shrinkage method was developed with the intention of using the process of disc creep as a measure of the effect of load on the spine. The equipment and procedure for high precision body height measurements were developed so that determination of body height presently can be made with a standard deviation around 0.6 mm. The figure refers to a set of five consecutive height measurements. In this research programme, approximately 50 people of both sexes were trained and measured, from the age of 18 years to 61 years. The subjects were students, office workers, and industrial workers. They all learned the procedure in less than one hour. No selection of subjects was made, but it was clear that some performed more consistently than others. It seemed as if subjects who exercised or were involved in physical activity regularly, who were young, motivated, careful, relaxed, and calm performed better, but the individual performance could not be predicted from these factors. The method was demonstrated to be applicable in the field as well as in the laboratory. The equipment is not expensive, and it does not demand long education or instruction until it can be handled by the experimenter.

There was agreement between all studies in this research, confirming the correlation between shrinkage and spinal load. This is illustrated in Figure 46, and it was also supported from Studies V–IX. The results obtained were also in agreement with results from disc pressure measurements and load-deflection experiments on spinal joint specimens, reported in the literature. The diurnal variation in body height seems to be caused mainly by the pattern of spinal loading arising from the erect and supine postures adopted during day and night time.

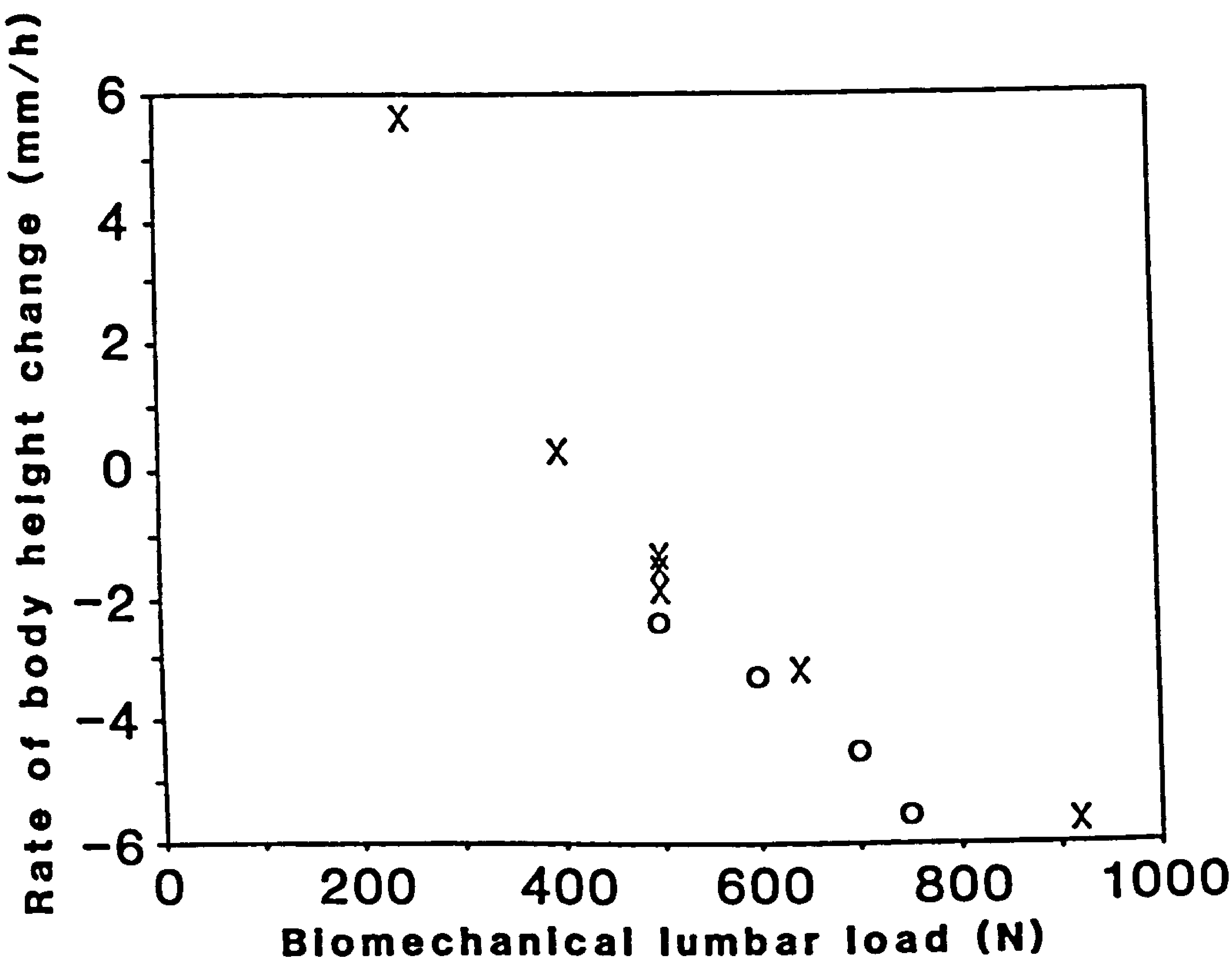


Figure 46. Average rate of body height change from the loading experiments in Studies III and IV, plotted as a function of estimated and calculated load on the L3 disc. The following loads were assumed: lying 250 N, sitting in an easy chair inclined at 110° *with a 4 cm deep lumbar support 400 N, sitting on an office chair 500 N, standing 500 N, standing + 10 kg load on the shoulders 600 N, standing + 14 kg shoulder load 640 N, standing + 20 kg shoulder load 700 N, standing + 25 kg shoulder load 750 N, standing + carrying 14 kg in one hand 920 N. Studies in which the loads preceding the experiments were controlled* (x)*, and studies which were uncontrolled* (0).

The studies have demonstrated that the method can give a reliable measure of the effect of loads on the spine. This method, and disc pressure measurements, can assess work loads on the discs directly in vivo. Since the method is non-invasive, it is suitable for field application. Shrinkage enables the assessment of passive loadings on the back, which EMG and IAP does not.

Further, shrinkage was shown in Study IV to be related to the experience of discomfort. It was assumed that it was the belt used in the "traction" situation that gave rise to increased discomfort, which in turn caused trunk muscle tensions, increased load on the discs, and the resulting increase in shrinkage. It was not probable that the discomfort arose due to the trunk muscle tensions, because the subjects related their discomfort in the "traction" situation to the pressure of the belt around the chest. Also, the discomfort arose immediately, which indicated that the belt, and not the trunk muscle tensions, was the cause of the discomfort. Further, those situations causing more shrinkage also caused more discomfort in all of the Studies V–IX. This relationship is promising for the usefulness of the method in the future. The method has subsequently been used by other researchers (see Appendix 9), and their results are in agreement with those presented in this study.

The measures of shrinkage, or in other words, disc creep and its rate of change, are related to geometrical changes and changed physical properties of the spine, such as disc bulging, space for nerve roots, end-plate bulging, load on the apophysial joints, tension of the collagen fibres of the annulus fibrosus, stiffness of the disc and the spinal joint, and the nutritional exchange of the disc. Since shrinkage is affected by both the spinal load and its temporal pattern, it is more directly linked to the abovementioned factors, and can be a more relevant predictor for the risk of back pain than a measure of only the load.

The quick recovery when unloading the spine (Study III), implies that the temporal pattern of work loads is important. Several short periods of rest for unloading the spine, or in other words more dynamic loading, would consequently cause less disc creep than fewer and longer periods of rest and static loading.

As can be seen in Figure 46, some of the studies were not controlled for sleeping and getting up time, start time or length of the experiment. This has probably increased the spread of the results. The control of loads preceding the experiments is important, considering the body height change during the day due to loads (see Study III), and the change of physical properties of the discs after being subjected to load (Kazarian 1972).

Considerable individual differences in shrinkage ability, and also differences due to age, were demonstrated, particularly in Study IV. This emphasizes the necessity of using the subjects as their own controls.

The individual difference in body height at the start of the experiments, between different experimental days, was on average 2–3 mm in most of the studies. The highest value obtained was 5.3 mm for one subject. No subjects were excluded because of too high differences or because of any other reason, but, as pointed out in Study IV, this might be possible as a control measure in the future in order to decrease the influence of a possible error. The measure is, however, an indicator of the quality of the study, regarding the control of the subjects' loading history.

One source of systematic errors of the measurements could be a height change due to compression in the joints of the lower extremities, changes of the foot arch, and compression of soft tissues under the feet. These were judged to be negligible in relation to the height change which takes place due to the spinal discs, according to the results of Forssberg (1899), also supported by Markolf and Morris (1974). In addition, pilot experiments, using markers on the skin, indicated that the potential shrinkage arising from the knees and feet were negligible. The random error of the height measure, due to the variability of measurements, was decreased by using the mean value of five consecutive measurements. It can be argued that a further reduction of the variability could be possible if more than five measurements are taken. Since the measurement situation itself imposes a load on the spine, and the body height therefore decreases during the measurement period, this factor would influence the results more the greater the number of measurements is. It was therefore decided to use only five measurements. Other errors can arise when the loading history has been different, as mentioned before. The error due to a random influence like this can be decreased if a group of subjects is tested.

A limitation with the shrinkage method is that it is not possible to detect if some parts of the spine have been subjected to a higher load than other parts, or if some discs have caused more height decrease than others. Another disadvantage with the method is that all the control measures which have to be taken are time consuming; however, further development of the method might lead to less time demanding control measures and experimental designs.

As the principle is uncomplicated and the apparatus inexpensive, the method has the potential of becoming relatively widely used.

Biomechanical methods

The biomechanical methods used had an important role in the chair evaluation process, because they enabled an assessment to be made of loads on specific structures of the body. Thereby, the influences of tasks and workplaces could be demonstrated. In this research, the biomechanical methods developed were shown to be suitable for evaluation of design features of industrial chairs for particular tasks, and sensitive for factors such as backrest height and seat inclination. The methods were possible to use both in the laboratory and in the field. When the posture assessment was made from photographs, and force assessment was made from the instrumented chair, the input data was obtained for a relatively low cost. Manual digitizing of the coordinates from a large number of photographs is however a very time consuming task.

In Studies V–IX, biomechanical assessments were made in conjunction with other methods. The results from them showed that in all comparisons, an increased biomechanical load on the spine also meant an increased rate of shrinkage and increased discomfort from the back. There was also a tendency for increased lumbar kyphosis or spinal flexion in Studies V, VI, VIII, and IX, at the same time as there was increased biomechanical load on the spine. Of particular interest was the spinal load due to passive forces when the spine was flexed. When spinal ligament forces are involved in resisting a moment instead of active muscle forces, and the lever arm of the ligaments is shorter, an increased compressive spinal load arises (compare Adams et al 1980 and Miller et al 1986). Flexion of the lumbar spine and pelvic tilt often occur in sitting postures. These aspects are not yet fully known, and have therefore not been included in the models. It is thus probable that the results from the biomechanical calculations are conservative estimations, because a fixed 5 cm lever arm between the disc and resisting structures was assumed. Further work with the methods devised could give solutions to these questions, and would also improve the accuracy of biomechanical models in sitting and forward bending tasks.

Biomechanical methods have advantages of being non-invasive, inexpensive, and they can be used in the field. Nor does the data collection demand highly trained and qualified personnel. In addition, they allow a comprehensive description of loads, i.e. compressive, shear and momental loads, acting along the three coordinate axes. A particular aspect is that the use of a biomechanical model enables a theoretical determination and evaluation of chairs, workplaces and loads before they exist. It should however be noticed that work postures can be influenced by the attitude, status, concentration, and relaxation of the sitter, which means that an unambiguous predictive result cannot be obtained.

The main problem when applying the method in the field was the difficulty to obtain an adequate assessment of the posture. This is dealt with below, under Posture assessment. The results from the biomechanical method devised in Study II are less accurate, because clothed subjects had to be used due to safety requirements. The fact that it is only possible to assess a few static postures limits the use of the method. This is a serious limitation in tasks which involve movements. These restrictions of the method point to the necessity to develop methods for continuous recording of posture, without imposing difficulties for the subjects to perform their tasks. This would allow determination of the temporal pattern of postures and of biomechanical loads.

There is little knowledge about physical properties of the spine under other loading conditions than compressive loads. In particular, this is so for shear forces and torques, and how these stress substructures of the spine. Therefore, the use of biomechanical methods are at present limited in tasks involving such loading conditions.

The method presented in Study II involves sources of error due to individual differences of body segment masses and the determination of the location of the centres of these masses. These errors will, however, decrease when comparisons of loads between different experimental situations are made for the same subject. The technique used in Study I meant that these approximative values did not have to be employed, with the exception of the weight of the body parts above the L3 plane.

The results from this study have shown that the use of biomechanics and measures of the forces acting on people in sitting work tasks can give increased knowledge about the ergonomics of sitting. Biomechanical methods are judged to be important in the future, because they can also allow prediction of loads resulting from alternative workplaces and tasks in the planning stage.

Subjective responses

Discomfort ratings and subjective assessments have been used in many studies, as reported in the literature review. It was considered that assessment of discomfort is more relevant for this project than assessment of comfort. One reason is that comfort can be seen as an absence of discomfort. Also, if the pain or discomfort is assessed, it seems more natural to relate this experience to physiological processes, such as transmission of nerve signals or changes in transmittor substances. When comparisons between two experimental situations are made, it is probably easier for the subjects to assess a relative difference than an absolute value for a particular situation. This, and an improved possibility for statistical evaluation, were reasons why the visual-analogue scale was chosen instead of a 5 or 7 point scale.

The results obtained in Studies V–IX, all showed that increased discomfort from the back occurred when there was higher biomechanical loads on the back, increased shrinkage, and increased kyphosis of the back. The method was sensitive in discriminating between different chair designs and also other design features. The reliability was judged as good, since the results were in agreement with the other results obtained. This was also supported by the agreement between the ratings performed during the experiments, the ratings and the preference assessments in the final comparison, and the final interviews. It can be concluded that subjective methods are suitable for several aspects of work chair evaluations.

The discomfort increased with time during all experimental sessions, but not necessarily always so for all subjects. In several cases, the increase in discomfort score tended to be faster in the beginning and slower towards the end. This was probably because the visual-analogue scale had not equidistant properties (compare Borg's, (1982) ratio scale). A difficult situation meant that the discomfort increased at a faster rate than in other situations, and the subjects sooner felt a desire to move or change posture in order to get release from some discomfort. In many cases, the discomfort was hardly noted until 20–25 minutes had passed, but started to increase then. This indicated that the results can be misleading if too short periods of experiments are chosen. The results thus contradict Wachsler and Learner (1960), who considered that 5 minutes experiments for chair evaluations were sufficient, but the results are in agreement with several other authors, for example Barkla (1964) who recommended longer experimental periods.

Results from subjective assessments can sometimes be difficult to interpret, due to irrelevant influences, or influences which turn out to be more important than was assumed in the beginning. It is also possible that the participants are influenced by the experimenter or what they think the experimenter expects when they make their assessment. Interviews therefore ought to be performed in addition to the ratings, in order to draw more correct conclusions and to decrease the number of possible errors.

The subjects quickly learned to perform the ratings. In the field studies, however, it took some time for the subjects to take off the safety glove, take the pencil, mark on the visual-analogue scale, and finally put on the glove and start to work again. A scale with distinct steps, shown to the subjects and a verbal answer would eliminate these problems. Further, it seemed as if it is important to let the subjects practice the performance of ratings before the experiments commenced. The costs of performing subjective evaluation studies were low.

One source of error which can occur in field studies is that the workers' responses in one plant are not independent due to previous internal discussions and influences. Therefore certain "epidemic opinions" about design features can spread and influence the results. Ideally, studies in which this might be a risk should be carried out in several independent companies with one or a few workers from each.

The division into body parts of the body map should be considered before each study. Many subjects experienced discomfort from the borderline between the upper arms and the shoulders, which imposed difficulties in the choice between these two body parts. In a few cases, subjects felt discomfort from the knees, wrists or elbow joints, which caused similar problems. A revision of the border-lines or adding areas for the joints mentioned above should be considered. The definition of "very, very high discomfort" on the visual-analogue scale needed to be explained in more detail. It was explained as maximum discomfort, discomfort not possible to withstand any more in a work situation, or such a severe discomfort that it forced the participant to stop performing the task.

This research showed that discomfort from the back can arise after a relatively short time among people without musculoskeletal complaints, when sitting with an increased lumbar load due to a kyphotic lumbar spine. Discomfort from the shoulders was shown in some cases to arise after a relatively short time. The arms and shoulders are often strained in seated industrial tasks. In those situations, people often compensate for this by leaning forwards, thereby decreasing the shoulder/arm load and the shoulder/arm discomfort somewhat. The result will be that the load and subsequently also the discomfort from the back increase, but not so much that the discomfort from the back starts to dominate over the discomfort from the shoulders/arms. This compensation occurred in Studies V and VI, and in addition, for the neck in relation to the trunk in Study VII. The phenomenon is a process of optimizing the distribution of loads or minimizing the perceived discomfort (compare Dul 1986, Melzack 1973).

Discomfort assessment is one very important method for the evaluation of work chairs, both in itself and as a control or comparison measure to see that the other methods chosen are relevant.

Posture assessment

Posture assessments with photography or video were quick and cheap, as long as only a few photograps were analysed for each session. Other authors have also used similar methods (Mandal 1986, Colombini et al 1986).

The major problem was as mentioned earlier that many industrial tasks require clothing which makes the assessment of posture more difficult or impossible. It was often difficult to obtain a free line of vision and long enough distance for the camera.

The method for continuous recording of neck posture is promising for future use. Advantages and disadvantages with the method were discussed in Study XI. It was considered to be appropriate for evaluation of work seats, visual and task demands, and especially when comparing alternative designs. The sensitivity of the method for such evaluations was also judged to be relatively high.

Effect measures and temporal patterns

It should be noted that there are three main methods which measure the effects of physical stress on the body, namely shrinkage, centre frequency of the myoelectric signals, and foot swelling. These effects seem to progress continuously, often at a decelerating rate, similar to an exponential function (Study III, Kogi and Hakamada 1962, Winkel 1985). Recovery seems to be fast in the beginning, which means that shorter work periods and a greater number of pauses are beneficial. Also, the structures of the body are visco-elastic, i.e. they and their properties are not only affected by the loadings on these structures, but also to a great extent by the time these loadings are acting. This implies the importance of also assessing the temporal patterns of the loads or the stress on the body. Methods for analysis and description of the time course are badly needed, in order to establish more precise relationships between exposure and discomfort/disease.

Seat design

The seat pan

The stability of a sitter can be influenced by the seat surface conditions. Force measurements from Studies V–VIII, and pilot experiments on varnished wood seats showed that a horizontal varnished wood seat does not cause sufficient friction to resist the force caused by the backrest, and can therefore not prevent the buttocks sliding forwards. Thereby, an increased lumbar kyphosis and a decreased backrest force will increase the load on the lumbar spine. Varnished wood seats are therefore inappropriate, which also is further emphasized by the non-optimal pressure distribution on the buttocks.

Some fork lift truck drivers complained about too short seat pans, and some complained about too deep seat pans. This complaint never occurred in any other task. The reason was judged to be the acceleration forces present in fork lift truck driving. Increased leg stability is therefore required from the seat, which can be obtained by a relatively deep seat, and to some extent also by lateral supports. A fixed seat depth can thus not be suitable for a population, considering the individual differences in thigh length.

As previously mentioned, it has been observed that sitting on hard and uncomfortable seats results in more frequent movements. Also there is an ergonomic criterion stating that static postures should be avoided, and that movements are physiologically beneficial. Consequently, it would be possible to draw the conclusion that hard and uncomfortable seats are beneficial to the spine, muscles, and blood circulation, and therefore ergonomical. However, this is in conflict with the criterion saying that ergonomic design also means comfort. A further analysis of this dilemma leads to the question of taking the seriousness of the consequences into account, for example if discomfort from the buttocks is preferable to back pain. This type of consideration about conflicting interests will probably be more common in the future when the knowledge about various influences is increased. The solution to this particular problem of hard and uncomfortable seats would probably be that there are other and more effective ways of enabling movements to occur in seated tasks without having to introduce seats with inappropriate pressure distributions. A good work organization and workplace layout means that the sitter is able to move and take different postures.

The sit-stand seat

A result which should be noted is the pronounced decrease of shrinkage when using the sit-stand seat compared to the conventional seat in Study VI. There was also less discomfort from the back and a tendency to less lumbar kyphosis for the sit-stand seat. In addition, recovery was found in Study IX, particularly for the sit-stand seat. In that study, the angle between the trunk and the thighs was relatively large for both seats, but particularly for the sit-stand seat. Similar results have been reported by Palmgren (1984), Davis (1982), Drury and Francher (1985), Bendix (1986), Bendix et al (1985), and Mandal (1976). These studies are in agreement that the load on the back decreases in postures with an increased angle between the trunk and the thighs. It seems as if EMG measurements of loads on the back muscles are less sensitive in this evaluation than posture and shrinkage measurements. The EMG activity of the back muscles was relatively low in the situations reported in the literature. It also seems as if the most relevant factor is not the level of EMG activity, but the discomfort and the load which arise due to lumbar kyphosis near the maximum range of spinal joint motion. The results from Harms-Ringdahl (1986) and van Wely (1970) also support that discomfort arises rapidly in joint postures near the maximum range of motion. In other words, there can be situations with a low EMG activity but with a high spinal load and a rapid growth of discomfort. This emphasizes the importance of using relevant methods for the evaluation.

Not only sit-stand seats, but also forward sloping seats, possibly with knee pads, enable an increased trunk-thigh angle. However, new problems and sources of discomfort can be introduced with these chairs. If knee pads are used, they can cause discomfort from the knees, as mentioned earlier. As shown in Study IX, discomfort from the buttocks due to sliding forwards, an unsuitable pressure distribution, and the perception of bad stability are other causes of these adverse effects. The conclusion which can be drawn is that there is no reason always to advocate a horizontal seat and 90° angle in the knees and the hips. Other combinations of seat angles and seat heights could be suitable in other work situations. It follows that there is no reason, either, always to advocate a seat which gives forward sloping thighs.

One problem which has not been solved yet is the discomfort due to the design of the sit-stand seat surface. Increased movements on the sit-stand seat emphasized the feeling of instability and sliding off the seat, expenenced by the sitters (compare Studies VI and IX). On the other hand, it is evident that the abilities to reach over large areas, and to a certain extent also the handling of goods are improved when using a sit-stand seat, compared to a conventional one. This conflict is important to consider and requires the use of the seat model to evaluate the critical variables. A more favourable shape, which does not give the disadvantages mentioned earlier, is badly needed for the possibilities of the sit-stand seats to be more used.

The backrest

The backrest design is often crucial for the appropriateness of the chair. However, the backrests are often not used in industrial tasks. The workers sit on the front edge of the seat and the back has no contact with the backrest at all. It has sometimes been assumed that the situation could be improved if the worker is instructed to use the backrest. Analyses with the industrial seat model can however point to the primary causes of why the backrest is not used, which in most cases are not lack of instructions. Examples of causes for no or little use of the backrest are given below:

- The armrests prevent the chair being pulled forwards far enough.
- Obstructions on the floor or from the workplace/machine prevent the chair being pulled forwards far enough.
- Too little space for the thighs between the underside of the bench and the seat, or a high chair with an incorporated footrest, or a chair without castors, prevent the chair being pulled forwards.
- Too great a distance in height between the work area and the underside of the bench causes an increased seat height, and insufficient space for the thighs, which again prevents the chair being pulled forwards enough.
- The work area is too far away or too low, which causes a forward-bent posture.
- Insufficient knee space positions the sitter too far away and therefore causes a forward-bent posture.
- The task involves substantial and repetitive trunk movements.
- The worker experiences discomfort from the shoulders and therefore uses trunk movements in order to decrease the need to reach forwards with the arms.
- The seat pan is too high, which forces the sitter to move forwards on the seat in order to avoid high pressure in the popliteal area.
- A too deep seat pan or too little depth adjustment of the backrest in relation to the thigh length of the sitter prevents contact with the backrest.
- A varnished wood seat causes the sitter to slide forwards and thereby decreases the contact force with the backrest.
- High levels of concentration, inexperience or insecurity cause forward-

bent postures.

- High visual demands, small work details or insufficient light cause a short viewing distance and a forward-bent posture.
- A defined viewing direction causes a forward or sideways bent posture.

By changing the primary cause, i.e. the chair and workplace design or the work task, possibilities for the worker to use the backrest will be created.

The importance of the backrest was stressed by Staffel (1883), Strasser (1913), and Åkerblom (1948). The reason why a backrest was advocated in the older references was mainly anatomical or a desire to assume an attractive posture with a lumbar lordosis similar to that in standing. Åkerblom (1948), however, also mentioned the need to let the backrest release trunk muscle forces and to decrease the load on supporting structures of the body. Åkerblom had observed that many bank employees sat on the front part of the seat, and they did not use their backrest while working. The further back people sat on their seats, the higher was the force on the backrest, the more the lumbar posture resembled the posture in standing, the more were the structures of the back unloaded, and the better was the situation considered from the ergonomics point of view. Åkerblom also performed experiments (unpublished), in which he saw that the force on the backrest increased the lower the chair was, and the smaller the angle between the trunk and the thighs was. His interpretation of this was that a lower chair gave a higher backrest force, increased the stability of the trunk, and Åkerblom believed that a low chair therefore was an advantage from an ergonomical point of view. Also, he had as a school child very strongly experienced the pain and discomfort which arose from too high chairs with a hard and sharp front edge, which compressed the underside of the thigh. Subsequently, he also demonstrated constriction of the blood flow in this situation. These arguments, and the fact that he considered that many people experienced low chairs as comfortable, formed his opinion that the seat height should be fairly low (Åkerblom 1985).

In the light of other investigations, it is possible to give the following arguments: When sitting down on a seat without a backrest, so that the angle between the trunk and the thighs changes from 180° to 90°, the pelvis is forced to rotate backwards approximately 30°. This is mainly due to increased tension of the hamstrings and gluteal muscles, and decreased tension of the quadriceps muscles. This causes a moment acting on the pelvis, which is largely due to passive muscle forces. The pelvic tilt causes a kyphosis of the lumbar spine. By introducing a back support, which allows the sitter's trunk to rotate backwards over the back support and opening the trunk-thigh angle, the pelvic tilt and lumbar kyphosis can be counteracted. A decreased angle between the trunk and the thighs, which increases the pelvic tilt, means that there is an increased need for an effective backrest and a higher backrest force in order to counteract the pelvic tilt. Where an increased angle between the trunk and the thighs decreases the pelvic tilt, there is a consequent decrease in the need for a backrest. The horizontal thrust on it is thus reduced. This means that the need of counteraction must be separated from the actual counteraction which is present in a particular situation.

This view was supported by Studies VI and IX, which demonstrated that the sit-stand seat gave lower backrest forces when compared to the conventional seat. The results from Studies V, VII, and VIII when sitting at rest supported this, since there was less force and a higher situated centre of pressure on the high backrest than on the low one. The two backrests consequently resisted approximately the same moment, which supports that the backrest resists an internally generated moment acting on the pelvis. The arguments above are simplified. Not only the trunk-thigh angle but also the gravity loads and the knee angle affect the pelvic tilt, and so do individual factors such as the length of the thigh muscles.

The function of the backrest is also, apart from the contributions mentioned above, to transmit some vertical load from the upper body. By encouraging lumbar lordosis, the centre of gravity of the upper body falls near or through the lumbar discs (compare Appendix 6). This enables minimal and intermittent muscle activity to hold the posture and to restore displacements of the centre of gravity. As a consequence of this, it is probably undesirable to use a high backrest in an upright sitting posture, since it would prevent deviations from the upright position, and therefore also the intermittent muscle activity. In the backwards reclined postures on the other hand, a high backrest is beneficial and allow muscle relaxation (see Andersson et al 1974 b).

The results from mainly Study X indicated that the curvature of the backrest is important for the perception of comfort. Depth adjustability of the lumbar pad of a high backrest is therefore a means to obtain a greater proportion of satisfied users. The depth of the lumbar pad was also shown by Andersson et al (1974 b) to influence the loads on the spine substantially. It is probable that adjustability of the lumbar pad in height also would be beneficial for the perception of comfort, but it has little influence on the loads on the back (Andersson et al 1974 b). It has therefore been debated whether height adjustability of the lumbar pad is necessary or not.

The industrial seat model

A large part of the present knowledge about chair design is based on empirical experience. Most studies of work seats reported in the literature have only dealt with a particular work task, which consequently prevents the results from being extended to more general conclusions about seat design. This situation emphasizes the need for a theory and a model. In this research, an industrial seat model was presented, which specifies important factors influencing the appropriateness or the effectiveness of industrial seats. The model lists characteristics of the work task and the workplace, which enhances systematic analysis and judgements about their influences on the sitter and consequences for seat design. An example of such a description is given in Table 21.

Table 21. A systematic description of demands and restrictions in a grinding task, according to the industrial seat model.

Work task	Consequences for seat design
Picking up workpieces from a pallet, 40–90 cm to the side, 0–80 cm in front of, and 10–30 cm above seat reference point. Grinding 45–55 cm in front of and approximately 30 cm above seat reference point. Workpieces picked up from the pallet, positioned for grinding and pressed on to the sanding belt a number of times and put on a new pallet. Workpiece weight 0.02–5 kg. Workpiece size, largest dimension 35 × 20 × 10 cm, smallest dimension 5 × 0.5 × 0.2 cm. Grinding force 10–150 N, directed forward and 5–35° upwards. Frequency 60–600 workpieces/hour. Duration of batches 15–90 minutes. Not more than 2 hours of grinding a day.	Need of trunk and arm movements to the side. Need of increased stability of the trunk in the rearward direction.
Workplace	
Sanding belt surface 5 × 10 cm, 85 cm above floor, footrest 5 cm. Viewing angle 50–60° below horizontal. Visual distance approximately 40 cm. Box for collecting burrs restricted the knee-room 20 cm in width and 25–40 cm in front of seat reference point. No acceleration forces. Intensity of illumination 300 lux.	

Often, the major difficulty of preventive actions is identification of the problem. The approach of using thorough and systematic analyses of the tasks and the workplaces according to the seat model, was found to identify the problem easier and also to make the choice of industrial seats easier. This also gave guidance in improving the work situation by altering the task demands.

According to the seat model, measures of the responses to seat and task factors are used for the evaluation. The seat model facilitates the choice of methods for the measurements to be made. The literature review demonstrated how, from a historical point of view, certain methods of measurement were used for chair evaluation during different time periods, very much as they became fashionable. This can be avoided by the use of the seat model and the consequent choice of relevant methods.

A comprehensive evaluation must involve a large number of aspects of the chair and therefore a large number of methods. Several of these were dealt with in the literature review, e.g. foot swelling and measurements of seat pressure. However, such a comprehensive evaluation would be expensive, and therefore it is probable that only a few methods would be chosen in future evaluation studies. Methods which particularly concern those factors or design features for which there is less knowledge available will probably be given priority in future research. It is of the utmost importance, however, that the critical factors in each particular study are incorporated.

The workplace and the work task were found to be a major influence on chair design. In particular, work factors such as presence of acceleration forces (Study X), demands for force exertion (Studies V and VIII), visual demands (Studies VII, X and XI), and handling of workpieces at the sides (Studies VIII and IX) were shown to have a substantial influence on the chair design. It was also noted that environmental factors, such as burrs, air pollution, and heat exposure changed the preferred postures, and thereby it is possible that also the appropriate chair design can be affected. The results from these studies were in agreement, and thus supported the relationships in validity of the model. It was shown that features such as backrest height and width, seat height and design were affected by the tasks.

A limitation to the seat model is that it is only qualitative. It does not give specified design recommendations, but enables the recognition of important relationships. Therefore, the model is still of limited use for laymen in industry in the process of choosing industrial seats.

The systemization provided by the seat model will facilitate the development of more appropriate chair designs and an improved standard of seating in industry. The model should not be seen as complete. It can be enlarged when more thorough knowledge of the influences has evolved.

Work chair design evaluations

When evaluating seat design in relation to the work task, several conflicting factors can be present at the same time. For example, one particular work chair design feature may be advantageous for one body part, but unfavourable for another body part. In Studies VI and IX, the sit-stand seat was found to be advantageous for the back but disadvantageous for the buttocks. In addition, the work task may demand two conflicting design features at the same time, such as requirements for stablity and also possibilities to move the trunk. An interesting example was the fork lift truck driving task (Study X), which included demands on stability due to acceleration forces. This required a high backrest. Demands to twist and move the trunk due to visual demands required a low backrest. The compromise in this particular case was shown to be a backrest height of approximately 40 cm. This type of conflict must be solved by determining which requirements are most important, by seeing if the work task demands can be changed and therefore also the requirements for the seat, or if a compromise in the chair design is the solution.

Studies VII and XI demonstrated how the task can influence the postures, loads, discomfort, and work chair design. They also demonstrated the potential for different types of preventive actions. Changing an unsuitable backrest was shown to alleviate approximately 4° of neck rotation in a sideways viewing task, but for a less unsuitable backrest a gain of only 0.5° was indicated (see Studies VII and XI). If the whole fork lift truck seat could be made to swivel, perhaps neck rotation could be diminished 5° (compare Bottoms and Barber 1978). A forward placed seat, in comparison with a sideways placed one, was shown to have a greater impact. The work organization, transport flow, and warehouse organization were not quantified in Study XI, but these factors were judged to have a substantial influence on the neck angles of the fork lift truck drivers.

Implications for workplace and work chair design

Different chair features can be discussed in terms of functions and properties. Functions have a role and a purpose of aiding the sitter in some respect, or compensating for various work demands (compare the industrial seat model). Properties are qualities of materials used or of particular functions. Functions can be exemplified in the following way: A deep seat pan and lateral supports can increase the stability of the legs for lateral forces. Lateral supports can also prevent the sitter from sliding out of the seat due to lateral forces. A lumbar support prevents pelvic tilt. A high backrest allows relaxation of trunk muscles and gives increased stability of the trunk, more so the more inclined the backrest is. An increased horizontal curvature and lateral supports of the backrest increase the stability of the trunk. A swivel backrest enables more reclined postures to be taken, and gives increased stability. Armrests give support, stabilize the arms, and facilitate rising from the chair. Castors facilitate movements of the chair while seated. Properties are for example friction of the upholstery and density of the padding. A curvature of the seat pan and lateral supports can give a more evenly distributed pressure on the buttocks. A swivelling backrest also has the property of giving a more evenly distributed pressure on the back.

For tasks which involve only few and short periods of sitting, there is little need for a complete adaptation or optimization of the chair design, and it would also be relatively time consuming to do so. The longer total time and the longer time periods spent sitting, the more critical is the chair design, and the more important it gets to adapt the chair design specifically to the work situation. A thorough adaptation means that conflicts between chair design features arising from separate work demands will be more likely.

It was noticed in the field studies (Studies VIII–X) that the postures for the grinders, punch press operators, and fork lift truck drivers were constrained. Restrictions of space and time were obvious and the necessary movements could often only be performed in one way. It was concluded that the industrial tasks caused considerable postural constraints. On the other hand, the office task reported in Study III, caused comparatively little postural constraints. If static muscle effort is needed to maintain a posture, discomfort will arise after some time. The higher the static muscle load needed, the sooner discomfort and muscle fatigue will occur. It can therefore be expressed as an aim in workplace design to create an upright and balanced posture, or a rearwardly inclined and supported posture. It should be possible to perform the job in different postures around the balanced position, involving both the agonists and the antagonists intermittently for the critical joints. In this way, muscles which start to experience fatigue can be unloaded and allowed recovery during the work activity. Seated tasks with demands for constrained postures and with demands for long periods spent holding these postures must receive more attention in the future. In particular, it is important to take actions in order to change the work demand and restrictions.

Hypotheses

Hypothesis 1, namely that different seated work tasks give rise to different loads on the body of the sitter, was shown to be fulfilled in Studies I, II and III. Also a comparison of the resulting loads between Studies V, VI, VII, VIII, and IX, which were designed similarily but included different tasks, supported the hypothesis.

Hypothesis 2, stating that if the chair design changes, the loads on the body and their responses may change as a result, was shown to be fulfilled in Studies III, V, VI, VII, VIII, IX, and X. All differences between the two chairs were however not significant in the studies, but the differences obtained were in the expected directions and in agreement with the methods of measurement used.

Hypothesis 3, namely that the appropriateness or effectiveness of a seat can be assessed using methods which measure the body loads, their effects and responses, was shown to be fulfilled in Studies II, III, and V–XI. Particularly Studies V–X were important in this respect. The results were not significant in all studies, but the results were in agreement, confirming the hypothesis.

Hypothesis 4, namely that the task is a major influence on effective chair design, was considered to be confirmed if chair Y can be shown to be preferable to chair Z in task A, but chair Z can be shown to be preferable to chair Y in task B. In Studies V and VIII, in which the tasks involved forward force development, it was shown that a high backrest was advantageous compared to a low backrest. In Study VII, involving sideways viewing, it was shown that a high backrest was disadvantageous compared to a low backrest. Also, it was shown in the fork lift truck driving task (Study X), that a low backrest was inadequate due to too little stability when acceleration forces were involved, and that a high backrest was unsuitable because it hindered trunk movements. These results were considered as having confirmed hypothesis 4. Further support could be obtained from Study VIII in relation to Study V, in which arm movements due to handling of goods decreased the advantage of the high and wide backrest. Also Study XI supported hypothesis 4.

This work has contributed to the evaluation and choice of seat design by proposing a systematic analysis of the work task as a basis for that. Further, three methods of measurement were developed, namely body height shrinkage and two biomechanical methods. Together with the methods for assessment of discomfort and posture, a methodology for industrial seat evaluation was created, which was shown to be effective in chair evaluation studies.

CONCLUSIONS

The body height shrinkage method was originally developed in this research for evaluation of work seats. The method is in its present state of development a useful tool for ergonomic evaluations and the only method to assess the effect of load on the spine in vivo. The sensitivity is good enough to separate between two situations with less than 100 N difference in loads on the back, with significant results for eight subjects. The method is suitable for field and laboratory studies, and there is no limitation concerning the choice of subjects, such as age or occupation.

The shrinkage measure shows a good correlation with loads on the back. It has also been shown to be related to the perception of discomfort. Body height shrinkage has a potential for wider use, including other fields such as clinical applications and sports.

Two biomechanical methods were developed specifically for the evaluation of loads in seated tasks. They were shown to be sensitive in differentiating between loads in different work activities and between alternative chair designs. They are suitable for static work postures. Ordinary clothing of subjects causes difficulties in determining the posture and biomechanical input data sufficiently accurately. Biomechanical calculations can be used for predictive purposes.

Subjective assessments give very important information about the strain on different body parts. They are neither expensive nor time-consuming to carry out. The results from ratings of discomfort can sometimes be difficult to interpret. It is therefore important to perform interviews as well.

Posture assessment, using photography or video recordings, causes difficulties when performed in the field due to lack of space and visual obstructions. Information about posture is, however, important for the evaluation. Assessment of static postures is often insufficient. There is a great need for methods and equipment for continuous recording of work postures, movements, and subsequent analysis of their temporal pattern. The equipment used for recording head posture is promising for the future in this respect.

Body height shrinkage, biomechanical loads, postures, and subjective responses were used in parallel for evaluation of work seats. They were all shown to be suitable for that purpose, and the results from the methods were in agreement with each other.

The simultaneous use of the methods was shown to be profitable for several reasons. The methods comprise different types of measurement, i.e. measures of loads, effects, and responses. Their sensitivity and ease of use varies between different situations. Finally, the use of several methods increases the strength of the results and the probability of drawing correct conclusions.

A comprehensive evaluation of work seat design would have to include more methods in order to consider the whole range of effects and responses in seated tasks. It is of particular importance that measures of the critical factors be included.

The choice and evaluation of industrial seats must emanate from the task and the workplace, i.e. from the demands and restrictions of the work task and of possible interdependences between them. A model for evaluating industrial seating was developed, which included a number of factors describing relevant work task influences. The model listed initial and subsequent responses of the sitter, and it also included methods for the evaluation of the appropriateness of industrial seats. A structured and systematic analysis of the work facilitated rational considerations, and made it possible to take into account, in a more relevant way, the influences of different work factors. The possibilities of drawing conclusions about seat design were thus improved.

Some conclusions regarding specific design features of industrial seats can be summarized as follows: A high backrest is advantageous in tasks demanding increased stability due to forces acting on the body. A low backrest is advantageous in tasks demanding trunk or arm movements due to visual demands to the side or due to reach demands. A narrow backrest is advantageous in tasks demanding substantial arm movements to the sides and backwards. Field studies of grinding showed that a high and narrow backrest is advantageous. In sideways sitting fork lift truck driving tasks, a 40 cm high backrest is a suitable compromise due to the demands of stability resulting from acceleration forces, and the demands of trunk movements resulting from the visual angles needed. A high seat which causes increased trunk-thigh angle is advantageous when the knee-room is restricted. For punch press work, it has been shown that higher seats, which opens the trunk-thigh angle, are advantageous for the spine. A severe limitation of sit-stand seats is that they are perceived as unstable and uncomfortable for the buttocks, especially when forces and movements are present. A varnished wood seat is inappropriate because it has too low a friction coefficient, and it cannot therefore prevent the buttocks sliding forwards on the seat. This creates a lumbar kyphosis and thereby increases lumbar loads.

This research demonstrated that different seated work tasks and also different chair designs give rise to different loads on the body. It was also shown that the appropriateness or effectiveness of a seat can be assessed using methods which measure the body loads, their effects, and responses. Further, it was demonstrated that the work task is a major influence on effective chair design.

The function of the backrest is to prevent pelvic tilt in sitting, which arises with a decreased angle between the trunk and the thighs (often 90°–100° when sitting at work). In this function, the backrest is effective. An increased trunk-thigh angle is potentially advantageous in several situations. To allow this, new chair design features has been proposed (forward inclined seats, saddle seats, sit-stand seats, and seats with knee pads). These designs have displayed other disadvantages, but they have not been sufficiently evaluated, nor finally developed.

In many ergonomically inappropriate industrial situations, the task and the workplace are the primary causes and should therefore primarily be changed, not the chair design.

Industrial seating is a neglected field, both regarding knowledge of appropriate designs and the standard of seats in industry. Further improvements and alternative industrial seat designs, in addition to increased knowledge of influences from the work task, are needed.

FURTHER PROPOSALS

Improvements of the body height measurement equipment and procedure in order to decrease the measurement variability would make the method more useful in a larger number of applications. There is a great potential for improving most of the control measures, for example the range of accepted weight distribution between heels and soles, the number and the design of the back supports, and the training procedure. One particularly interesting potential improvement is to note the exact time of all height measurements in the set. This would then be a base for a regression analysis to calculate the "correct" body height. Further experience of experimental designs in comparative evaluations is needed. The effect upon sensitivity and the extent of error introduced if several experimental conditions are performed in sequence in one day, but with a balanced experimental design, compared to performing one experiment per day and per subject should be investigated. If the former experimental design could be introduced, substantial savings in experimental time could be made. Further data on the repeatability of the method is also needed.

Improved quantitative results on the relationship between spinal loads and shrinkage is needed, particularly related to individual differences. This might make it possible to use control groups in the future, instead of using every subject as his own control. Improved mathematical descriptions and models of the response of the spine to loads are also needed. Assessment of the effects of the temporal pattern of loads has a high priority, since much recent research points to this factor as being very important for the occurrence of musculoskeletal disorders. Further knowledge is also needed about spinal loadings due to passive structures, such as the loadings arising from lumbar kyphosis. Finally, there is a potential for the method to assess a measure of individuals' properties regarding patterns of response to standardized loads, for example the degenerative state of the discs. This could find a wide range of use in the medical field. It would also permit investigations concerning long term effects on individuals due to occupational exposure.

Biomechanical methods have a substantial potential for further development and improvement. One field of improvement is to allow a series of static calculations to be made in order to describe the temporal pattern of loading, while another field for the future is the development of dynamic models. Improved methods for the collection of input data are also needed, especially automated methods for continuous recording of postures and forces. For research into the causes of back pain, the calculations must involve the determination of loads on various substructures of the spine. The biomechanics of the pelvis, the lumbar spine and the function of the backrest are not fully understood yet, and need to be further explored.

The discomfort assessment methods need further standardization in order to increase the possibilities of comparisons between different studies.

An inexpensive optical system for continuous measurement of the co-ordinates of small body markers would be of wide use in future studies. Also, further development of body-borne equipment for continuous posture recording is urgent. The equipment used for measurement of head posture in Study XI would gain a wider field of use if it could be made smaller. The use of inclinometers should if possible be avoided, in order to eliminate problems with delayed response, overshoot, and oscillations. Improved methods and equipment for data collection are also needed.

More knowledge is needed in the field of neck posture as a cause of neck pain. Analyses in one dimension are not sufficient, as pointed out in Study XI. Three-dimensional analyses of flexion-extension, lateral bending, and rotation are needed. In addition, methods should be developed to describe the temporal pattern of loads and postures. The above proposed improvements of exposure measures would facilitate further epidemiological studies, from which the results could form a wider base for preventive approaches.

Very little knowledge exists about the importance of stability and the perception of stability when sitting in chairs. There is a need for further research within this field, which was emphasized in Study IX.

A central question in this work is how to improve the standard of seating in industry. Two possibilities should be explored. First, arguments should be brought forward that industries should calculate investments in workplace equipment in quantitative and qualitative measures, in other words not only in economic terms, as is mostly the case at present. Here, there is an educational need, and also a need for better knowledge of how to appreciate qualitative seat factors which benefit the worker, improve attitudes and so on. Secondly, a substantially better body of knowledge is needed about the effects of various seating arrangements in relation to work tasks and workplaces in terms of discomfort, productivity loss, and the economic consequences of these. This information must be systemized to allow economic, quantifiable calculations to be made for decisions about investments.

The variation of industrial tasks causes a variety of chairs and chair design features to be required. The most realistic way of fulfilling these needs is a modular system, with different alternatives for castors, bases, seats, backrests, and armrests. There is also a great need to improve the shape of the sit-stand seat for better comfort.

Hopefully, chair evaluation studies will in the future analyse and present the characteristics of the work task and workplace, for example according to the industrial seat model. This would not only enable comparisons between different studies, but also increase systematic knowledge about chair design.

A further advantage of using systematic descriptions of the work and attempting to understand the work influences is that in the future this will enable the classification of similar jobs into categories or "families". These "families" would be based on the demands and restrictions from the work. Thus, a specification of a relevant seat design for each "family" would be possible. The process of evaluating individually each work situation can then be reduced and simplified. Such a classification should not contain too many "families" in order to avoid complexity and should be simple enough to be used practically in industry.

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