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# EFFECTS OF SEAT ANGLE ON COMFORT AND LOWER BACK PAIN AT WORK

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# Abstract

Immobile, seated postures produce static loading of the biomechanical structures of the back, so they pose a potential risk factor for musculoskeletal discomfort and pain. Seated work has often been reported as being associated with lower back discomfort, however, few studies have been able to find correlations between spinal load and the incidence of pain and attempts to find a dose-response relationship have been unsuccessful. This may indicate that there is no direct causal link, or that multiple factors mediate the relationship. The amount of spinal load depends on body posture and the frequency and degree of movement, which are all at least partly influenced by chair design. If a chair design encourages seated movement, it should reduce spinal loading and, thereby, the risk of back pain and discomfort. Apart from seat design, factors such as the task undertaken while seated, the length of time seated and individual control of sitting duration and chair parameters may be important.

This dissertation aims to evaluate the influence of these proposed mediating factors on seated movement behaviour and lower back discomfort. The emphasis is on the relative importance of seat design, training in seat used and the nature of the task undertaken.

The methods used include measurements of EMGs (back muscles), foot force via footplates and spinal loading (via stadiometer). An observational tool for monitoring and evaluating seated postural behaviour was developed for the series of studies. Subjective values such as pain, discomfort and comfort are assessed by structured interviews and questionnaires. These were also used to measure beliefs and knowledge of subjects. One study required the development of an experimental chair, where the shape and seat slope could be manipulated by computer and all other important parameters of the chair could be individually adapted.

It was found from the studies that:

- Compared to slightly backward sloping seats (-2°), slightly forward sloping seats (4° to 6°) produce a tendency (not statistically significant) to less frequent kyphotic postures of the spine and a more even distribution of sitting positions (forwards, middle or backwards postures).
- A seat shaped with only the front portion sloping downwards produces similar body position behaviour to that observed on seats sloping forwards over the whole surface and this modification increases the frequency of posture change, whereas sloping the whole seat does not.
- Chairs with freely-moveable seat angles provide no substantial advantage in terms of spinal compression over a two-hour work period compared to fixed

seats. It was argued that a two-hour period is sufficient to conclude that there will be no difference at the end of a working day on spinal compression.

- Chairs with the so-called synchronized mechanism, a freely-moveable seat angle facility where the backrest angle is coupled to the seat angle, are more comfortable for subjects than chairs with fixed seat angles, although no significant differences were found between postural behaviour on them compared to on fixed seats.
- The matching of furniture adjustments to body proportions was generally found to be very poor in school pupils and adjustable chairs were not found to substantially improve the matching of furniture to body proportions compared to non-adjustable furniture. School pupils understand the mechanism for adjustment, but generally not know how to determine the correct settings.
- With adults, face-to-face training of subjects improves the adjustment of furniture to body proportions and confidence in using the seat angle adjustment possibilities (change of angle, fixed or free-swinging). It was concluded that training in the use of seat angle change mechanisms improves seated comfort.
- Clear postural behaviour differences were found between various work tasks. The task undertaken while seated was concluded to be a more powerful determinant of seated posture and position than the possibility for seat angle change. Work tasks which have been associated with a higher incidence of back discomfort were found to show less frequent and less marked postural change than more comfortable tasks.
- The studies support the view that comfort and discomfort are perceived separately and not as opposite poles of a single psychological construct.

The results indicate that future ergonomic studies on seating should focus less on the mechanical and design aspects of the chair and more on the system in which the chair is used. Task determinants are more important for avoiding back discomfort than the seat angle, however, the possibility for seat angle change improves back comfort as long as the subjects are trained in the use of the change mechanism.

# Zusammenfassung

Sitzende Arbeitshaltungen wurden immer wieder mit Rückenbeschwerden in Zusammenhang gebracht. Immobile Sitzhaltungen führen zu statischen Belastungen von biomechanischen Strukturen des Rückens, wodurch diese Haltungen zu potentiellen Risikofaktoren für muskuloskeletale Beschwerden und Schmerzen werden. Nichts desto trotz waren nur wenige Studien in der Lage, Korrelationen zwischen der Belastung und dem Beschwerdegrad aufzuzeigen, und Versuche, ein Dosis-Wirkungsverhältnis nachzuweisen, sind bis jetzt erfolglos geblieben. Dies könnte darauf hindeuten, dass keine kausale Verbindung besteht oder dass mehrere Faktoren bestimmend wirken. Der Belastungsgrad der Wirbelsäule hängt von der Sitzhaltung und dem Bewegungsgrad ab. Dieser sollte zumindest teilweise durch die Stuhlgestaltung bestimmt sein. Wenn nun die Stuhlgestaltung Sitzen in Bewegung fördert, sollte die Wirbelsäulebelastung und somit auch das Risiko von Rückenbeschwerden reduziert werden. Abgesehen vom Stuhldesign könnten auch Faktoren wie die Art der sitzenden Arbeitstätigkeit, die Dauer des Sitzens und die individuelle Kontrolle über die Sitzdauer und Stuhleinstellungen eine wichtige Rolle spielen.

Die vorliegende Studie evaluiert, aufbauend auf mehreren Detailstudien, den Einfluss einiger der bestimmenden Faktoren des sitzenden Bewegungsverhaltens und des Rückenkomforts. Der Schwerpunkt wurde auf die relative Bedeutung der Sitzgestaltung, auf die Schulung und auf die Anforderungen der Arbeitsaufgaben gelegt.

Die zum Zweck der Studien verwendeten Messungen beinhalteten EMGs (Rückenmuskulatur), Druckmessungen der Fussbelastung (mittels Messplatten) und Messen der Wirbelsäulenbelastung (mittels Stadiometer). Eine Beobachtungsmatrix wurde für die Studienreihe entwickelt. Diese Matrix erlaubte das Beobachten und das Evaluieren von Sitzhaltungen. Die Methoden zur Beurteilung und Auswertung von subjektiven Werten, d.h. Komfort und Diskomfort, Wissensstand und Meinungen umfassten strukturierte mündliche Befragungen und Fragebögen. Eine Studie erforderte die Entwicklung eines experimentellen Stuhles, bei dem Sitzform und Sitzneigungswinkel mittels Computer justiert und alle anderen wichtigen Parameter des Stuhles individuell adaptiert werden konnten.

Es wurde gefunden:

- Verglichen mit leicht nach hinten geneigten Sitzflächen (-2°) tendieren leicht nach vorne geneigte Sitzflächen (4° bis 6°) zu einer gleichmässigeren Verteilung der Sitzhaltungen (nach vorne, mittig, nach hinten) und zu einer geringere Häufigkeit von kyphotischen Haltungen.

- Eine Sitzform, an denen nur der vordere Teil nach vorne neigt, bewirkt ähnliche Sitzhaltungsmuster wie bei den Sitzen auf Stühlen mit der ganzen Sitzform nach vorne geneigt. Zudem bewirkt es eine Zunahme der Häufigkeit der Haltungsänderungen.
- Das Arbeiten auf Stühlen mit frei verstellbaren Sitzwinkelneigungen im Vergleich zu denen mit einen fixierten Sitzneigung ergibt keinen nennenswerten Vorteil in Bezug auf die gesamte Kompression der Bandscheiben.
- Stühle mit dem sogenannten Synchron-Mechanismus – eine freibewegende Sitzneigung mit angekoppelter Rückenlehne - wurden als komfortabler beurteilt als nicht-kippbare Sitze, obwohl keine signifikanten Unterschiede in Bezug auf Bewegungshäufigkeit oder Sitzhaltungen festgestellt wurden.
- Das Anpassen an die Körperproportionen durch verstellbare Schulmöbel erwies sich im Allgemeinen als unzureichend und im Vergleich zu nicht-verstellbaren Schulmöbeln ergaben verstellbare Stühle keine Hinweise auf wesentlich verbesserte Anpassungen. Die SchülerInnen begreifen zwar die Funktionsweise des Verstellmechanismus, wissen aber nicht, wie die korrekten Einstellungen zu bestimmen sind.
- Die Schulung einer Gruppe von Erwachsenen verbesserte die Anpassung der Möbel auf deren Körperproportionen und deren Selbstvertrauen in Bezug auf die Benutzung der Sitzneigungsverstellung. Es wurde gezeigt, dass eine Schulung über die Benutzung der Sitzneigungsverstellung den Sitzkomfort verbessert.
- Unterschiedliche Arbeitsaufgaben zeigten deutliche Unterschiede im Sitzhaltungsmuster auf. Die Studien kamen zum Schluss, dass die Arbeitsaufgabe auf die Sitzhaltung stärker bestimmend wirkt, als die Möglichkeit die Sitzneigung zu ändern. Arbeitsaufgaben, die mit einer höheren Häufigkeit von muskuloskeletalen Beschwerden vorkamen, wiesen weniger häufige und weniger deutliche Körperhaltungsänderungen auf.
- Die Studien unterstützen die Meinung, dass Komfort und Diskomfort separat wahrgenommen werden. Sie scheinen nicht Gegenpole eines einzigen psychischen Konstruktes zu sein.

Die Resultate weisen darauf hin, dass sich zukünftige ergonomische Studien über sitzende Tätigkeit weniger auf die mechanischen und gestalterischen Aspekte konzentrieren sollten, sondern den Fokus auf das Umfeld richten müssten, wo die Stühle eingesetzt werden. Die Aufgabeneigenschaften wirken eher bestimmend auf die Vermeidung von Beschwerden als die Sitzneigung, wobei die Möglichkeit der Sitzneigungsverstellung den Komfort verbessert, sofern die Personen in deren Nutzung geschult wurden.

# 1 Transfer to Practice

## 1.1 The importance of ergonomic chair design

Chairs, which were once used only rarely for relaxation, have become the most common work tool. With the increasing automation of work over the last half-century a significant change has taken place in workplace activity in industrialised nations. Whereas once, most work involved manual tasks undertaken largely outdoors, today in all European countries more than half of the workforce is employed in service industries where they sit much of the working day. Even in the production sector, work has changed such that manual tasks are being replaced by surveillance and controlling tasks which are undertaken mainly at seated workplaces. This change has profoundly altered the physical demands made by work on the human body and has made ergonomic chair design an important element of productivity.

The challenge facing chair producers is how to best design chairs which support the physical and mental requirements of people whose work requires them to sit for long periods. When physical and mental requirements are not met, the sitter experiences feelings of discomfort, and, as discomfort probably affects productivity, employers should also be interested in providing chairs which avoid discomfort.

## 1.2 Sources of discomfort during seated work

Pain and discomfort generally serve as warning systems of possible future disorders. In part, the perception of pain and discomfort is a learned response, as it is influenced by experience, but it also depends on mood. Pain perception results from the mind's interpretation of nocioceptive signals, which depends on previous experiences related to them and the environment in which the signals are received. Limitations to movement, however, generally produce feelings of discomfort, probably because movement is essential for the optimal function of many body systems.

Static loading of the musculoskeletal system is generally more likely to produce discomfort than dynamic loading and fixed seated postures impose a static load on the musculoskeletal system. Lower back discomfort experienced during seated work may therefore be related to insufficient movement. The optimal functioning of the musculoskeletal, circulatory and nervous systems depends on body movement. Even brain function benefits from physical exercise. Although seated work reduces the load on the lower body and requires less energy than standing, it increases pressure on the abdominal and thoracic organs, hindering their function.

It has been proposed that prolonged sitting may lead to spinal disorders, but evidence for this is lacking, and the results from this series of studies indicate that, although prolonged immobile sitting postures produce feelings of discomfort, it probably does not produce any spinal damage. Most notably, it is probably not relevant to the load on the spinal discs.

The relevant theory states that back pain will result from seated work due to intervertebral disc degeneration. This degeneration results from the continuous load imposed by long-term sitting and produces increased pressure on surrounding nerve roots and other paraspinal tissues. In an *in vivo* experiment, the influence of movement on spinal load was investigated by varying the settings of chairs (fixed or freely moving seats) and comparing this with short periods of standing. It was concluded from the study that chairs with a freely moveable seat angle facility, so-called synchronized mechanism chairs, produce no substantial difference to the total compression on intervertebral discs. Although the fixed seat tended on average to produce slightly more load than the tilting seats and standing breaks, individual variability was great and the difference insignificant compared to other types of loads.

Discomfort experienced during seated work should therefore be viewed as a warning sign which encourages postural change in healthy people. It is due to continuous loading of body structures such as the muscles and connective tissues, abdominal pressure, the circulatory system and central nervous system but probably not the spinal discs, which are not enervated.

## 1.3 Important criteria for back comfort

Avoiding discomfort does not necessarily mean producing comfort, as comfort depends on factors other than only avoiding discomfort. It reflects the sum of multiple factors and depends on attitudes and beliefs as well as the physical properties of the chair and the absence of discomfort. It depends in part on training in the use of seat mechanisms and on values regarding health. Ease of postural change during seated work promotes comfort and feelings of wellbeing.

The results of the investigations in this work indicate that the most important factor in back comfort during seated work is the belief that postural change is possible. This is influenced by the chair dimensions and the adjustment possibilities, as well as by an understanding of the adjustment possibilities. It is, however, not essential that posture be frequently changed. It is sufficient that the sitter believes that they are free to change posture.

### 1.3.1 Aspects of the chair which influence movement behaviour

Several aspects of chair design influence postural behaviour. In this study, the aspects of seat shape and slope were investigated as well as the use of seat adjustments. Although a tendency was found for the upper body position to positively correlate with the seat slope (forward on forward sloping seats and backward on backward sloping seats), seat shape was found to have more effect on body position than seat slope. Most seats are relatively flat, although a slight concavity in both axes is common. A seat profile which differs from standard seats in that the front third tips downwards (8°) results in the adoption of a wider range of upper body positions, and tends to reduce the frequency of kyphotic (pelvis tipped backward) postures. The results indicate that when the modified shape is in the horizontal position, it produces similar postural behaviour to forward sloping seats, without producing feelings of discomfort related to forward slipping. It was rated as more comfortable and more frequent postural changes were observed. The investigation was done for both assembly work and VDU work. Seats shaped with a forward sloping ramp on the front border are therefore recommended for seat design. The design has been commercially produced and has proven popular with chair purchasers.

Confirming the study with adults, investigations with school pupils over a five-month period showed that slightly forward sloping seats (4° to 6°) had no substantial effects on the postural behaviour of school pupils compared to horizontal seats, however, a tendency to a more even distribution of upper body positions (forwards, middle or backwards) and less frequent kyphotic postures was found. The forward sloping chairs were preferred to the traditional chairs, despite the tendency to slide forwards, but this may have been due to changes in the furniture other than the change in seat slope. The changes increased the possibilities for individual adjustment, increased the seat springing, enlarged the surface area of the backrest and increased the stability of the chair. Compared to the traditional furniture, the new furniture was rated as generally more comfortable by the children. The proposed furniture changes were all later implemented by the school authorities.

Although the seat angle is less important to movement change than the seat shape, tiltable seats (with a synchronized mechanism) are recommended over chairs with fixed seat angles, because they are perceived to be more comfortable. In a study described in this work, postural behaviour on tiltable seats was not found to be substantially different on synchronized mechanism chairs than on fixed seats for VDU work, but the tiltable seats were rated as more comfortable by the users. There is no evidence that they substantially improve the pattern of seated movements or reduce spinal loading.

### 1.3.2 The influence of training

How well are chair adjustments are made without training? In the school study comparisons were made between the use of the new adjustable furniture and the traditional non-adjustable furniture in the schools. In all school classes the matching of furniture to body proportions was found to be poor. The seat height adjustment was not found to significantly improve the matching of the chair to body proportions, but the seat depth adjustment resulted in improved matching. Overly high tables were more frequent when pupils had to share them, indicating that the height tended to be adapted to the taller pupils. It was found that the pupils understood the mechanism for adjustment of the new furniture, but generally did not know how to determine the correct settings for themselves.

The effectiveness of training was investigated with adults, who had synchronised mechanism chairs. The use of the mechanism was improved by training and the trained subjects felt more comfortable at their workplaces. The training programme was found to be more effective than providing an instruction leaflet at each workplace.

The results of this series of experiments indicate that modern office chairs with adjustment possibilities and the synchronised tilting mechanism potentially improve seated comfort and health but that training is necessary to ensure that the advantages that they offer are effectively used.

### 1.3.3 Recommendations for the workplace

Back disorders and discomfort are a major source of lost work time and worker dissatisfaction. Some of these problems can be attributed to poor seating, lack of knowledge about ergonomics or poor workplace organisation.

Active seating, where the sitter utilises multiple postures and positions, should be encouraged as it promotes comfort and reduces discomfort. It is influenced by the type of furniture and how well it is used. A good chair is one which allows the sitter to easily change position and postures. It thereby reduces discomfort by giving the sitter the opportunity to vary which groups of postural muscles is used and relieve stress to other body organs. In theory, a tiltable chair increases the sitter's options in terms of posture but these studies show that they are not used as effectively as would be expected. Nevertheless, they are perceived to be more comfortable. Obviously, it is the feeling of being able to easily change body position which is essential to perceptions of comfort rather than the actual movement.

The most significant implication for industry that can be drawn from this study is that the present popular belief that dynamic, synchronised mechanism, office chairs have positive effects on disc health should be regarded with caution. There are multiple reasons why employees should be encouraged to move about at their workplace, not just spinal load. It would, however, be very dangerous to believe that employees who are provided with synchronized mechanism chairs have sufficient movement during their working day if they do not leave the chair. The amount of movement which, in reality, takes place is not sufficiently different to that on fixed upright chairs, at least in terms of spinal load.

If the design features of a chair are to be effectively used, mismatches of chairs and workplaces to the dimensions of the user should be avoided. The results in this work indicate that user-training is very important. Most users, although they may understand how to alter the furniture, do not know how to adjust it correctly to their body proportions.

The training was shown in the studies to produce better adjustment of the furniture to body proportions and increase confidence in using the ergonomic options that the chairs offer, such as the synchronized mechanism. From these studies, it does not seem necessary to change peoples' attitudes to ergonomic seating, as these are generally already positive. Most important is that they obtain knowledge about how to determine the correct setting for their own needs.

People need to be aware that seat adjustments need to be matched by table height adjustments. The investigation of the effects of seat shape and slope indicated that it is undesirable to simply alter traditional chairs into forward sloping chairs and place these into the workplace. The chair and table form a unit and should be adjusted together.

Chairs also need to be appropriate to the working task. A backwards-sloping chair, for example, is inappropriate for a predominantly forward situated task as the backrest is unlikely to be used and the sitter will not gain support of his posture from it. Several studies were done on the influence of task on postural behaviour. The results of these studies provide benchmarks for seated movements. Work tasks which have been associated with a higher incidence of musculoskeletal discomfort and absenteeism, such as computer work and cashiering work were found to produce less frequent and less marked postural change.

From the studies, task type was concluded to be a more powerful determinant of seated posture and position than chair type. Although modern ergonomic furniture is indispensable for comfortable seated work, the first line of action should, therefore, always be job redesign rather than seat redesign. Most modern office chairs fulfil the necessary requirements for good ergonomic seating. Synchronised mechanism chairs promote comfort and are favoured by users. For this reason they are recommended.

Back discomfort arising from seated work is multi-factorial in origin and seat design characteristics, although important, cannot be considered the primary factor in its genesis in workplaces today. Task demands, training and psychosocial aspects of the workplace are at least as important. Future ergonomic studies on seating should focus less on the mechanical and design aspects of the chair and more on the environment in which the chair is used. Training and task organisation are at least as important in the prevention of discomfort than the provision of modern adjustable movement enhancing furniture. Comfort depends on all of these factors.

### 1.3.4 Recommendations for chair manufacturers

The nature of the task which is carried out while seated is very important to seating behaviour. Some tasks limit the types of movement which are possible to only forwards leaning postures. Examples of these tasks are cashier workplaces and some assembly tasks. For these tasks, it is very important that the chair is designed so that the angle between the trunk and the thighs can be opened over 90°. This can be achieved either by sloping the seat forward or by a seat design with the area in front of the ischial tuberosites sloping towards the floor. In both cases, the backrest should never tip forwards, as this closes the trunk-thigh angle and produces discomfort. Comfort is reduced in that the sitter feels trapped by the chair.

For VDU tasks chairs should encourage the use of the backrest and backward leaning postures. This relieves the static load on of the back and particularly the muscles the neck and shoulders. It also reduces the pressure on the abdomen and diaphram which is associated with forward and middle sitting postures. It should however be easily possible to shift into these postures at will. Backwards sloping seats which are not easily tipped forwards produce kyphotic postures, where the trunk is bent backwards like a banana. These produce marked discomfort while sitting.

It is important that the mechanisms for adapting the chair to the user are easy to understand and use. These should be tested before production in a usability laboratory as these studies show that they are often not well understood or used. Training should be offered to purchasers and this should include not only training in the use of the mechanisms but also in how to determine the correct adjustments for oneself and the task that one undertakes. Allowing the potential user to trial the chair for a couple of weeks will detect any sources of discomfort which may not appear in brief trials.

# 2 Introduction

The accepted criteria of good seating behaviour have changed substantially in recent decades. It is thought today lower back pain and disorders at seated workplaces may be due to insufficient movement. It is therefore proposed that seating should be active and not passive and that chair design should encourage active seating. The relationship between chair design and movement behaviour has, however, not been investigated. It is not known what other factors determine postural behaviour at seated workplaces and how these inter-relate with chair design. Furthermore, the relationship between seated movements and back discomfort, health and comfort is not well understood.

## 2.1 Back pain and disc degeneration

Back pain is a relatively common occurrence which results in a great deal of disability and lost work productivity (see Annex A). The term back discomfort as it is used in this paper generally means discomfort in the lumbar region but it may also be used as a collective term for pain or discomfort in any of the regions of the spine. The lumbar region of the spine is a common site of discomfort, however pain in the cervical, or neck, region is also common during seated work, especially in VDU workers. Pain in the thoracic region is much more rare. Various mechanisms have been proposed to account for the phenomenon of lower back pain. To explain the back pain or discomfort experienced during seated work it is first necessary to explore the various mechanisms which may produce pain.

### 2.1.1 Aetiology of lower back pain

In many cases of back pain, the cause cannot be readily identified (Nachemson, 1992; Fraser et al, 1997). Back pain typically occurs in the lumbar or cervical regions, which are the most mobile parts of the spine, and the patterns of factors which influence it are similar from individual to individual. Physical, chemical or inflammatory irritation of any of the innervated structures of the spine can produce pain, but it is often difficult to determine exactly which structures are involved in a particular case. For instance, pain may stem from the annular fibres of the discs, from the spinal ligaments, from the facet joint capsules or from the muscles attached to the spinal structures. The outer regions of the disc, the vertebral end-plates and the posterior longitudinal ligament contain nerve cells and are very sensitive to mechanical stimulation. It has therefore been assumed that these transport the initial pain messages (Adams and Dolan, 1995). Micro-fractures and arthritis of the vertebral end-plates and facet joints have also been identified as possible causes of back pain (Lelong et al, 1992). The symptoms from all these areas are very similar.

Pressure on the nerve roots from swelling or bulging of the adjacent structures is also known to produce pain and, where the disc has deformed sufficiently to produce a herniation, severe pain results. Specific types of spinal loading are known to increase the risk of lumbar disc herniation or prolapse (Kelsey et al, 1984; Mundt et al, 1993; Marras et al 1993). With disc herniation, however, the pain is felt typically in the region that is supplied by the affected nerve. For example, pressure on the sciatic nerve produces pain radiating over the buttock and leg on the affected side. Nerve root pressure is therefore relatively easy for physicians to diagnose compared to the other disorders mentioned. Other types of mechanical failure are therefore suspected to be the cause of much of the other back pain which is found.

### 2.1.2 Mechanical failure and degeneration

It has long been assumed that disc damage can be caused directly by acute compressive loading but this theory is no longer accepted by some authors (Hutton and Adams, 1982; Brinckmann et al, 1988). They maintain that compression overload always affects the adjacent vertebral body first and that torsion loading damages the apophyseal joints before the disc. The only loading conditions which have conclusively been found to cause posterior disc prolapse (the most common herniation) involve a combination of compression, lateral bending and forward bending (Adams and Dolan, 1995). In cadaver studies, Adams and Hutton (1982) found that the discs which prolapse most readily are those from people less than 50 years of age which show no gross signs of degeneration. They propose that, because the nucleus of degenerated discs is fibrous, it may be that degeneration in fact increases their resistance to prolapse.

The weakest link of the spine is the vertebral body (Liu et al, 1983). Its compressive strength depends on age, sex and the body-mass of the individual. Failure occurs at much lower loads during repetitive loading. The damage mostly occurs in the end-plate or in the trabeculae just behind it (Brinckmann et al, 1988). Compressive fatigue damage is probably a common event in life, because micro-fractures and healing trabeculae are found in most cadaveric vertebral bodies (Adams and Nolan, 1995). Alternating forwards and backwards bending movements cause large stress reversals in the pars interarticularis and this has been proposed as a possible mechanism to explain vertebral instability in sportsmen who frequently flex and extend the lumbar spine (Hardcastle et al, 1992). The articular surfaces of the apophyseal joints are not well designed for resisting compressive loading and backwards bending movements produce high stress concentrations on the lower edges of the joint surfaces. The effect is increased after sustained loading when the disc height is decreased (Adams et al, 1994).

During compression, bulging of the end-plates is pronounced so this may well be the site where failure eventually occurs. Compression has been shown to cause end-plate fractures at high levels and when repeated at lower levels (Brinckmann et al, 1983), although this rarely occurs. In any case, structural disturbance alters the mechanics of the tissues, interferes with metabolite transport to the cells and, by breaking down barriers, eventually results in inflammation reactions. Additionally, there is evidence that back pain contributes to a reorganisation of posture and movement strategies (Martin, et al. 2001). These processes may eventually turn an acute back pain episode into a chronic disability.

### 2.1.3 The predictive value of disc height loss for back pain

A relationship between disc height loss and low back pain has not been clearly established. It has been suggested that repeated micro-traumas can cause increased degeneration of the intervertebral discs. One proposed mechanism for this is that micro-trauma interferes with the fluid transport to the disc which ultimately results in degeneration (Chaffin and Park, 1973). It has been shown that the stiffness of a motion segment (the disc and its surrounding structures) increases after desiccation of the disc (Köller et al, 1984). Sideward expansion is also increased in degenerated discs. The increase in stiffness has been shown to occur before it is possible to see any changes on x-ray. Keller et al (1987) investigated the consequences of disc degeneration and found that degeneration is associated with higher height loss at equal compressive load. A cause and effect relationship is, of course, not necessarily the case. It has been suggested that in many people, degeneration may have preceded the acute episode of pain but this has not been demonstrated and remains according to Adams and Dolan (1995) an untested hypothesis.

From their review of the literature on this subject van Dieen and Toussaint (1993) conclude that the type of damage which occurs as a result of compression of the spine appears to be relevant in the aetiology of some lower back pain and that height loss is a predictor of this type of damage. They further conclude that measurements of height loss are therefore highly relevant, particularly because height loss depends not only on the force applied but also its duration, the pattern of loading and the condition of the structures.

### 2.1.4 Tissue responses to injury

It is not wise to apply engineering concepts such as ‘fatigue failure’ without reservation to biological tissues, as biological systems are capable of an active response to stress. Skeletal tissues respond actively to their mechanical environment such that the results of loading vary between adaptive improvement and degeneration depending on the circumstances (Adams and Dolan, 1995). In the short term low levels of sustained muscular exertion result in longer-lasting fatigue than intermittent exertions. The extent of this fatigue may be underestimated by subjective perception (Martin et al, 2001)

Skeletal tissues generally respond to increased forces by becoming stiffer and stronger. This phenomenon has been noted in sportsmen. For example, professional tennis players have increased bone mineral density in their racquet arm (Jones et al, 1977) and weight lifters have very dense vertebrae (Granhed et al., 1987). Ligaments also increase in size with increased work. Articular cartilage becomes thicker and its proteoglycan content increases in response to repeated mechanical loading (Adams and Dolan, 1995). It is not known whether the intervertebral discs also respond by becoming stronger but at least one study has found that physically active people have stronger discs and vertebrae (Porter et al, 1989). It has also been found that supervised fitness exercise programs provide effective treatment for back disorders of unspecified origin lasting between one week and three months (Nachemson, 1992).

This process of strengthening after repeated loading is termed adaptive remodelling (Adams and Dolan, 1995) and one of the principles is that cells within tissue which is under strain respond by producing more matrix molecules. This serves to stiffen tissue and therefore resist strain. This is a type of negative feedback because the tissues respond to changes in their environment in such a way that the effects of the change are reduced. It is a reversible process as distinct from degenerative change.

Micro-damage stimulates the adaptive remodelling response, but structural failure generally results in little evidence of healing with the tissues deteriorating markedly. Damaged vertebrae do heal but the original shape is not usually regained (Brinckmann et al, 1994) and injured intervertebral discs show little sign of true healing but rather continue to deteriorate. For herniated discs Nachemson (1992), for example, has concluded that laminectomy (removal of the disc) is the most effective treatment if the pain has continued for more than three months. Damage to the end-plates of the vertebrae results in a reduction in hydrostatic pressure in the nucleus pulposis of the adjacent disc, probably because there is more space available to the nucleus. Ultimately this reduces fluid flow and leads to a progressive degenerative process in the disc rather than a remodelling response (see Adams and Dolan, 1995, for a detailed discussion on the effects of spinal tissue damage). The discs are the largest avascular structures in the body and therefore have a low capacity for remodelling and repair.

Degenerative disc failure is the result of a gradual weakening process which is opposed by the strengthening adaptive remodelling process. The amount of remodelling which occurs in the discs depends on cell metabolism. This may be reduced, depending on the loading pattern on the affected structures. It works best when loading is increased gradually. Degenerative disc failure is initiated by sudden increases in loading. It manifests particularly when the loading is severe and repetitive.

It should be mentioned here that the paraspinal muscles might also play a role in the persistence of back pain. It has been proposed that an initial attack of pain may give rise to abnormal muscle function, as the muscles are enlisted to help stabilise the affected area. This may adversely affect posture and movement patterns leading to further trauma (Cooper et al, 1993). The role of psychological processes should also not be ignored.

### 2.1.5 Pain perception

Back disorders do not necessarily produce back pain and, conversely back pain is not necessarily indicative of any underlying disorder. Pain is a sensation which results from the synthesis in the brain of many inputs. It serves as a warning of damage or potential damage, but back pain and discomfort may occur irrespective of the current or previous load on the spinal tissues.

There has been a lot of research into the mechanisms underlying the perception of pain. It is known that there are special pain receptors, called nocioceptors, which respond to external stimuli such as heat, chemicals and pressure. Pain is, however, difficult to define or assess objectively as it relates to the experience of the perceiver. The experience of pain has been shown to be influenced by culture, motivations, experience and expectations as well as by age, sex, social background and personality (Weisenberg, 1977).

Back pain is particularly complex, as a wide variety of structures and disorders can give rise to similar pain symptoms and the same disorder can produce different symptoms in different individuals. In 1965, Melzack and Wall published their Gate Theory of pain. Although this theory is not widely accepted today, the concept that the central nervous system has a primary control function in pain perception is well established. Psychological factors such as attention, past experience and the meaning of the situation play a significant role. The brain is an active system that filters, selects and modulates inputs. In fact, the brain itself can generate every quality of experience which is normally triggered by sensory input (Melzack, 1993) without any external input. Pain cannot, therefore, be equated with injury; the qualities of the pain experience are generated by structures in the brain. At a particular moment in time, we feel complex qualities from all of the body but the experience of the body involves multiple dimensions – sensory, affective, evaluative, postural and many others. Sensation occurs only after the inputs have been analysed and synthesised sufficiently to produce meaningful experience. We respond to an experience that has sensory qualities, affect (mood) and meaning as a dangerous (or potentially dangerous) event to the body. The response may be the perception of pain, discomfort or even nothing at all, depending on the brain's interpretation of the situation.

It is also known that the body produces chemical pain inhibitors, endorphins, which increase in production during physical exercise (Harber and Sutton, 1984). Long periods of sitting, because of the low level of physical activity, would probably result in low levels of endorphins in the blood, therefore sitting may result in increased sensitivity to pain in comparison to walking about.

Several possible physiological mechanisms for the aetiology of back pain have therefore been proposed and it is most likely that various different mechanisms will eventually be described which lead, in different ways, to its development. This view was also expressed by Kumar (2001) in his review of the issue.

## 2.2 Spinal load comfort and discomfort

Assessing comfort appears, on first impression, to be relatively easy. The investigator who attempts to design a questionnaire to evaluate comfort, however, soon realises that it is not as straightforward as it initially appears, not least because comfort is highly subjective. What is comfortable to one person is not necessarily comfortable to another. It is not easy to define precisely what comfort is. The variables which determine seating comfort have been the subject of several research studies which will be described here.

The most well established scale for assessing chair comfort is Shackel et al's (1969) General Comfort Rating scale. This uses an 11-point scale with verbal anchors ranging from 1 = I feel completely relaxed, to 11 = I feel unbearable pain. Corlett and Bishop (1976) argued that comfort is the absence of discomfort and is therefore an absolute state which can by definition not be measured. Following this reasoning, it is more logical to assess discomfort, which has a measurable range from none at all (comfort) to agony. They developed the similarly well-accepted Body Part Discomfort Scale, which can be used for all types of work. Using this scale, subjects are asked to consider an illustration of a human body which is segmented into parts. They are asked to decide which part is the most uncomfortable and to give it a score on a 5-point scale, according to how much discomfort they feel. The other parts are then rated similarly in order of level of discomfort. The sum of the scores from the parts forms the discomfort index.

Another well-accepted method which can be used to evaluate discomfort is the Nordic questionnaire (Kuorinka et al, 1987), although it concentrates on detecting pain rather than assessing comfort. The method uses a questionnaire which was designed primarily as an epidemiological tool to comparatively evaluate workplaces or assess the effectiveness of interventions. There are three types of questionnaire all of which use forced choice answers; a general questionnaire and two specific questionnaires which focus either on lower back or neck and shoulder symptoms. The general questionnaire uses a diagram of the human body viewed from the back and divided into nine parts. Questions are then placed, for each part in turn, relating to whether the subject has experienced troubles in the respective area during the last 12 months. The specific questionnaires are similarly structured but concentrate on the particular body area in question and probe more deeply for responses.

The view that comfort and discomfort form a continuum has been recently challenged by Helander and Zhang (1997), who argue that comfort and discomfort are independent entities. Discomfort depends on biomechanic and fatigue factors, whereas comfort depends on a sense of well-being and aesthetics. A reduction in discomfort does not necessarily result in a feeling of comfort but for comfort to occur discomfort must be low. Conversely, for discomfort to be experienced comfort must be low. Helander and Zhang developed a new checklist for the evaluation of chair comfort and discomfort. In their chair studies, they found that discomfort was related to fatigue and changed over time. The feeling of discomfort, they argue, is associated with pain, tiredness, soreness and numbness which result from constraints in the design of workplaces and is mediated by such factors as joint angles, tissue pressure, muscle contractions and circulatory system disturbance. Ratings of comfort in their studies, on the other hand, were not time dependant and were therefore established during the first experience with the chair. They concluded that comfort and discomfort can and should be evaluated separately.

## 2.3 The search for an ideal sitting posture

For over a hundred years, it has been recognised that our seated postures are important to the maintenance of the health of our backs and poor seated workplace ergonomics have long been targeted as a possible cause of work-related lower back disorders (see Zacharkow, 1988, for an historical account) and more recently, upper limb disorders (Hagberg, 1982, amongst others). Until recently it was believed that seated postures put more load on the spinal discs than standing postures (Kroemer and Grandjean, 1997; Schobert, 1989; Zacharkow, 1988; Pheasant, 1986). The assumed health consequence was that higher interdiscal pressures would lead to faster degeneration of the discs. This view follows from the work of Andersson and Nachemson (1974) who compared the pressure inside intervertebral discs during various postures and concluded that unsupported sitting resulted in higher intradiscal pressures than standing. The lowest seated intradiscal pressure was achieved, in their studies, on chairs having a backrest with pronounced lumbar support and armrests. These results prompted chair manufacturers to design chairs that optimise the support of the back.

More recent *in vivo* recordings of the intradiscal pressure (IDP) by Wilke et al (1999) and Rohlmann et al. (2001) show, however, that seating may produce less intradiscal pressure than standing. These findings have been supported by stadiometry studies (see Annex B). Furthermore, the standing posture has several disadvantages in terms of spinal mechanical function compared to seated postures. Lordotic postures, such as in standing, impair the supply of metabolites to the posterior annulus fibrosis (Figure 1), reduce the volume of the spinal canal, increase the loading of the apophyseal joint surfaces and generate compressive stress concentrations in the posterior annulus fibrosus (Adams and Dolan, 1995). Furthermore it has been found that intervertebral disc degeneration is comparatively rare among populations who frequently adopt squatting postures, where the lumbar spine is kyphotic (Fahrni and Trueman, 1965; Bridger, 1987). Adams et al (1994) found that the reduction in hydrostatic pressure in the nucleus of the disc in kyphotic postures is not evident once the disc is loaded over 3 kN and that it isn't found at higher loads because the load is shifted from the nucleus onto other structures, namely the posterior annulus and the apophyseal joints, which are less able to resist it. They argue that a slight lumbar lordosis may be beneficial during walking because it causes the intervertebral ligaments, the posterior annulus, and the lumbodorsal fascia to become slack. Spinal stability must then be provided by muscles and tendons, which are better adapted to absorb strain energy during movement and to dissipate heat. In any event it is no longer safe to assume that the postural loading of seated postures results in an increase in intervertebral disc pressure and that this results in negative effects for the disc.

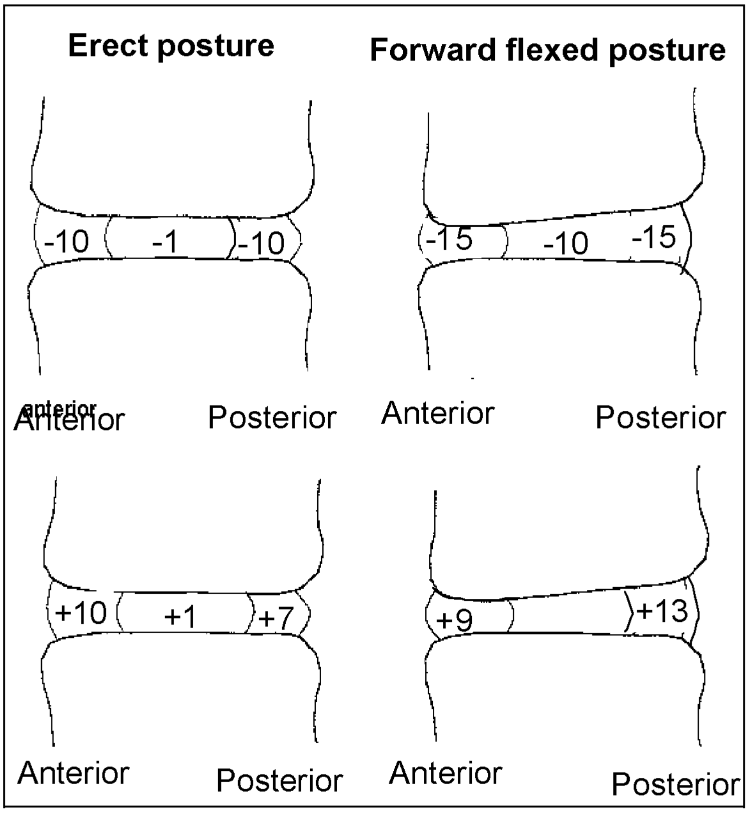



**Figure 1** Fluid loss (above) from a disc and diffusion into a disc (bottom) over 4 hours in the erect posture and forward flexed posture (Adams and Hutton, 1985). Numbers represent relative ratios.

The effect of sitting on the curvature of the lumbar spine was systematically studied by Keegan (1953). He showed that postural adaptation to sitting occurs in part by a change in angle of the pelvis and in part by changes in spinal curvature. When standing upright the lumbar spine has a lordotic curvature, which flattens by about 20-35° during upright sitting (Figure 2). When the upper part of the body is tipped forwards over the hips (forwards position), there is a tendency for the lumbar spine to adopt a kyphotic curve rather than further tilt the pelvis.

At the beginning of the last century, people were taught to sit upright, with a straight back and with their knees and hips forming right angles, irrespective of the task that they were performing, or the type of chair that they used. Chairs were assumed by the 'experts' to be ergonomic if they helped keep the sitter in the upright posture. As early as the nineteen-sixties work scientists began to question whether the upright sitting posture really is the best sitting position. Some argued that it is simply impossible to maintain (Branton. 1969; Grandjean and Hünting, 1977; Bendix, 1986). Others argued that it is biomechanically unbalanced (Corlett and Mananica, 1980; Mandal 1981; Schobert, 1989), which may be the reason that it is difficult to maintain. In any case it is generally not perceived as comfortable.

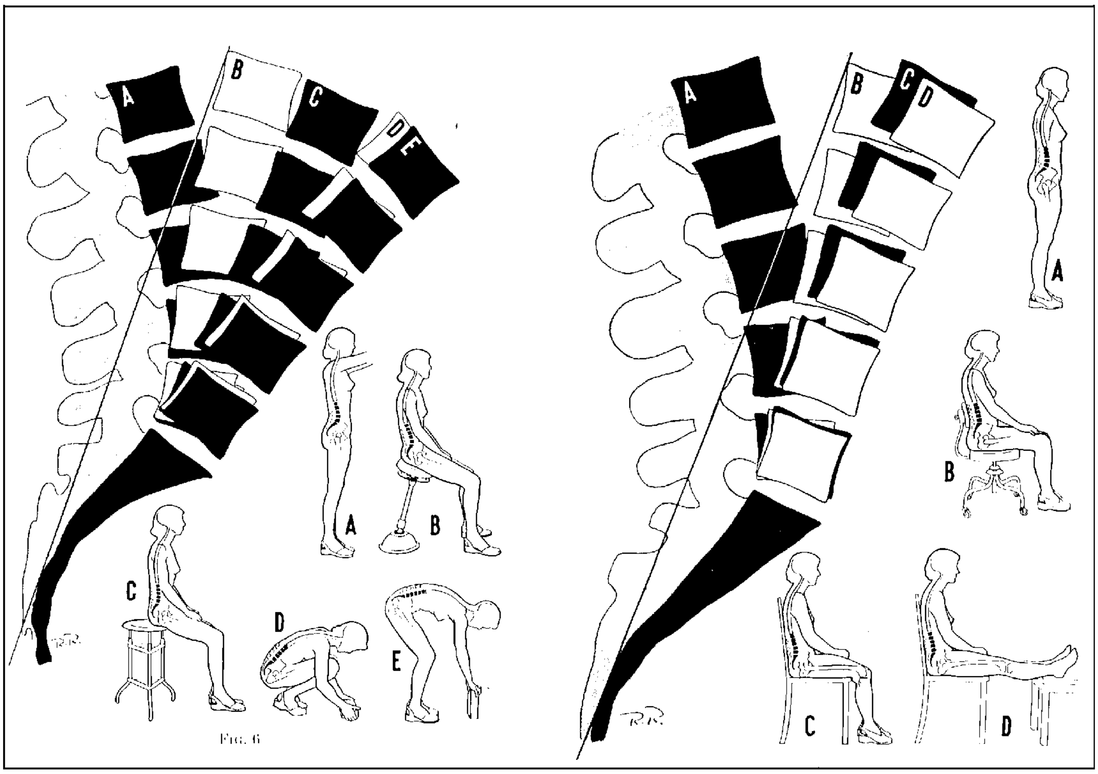



**Figure 2** The adaptation of the spine in sitting and while performing other tasks (Keegan, 1953).

Following the findings of Keegan, Mandal (1985) argued for steeply forward sloping seats which, he maintains, tilt the pelvis forward and increase the lordosis of the lumbar spine, bringing it closer to that of the standing posture. Bendix (1986) also based his recommendations for increased seat height and sloping desks on the belief that reducing kyphosis is beneficial to the spinal structures. In support of these views, Lelong et at (1992) found that sloping the seat 10° forwards resulted in up to a 30% decrease in intradiscal pressure. With larger forward slopes greater variability is found, which the authors attribute to increased muscular tension. A lumbar support only reduces the IPD by a maximum of 15% and armrests by 5%. On the other hand IPD increases substantially with kyphosis or hyperlordosis.

The efficacy of this type of seat design has, however, been shown to be rather limited in practice, as it is easily possible to adopt a kyphotic posture on forward sloping seats and no chair design has been found that reliably and comfortably maintains the body in one single posture. Eventually the idea emerged that no posture should be held continually for long periods and that there cannot be a single ideal sitting position. Cantoni et al. (1984), for example, while investigating reports of discomfort, compared work at an older style switchboard with work at a new ergonomically designed VDT switchboard and found a significant increase in the degree of postural fixity, which they suggested may cause the discomfort. Today postural fixation, or lack of movement, is itself suspected to be a cause of musculoskeletal disorders.

## 2.4 Active seating and chair design

Adams and Dolan (1995) suggest that alternating the mechanical loading may positively affect skeletal tissue cells by influencing metabolite transport. Lumbar flexion stretches and thins the posterior annulus fibrosis which, they maintain, enhances the diffusion of metabolites from the disc periphery into the middle of the posterior annulus, the region with the most metabolically active cells and the most precarious nutrient supply. In this way inadequate movement may cause disc malnutrition, and by implication degeneration, in this region. Mechanical loading also increases fluid flow, which is the most important mechanism for the transport of high-molecular-weight molecules such as proteins, which regulate and co-ordinate cell metabolism. In this way the large fluid movements associated with postural change have a significant effect on metabolite transport, which is improved by alternating rest with activity and flexed postures with lordotic postures.

During prolonged sitting, there is little variability in disc compressive forces. This may reduce the transportation of fluid and the exchange of nutrients and waste products to and from the discs. Therefore, alternate loadings and unloadings of the spine would be desirable. (Helander and Quance, 1990; Winkel, 1987). This mechanism has been proposed to explain the high incidence of back discomfort which has been observed in both people who stand for long periods of the day or who sit for long periods. Magora (1972) first suggested from his observations of these two phenomena that sitting should be interspersed with brief repeated periods of standing. Eklund, who listed a number of other disorders in which sufficient movement aids in prevention, e.g., varicose veins and colon cancer, supported this view. Winkel (1979) also discussed the role of movement in the prevention of pulmonary emboli and cardio-vascular strain.

The effect of movement on the muscular system is also important. If muscles are not regularly used their performance deteriorates, conversely, they generally respond to increased use by becoming stronger. Although performance measures of the back muscles do not reliably indicate past activity levels, it is reasonable to assume from surveys of muscle performance undertaken over large groups, where age and sex effects are considered, that the people with the poorest performance also tend to be those that have had the least activity. From this perspective the prospective study of Luoto et al (1994) is interesting. Their study did not include direct measures of activity levels but they found that tests of static back muscle endurance were good predictors of the development of low back pain over a one-year period. On the other hand Dumas et al (1995) reported that in a prospective study of pregnant women neither posture nor the incidence of back pain were related significantly to attendance at pre-natal exercise classes. They concluded that the back pain experienced by pregnant women is probably multifactorial in origin and that exercise regimes, as taught in the classes, may not be appropriate. This may also be the case for back pain in seated work.

Some movement can be achieved by changes in body position and posture while seated. Bearing the foregoing in mind, a chair should prevent extreme body postures and positions, not produce any pain or discomfort for the sitter, and should support the body in multiple positions, giving the sitter the opportunity to vary their body posture. Standards have been formulated for chairs to ensure that the first conditions are met but a valid tool for recording and evaluating postural change at seated workplaces has not yet been formulated. The principle two issues which need to be addressed are: How often should the sitting position change? And what is the optimal range of these changes?

Sufficient movement is particularly important when the task to be performed requires extended periods of sitting, as is the case in many occupations today. The term dynamic seating has sometimes been used to describe the idea of changing body position to allow the different groups of postural muscles periods of rest. Some chair manufacturers use the term to describe a type of chair mechanism rather than how people sit. Therefore, the term, ‘active seating’ will be used in this paper to describe sitting behaviour, where frequent position changes are observed, including occasional standing. The term ‘active seating’ refers only to the postural behaviour of the sitter.

## 2.5 Aim of this work

The aim of the following series of investigations was to test some of the current hypotheses relating to the causes of lower back pain and discomfort associated with seated work and the effects of active seating. Most studies on the theme of back pain have been limited to physiological and biomechanical mechanisms, however, factors such as the task undertaken while seated, the length of time seated, and the amount of individual control at the workplace may be just as important. An important resource for individual control is training, and environmental factors such as climate, noise and lighting may play a significant role. This dissertation evaluates the effects of some of these proposed mediating factors. The emphasis is on the relative importance of seat design, task requirements and training.

The mechanism relating to lack of movement, or postural fixity, can be described in the following hypotheses:

- Chair design affects the amount and quality of postural change while seated.
- The amount of postural change while seated substantially affects spinal load.
- Loading of the spinal and supporting tissues results in lower back discomfort related to seated work. Complete testing of this hypothesis would require extensive epidemiological studies to establish a dose-response relationship, which is outside the scope of the work. A summary of the available epidemiological evidence can be found in Annex A.
- Chair design is the principle factor in determining seated movement behaviour. This hypothesis is tested by comparison of the relative effects of other possible mediating factors.

The most important question in the study is, therefore, whether back discomfort develops from the lack of movement caused by prolonged sitting and how this relates to comfort. Movement affects many of the body's structures but particularly those intimately involved in the production of the movements; the muscles, bones, connective tissues and joints. The purpose of the first studies, where subjective reports of discomfort are used as an indicator for back pain, is to investigate the relationship between active seating and back discomfort. In the following studies, the mediating effects on this relationship of various factors are compared to assess their relative importance. The factors investigated are seat design, tasks done while seated, workstation adjustments and training. The possible mediating effects of other psychosocial factors and the factors which determine comfort at seated workplaces are discussed in a final chapter.

# 3 Seat slope and movement behaviour

## 3.1 Introduction

Ergonomic improvements were sought for the chairs and tables in the primary and secondary schools of Zurich. A prospective study accompanied a trial of the proposed new furniture to investigate the effectiveness of the proposed design changes. The study concluded that slightly forward sloping seats (4° to 6°) are more comfortable for the pupils than the traditional slightly backward sloping seats, however, after a period of five months, no substantial effects on their postural behaviour were found. This indicates that the seat angle may not be a determining factor in seated movement behaviour.

During the 1980's, a number of studies were published on the postural effects of forward sloping seats. Bendix and his colleagues (1984, 1985) advocated a forward sloping seat with a tilted desk as a means of improving seated posture. Mandal (1976, 1985, 1991) was a principle exponent of steeply forward sloping seats, especially for schools, and chair manufacturers were quick to take up the idea in office furniture. Steeply forward sloping chairs with shin supports and no backrests rapidly made a significant impact on the office chair market.

It was argued that forward sloping seats reduce the flattening of the spine (kyphosis) which occurs when one sits on traditional horizontal seats (see Keegan, 1953). A reduction in kyphosis is assumed advantageous because the spine is closer to the mid-point of its range of movement. Forward sloping chairs theoretically achieve this reduction because the pelvis is tipped forwards on its axis by gravitational pull, and because the opening of the angle between the thigh and the pelvis reduces tension on the posterior thigh muscles, which otherwise pull the pelvis backwards. In experimental studies, some lessening of kyphosis to that of flat or slightly backwards sloping chairs has been repeatedly demonstrated (among others by Mandal, 1976; Bendix, 1984; Bridger, 1989). It has, however, been noted that the effect of these forward sloping chairs on the posture of the lumbar spine is not as great as would be expected (Ericson and Goldie, 1989), possibly due to the lack of backrest support.

In practice, most traditional office chairs have a 2-4° backwards slope at the area where the ischial tuberosites rest when the back of the sitter is in contact with the backrest. The opening of the trunk-thigh angle can be achieved simply on horizontal or traditional slightly backward sloping chairs by increasing the backrest angle. This has been shown to reduce lumbar muscular activity and disc pressure (Anderson et al., 1979). However, the task to be performed in the chair may restrict postural movement such that leaning backwards to use the backrest is only rarely possible (see Chapter 8). Most seated work is done in forward leaning postures or with the head directly over the pelvis. It is therefore necessary that work chairs support postures other than only that of leaning backwards.

The traditional chairs used in Zurich schools are composed of a moulded wooden seat-base and backrest mounted onto a metal frame (see Figure 3.). The seat is height adjustable using a key, which is generally held by the class teacher, who is responsible for the correct adjustment. The backrests cannot be adjusted in any way and there is no possibility to adapt the length of the seat to the length of the thigh.

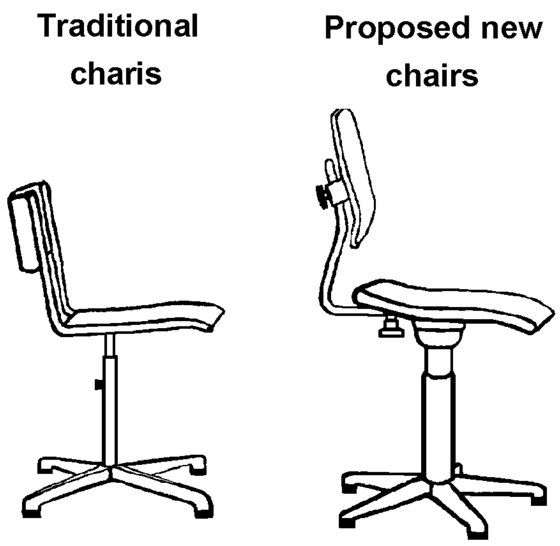



**Figure 3** The two chairs to be compared. The chair on the left is the traditional chair that is used in the schools. The chair on the right is the proposed, forward sloping chair.

The new chair was proposed by the education department medical advisors to alleviate some of the ergonomic "deficiencies". The new chair had a height adjustable backrest with moulding to support the lumbar curve. It was lightly mechanically sprung. The seat depth could be adjusted and, by means of an integrated spring-lift mechanism, the children of the secondary classes were able to adjust their own chairs at any time themselves.

The most contentious change was the tilting of the seat-base 7° forwards. The traditional chairs were lightly (2°) tilted backwards. As discussed above, the forward slope of the seat should open the angle between the thighs and the body and thus, by reducing the pull of the thigh muscles on the pelvis, allow a more upright position of the pelvis. Desk-work using a chair with a horizontal or slightly backwards sloping seat (the traditional chair) is associated with a backwards-tilting pelvis. The thigh-torso angle is mostly less than 90° and the lumbar curve is kyphotic (flattened). The amount of curvature of the lumbar spine which is found in standing postures cannot, in any case, be achieved while sitting, but, to retain a minimal lordosis (anterior curve), without use of a backrest, the postural muscles (here the milliopsoas) must actively hold the pelvis in the upright position (Anderson et al. 1979; Keegen 1953). This imposes a heavy demand on the postural muscles and they tire quickly. The pelvis can more readily be held upright with a forward sloping seat-base. This reduces the load on the postural muscles and the more lordotic spinal curve can be maintained longer. It is generally believed that an extreme or actively long-held kyphosis of the lumbar spine can lead to back disorders (Grandjean 1991; Schobert 1989; Mandal 1981).

It was uncertain whether the forward sloping seat would actually affect the physiological lordosis over a longer period without an active behavioural change program. It was also uncertain how much the tendency to slip forwards would negatively affect comfort, or whether the forward slope would place an unacceptable load on the legs. Various studies with forward sloping seats, notably those requiring knee bracing, have found that this is a negative factor. Ericson und Goldie (1989) found that spinal shrinkage on knee-support chairs (Balans chairs) was higher than on chairs with horizontal seats. Spinal shrinkage is believed to be an indicator of spinal load (see Chap. 6 for a discussion of the method). Lander et al. (1987) found an increase in the electrical activity of the muscles of the lumbar spine on forward sloping chairs. Neither of these teams was able to reproduce the postural improvement that Mandal (1981) obtained.

All of these studies were undertaken with chairs where the angle of the forward slope was relatively large. The Balans-chairs have a seat angle of approximately 15° and the resulting forward thrust of the body makes some additional support necessary. From a biomechanical viewpoint, the immobility of the flexed knees is not recommended. It is also not in an optimal posture to support a load (Schoberth, 1989). Drury und Francher (1985) found an increase in leg discomfort of VDU workers who used a knee-support chair. In the previous study, it was found that leg discomfort on 8° forward sloping seats was increased in comparison with sitting on horizontal seats. Bendix (Bendix 1984; Bendix et al. 1985) concluded that 4° of forward slope is the maximum acceptable angle. According to these studies, larger angles lead to disorders of the lower legs.

Apart from the chairs, new desks were to be introduced. It is necessary to regard chairs and tables as a functional unit for seated work, as the more upright sitting posture on forward sloping seats would be hard to maintain, if the angle of the desk was not adjustable (Bendix et al. 1985). Both the traditional and the proposed desks could be height adjusted. Both types had a shelf for school material situated beneath the top plate. The angle of the traditional desk could be continually adjusted to a maximum of 10° by raising the edge furthest from the sitter. The proposed desks had only two positions; horizontal to the floor or tilted to an angle of 16°. The most significant difference between the proposed and the traditional desks was that the children were no longer forced to sit in pairs, as the new desks were for individual use and could be individually adjusted.

The main aim of the study was to answer the question of whether the proposed changes, particularly the seat slope, would produce long-term changes in seated postural behaviour. The basic questions were:

1. Does the forward sloping seat improve the sitting posture of the children in the long term? An improvement was defined as a reduced frequency of kyphotic postures or a more even distribution of upper body positions (forwards of hip, directly above hip, backwards of hip), provided that the frequency of postural change does not decline. An increase in the frequency of postural change may also be interpreted as an improvement, however this would need to be interpreted carefully, as it may indicate discomfort.

2. Would the proposed changes be acceptable in practice to both the teachers and the children? The criteria were that the new furniture is preferred over the traditional furniture and that it was rated as more comfortable.

## 3.2 Methods

The study was conducted in two schools: a primary school and a secondary school. In the primary school (ages 6-12 years), four classes received different versions of the proposed new furniture. Two classes retained the traditional furniture for control purposes. In the secondary school (12-16 years), three classes received the new furniture and one class, with the "old" furniture served as a control group.

### 3.2.1 Subjects and furniture

With the new furniture, there were differences in the angle of the seat surface, depending on the moulding. Measured at the area underneath the ischial tuberosities on the seat surface, it was found that the real angle of the seats varied between 4° and 6°. In one exceptional case (one of the primary school classes), the seat angle under the ischial tuberosities was only 2° forwards. The differences probably resulted from differing measurement methods used by the various furniture producers, who were competing for the contract. Some appear to have measured the angle on the edge of the seat, ignoring the influence of the moulding.

### 3.2.2 Posture studies

The methods used for studying the ergonomic effects of seating have generally been those developed for the study of heavy manual work. Postural analyses rely on data from laboratory studies which measure disc pressure, electromyography, radiography, stature variation or subjective assessments. Descriptions of ideal sitting postures have been developed from these investigations. But how do people really sit? Observational tools for body postures have been developed for assessing the postural load of different types of manual work, but generally, these do not discriminate between different seated postures. For a detailed description of the methods used, see Grieco (1986). He emphasised the need to measure postural fixity by considering the real postural sequence, the time spent in different situations of lumbar load and the frequency of posture change. For the purposes of these studies, it was necessary to design a posture classification system specifically for seated activity. The system was based on the Ovako Working Posture Analysis System (OWAS) developed by Karhu et al (1981) in that it places multiple postures within a matrix for coding.

With the seated posture classification matrix (Figure 4), 68 different positions, almost exclusively seated positions, are represented in a matrix. Recordings can be made either manually by recording column and line numbers or via a barcode reader. For this study, barcode readings were taken. For each recording two entries are made; one for each axis on the matrix. Each recording was decoded by a hand-held computer and recorded as an event along with the time in an excel spreadsheet for later analysis.

The system is used in the following way:

If the **shoulders** are parallel to the hips (shoulders straight) the front side of the recording sheet is used, whereas if they are bent sideward or twisted relative to the hips the reverse side is used, which enters different barcodes.

The **first recording** requires two decisions. The first regards whether the lumbar spine is in a lordotic (hip more or less upright) or a kyphotic posture (hip tipped backwards). The observers were instructed to score a kyphotic posture only when the spine was markedly curved backwards in the lumbar region. Distinction is then made between whether the upper trunk is tipped forwards relative to the hips, is over the hips (middle) or is tipped backwards.

The **second recording** is for the leg position, dependant on the position of the knees relative to the hips (thigh angle). There are six possibilities:

1. Both knees above hips
2. One knee above hips, one at same height as hips
3. Both knees at same height as hips
4. One knee below hips, one at same height
5. Both knees below hips but still seated
6. Standing

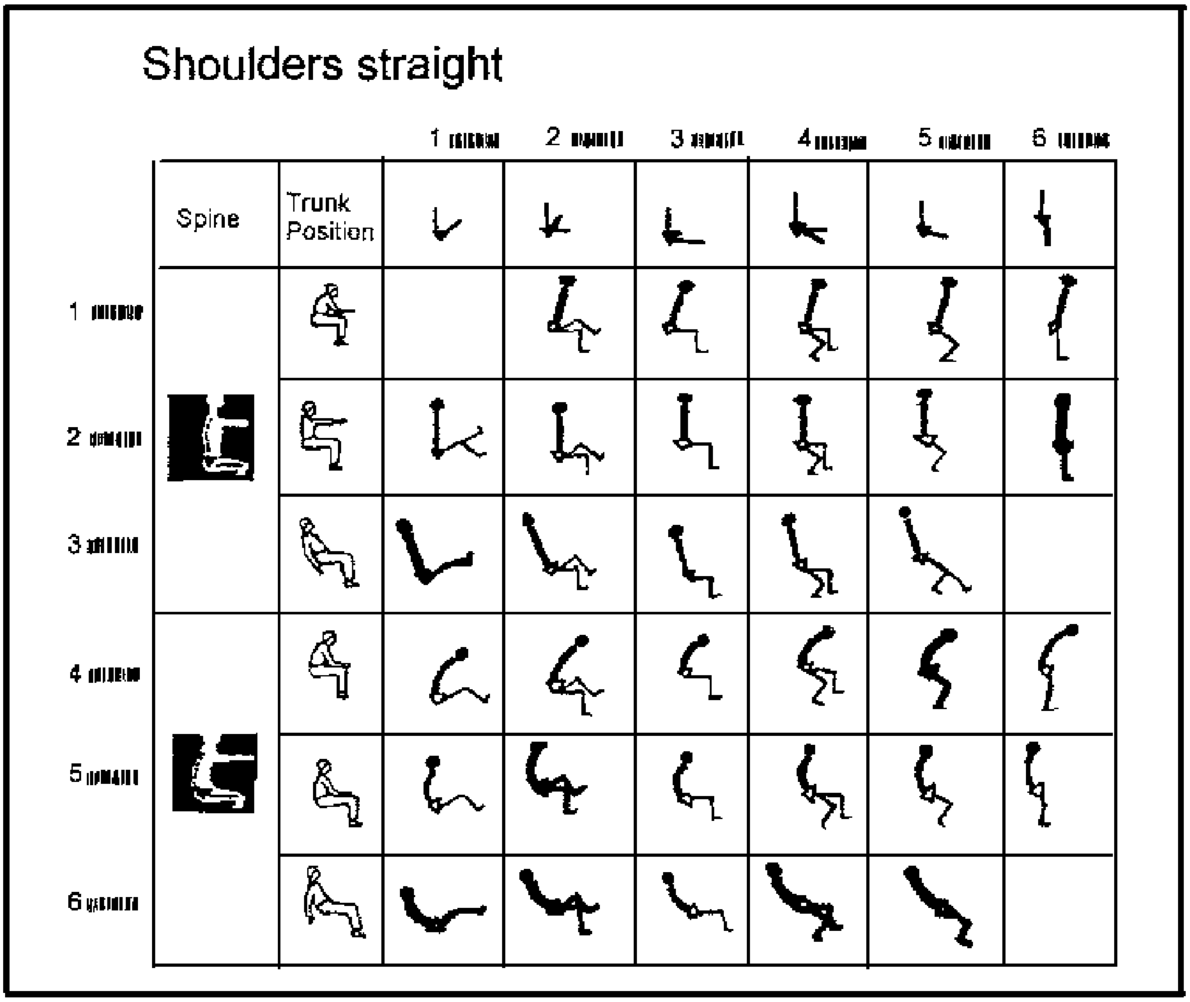



**Figure 4** One side of the seated posture classification system. For body postures with twisted or bent shoulders, the reverse side was used. The bar codes (next to the numbers on the axes) were used for electronic registration directly into a handheld computer.

It is also possible, with separate codes, to register other postural activities such as whether the arms are being used to support the upper body, whether the backrest is being used or if the feet are being supported. The spreadsheet analysis provided the frequency of the different body postures and leg postures. It was also programmed to record whether a change from the previous recorded trunk position had taken place. It was intended to provide a comparative measure rather than to quantify movements and positions.

In all of the classes, four measures were undertaken periodically over a five-month period. The measurements included observations that were either directly recorded in the classrooms or recorded later from video films. For each measurement, four children were randomly selected from each class for observation. They were observed or filmed over a one-and-a-half hour period (90 minutes) of frontal classroom teaching during the morning. Using this classification matrix, the body postures were classified once per minute for one and a half hours.

The children performed their normal tasks, e.g. reading, drawing, doing maths, learning history, etc. Their position was recorded at intervals of one minute. The frequency of kyphotic postures, the position of the thigh and the position of the body relative to the hips were of most interest in this study. Additionally the frequency of standing up was recorded and the frequency of postural change. In total some 13'000 observation were analysed.

### 3.2.3 Questionnaire

Questionnaires were distributed to all of the teachers involved in the study at the beginning of the five-month trial period. The teachers of the classes with the new furniture received a further questionnaire at the end of the trial. The questionnaires were designed to assess the subjective acceptance of the new furniture and to ascertain whether any unforeseen difficulties had arisen with it.

For the surveying of the children, a similarly designed questionnaire was used. In the first and last of the measurement trials six children were randomly selected from each class and structured interviews conducted to evaluate their subjective assessments of the furniture. For details of the questions for the structured interview, see Annex D. In total 108 interviews were conducted.

## 3.3 Results

### 3.3.1 Posture studies

It was found that the thigh position changed with the use of the new chairs (Figure 5) in that both knees were more frequently observed to be below the level of the hips with the new furniture than with the old ($p<0.001$). The difference was mainly at the cost of having the knees at the same level as the hips ($p<0.001$), as no significant differences were found in the frequency of other leg positions. On both types of chair, the knee position 'both same height as hips' (position 3) correlated with kyphotic lumbar spine postures ($r=0.25$, $p<0.01$ for the new furniture and $r=0.32$, $p<0.03$ for the traditional).

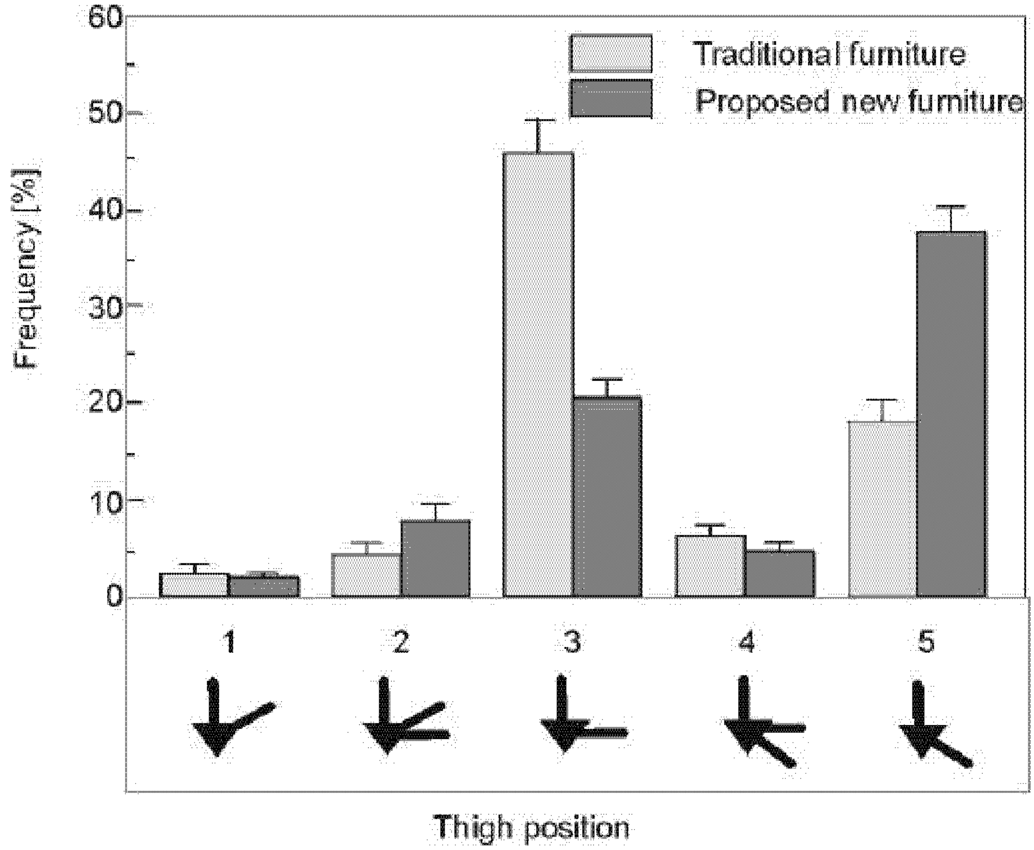



**Figure 5** The frequency of the various knee (thigh) positions. (See Figure 3 for a description of the furniture)

The frequency of kyphotic postures can be seen in Figure 6. On all of the measurement trials, the analysis of body posture showed no statistically significant differences for the frequency of kyphotic postures between the old and the new furniture, however, on the new furniture kyphotic postures tended to be less frequent than on the old furniture ($p=0.056$). Individual variation was considerable (see standard error bars). A correlation was found on both types of furniture between kyphotic postures and the use of the back-rest ($r= 0.59$, $p=.0001$ for the traditional furniture and $r=0.52$, $p<.0001$ for the new furniture).

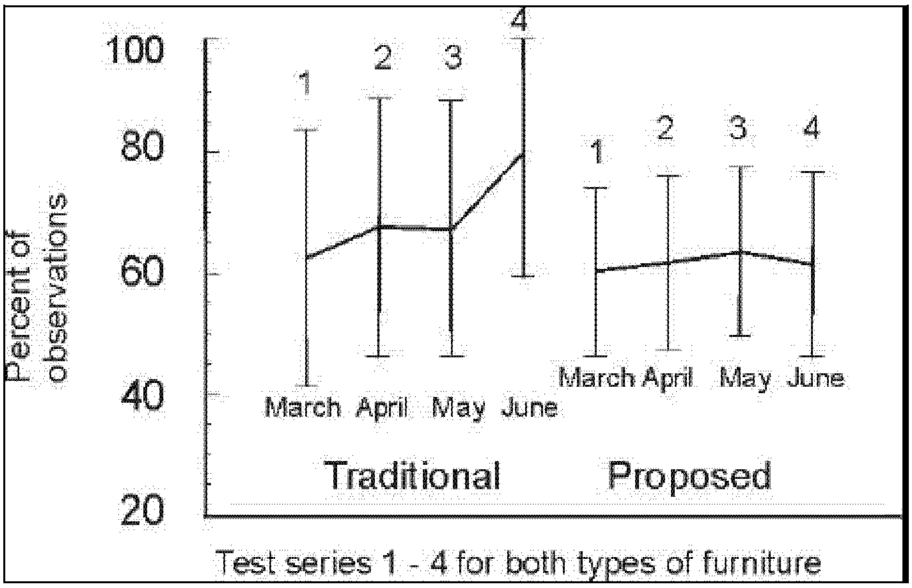



**Figure 6** The percent of observations with kyphotic postures using the traditional furniture compared to using the proposed new furniture (ca. 13,000 observations). Vertical bars indicate the standard error.

The position of the upper body in respect to the hips was only marginally influenced by the new furniture (Figure 7). With the new furniture, forward sloping seats, the forward leaning posture was observed less frequently than on the traditional furniture with backward sloping seats ($p<0.035$). Additionally the backrest was used more frequently on the new furniture (15,9% of the observations compared to 10,5%, $p<0.05$). There was a tendency towards more frequent upright (middle) body position but the difference was not significant.

The forward leaning posture was the most frequent with both furniture types and the backward leaning posture the least frequent. The forward leaning position correlated with kyphotic postures on both types of chair ($r=0.58$ $p<0.001$ respectively $r=0.55$, $p=0.002$), and also with support of the arms on the desktop ($r=0.67$, $p<0.001$ and $r=0.80$, $p<0.001$). The use of foot support (resting the feet on the bar between the desk legs on the new desk) correlated weakly with backward leaning body positions ($r=0.25$, $p=0.04$) and with kyphotic positions ($r=0.34$, $p=0.02$).

No differences were found between the chairs in the frequency of position change (see Figure 8). This was the case with both school levels. The frequency of twisted or bent (to the side) postures also showed no differences for furniture type but there was a slight tendency ($p=0.09$) to more on the traditional furniture.

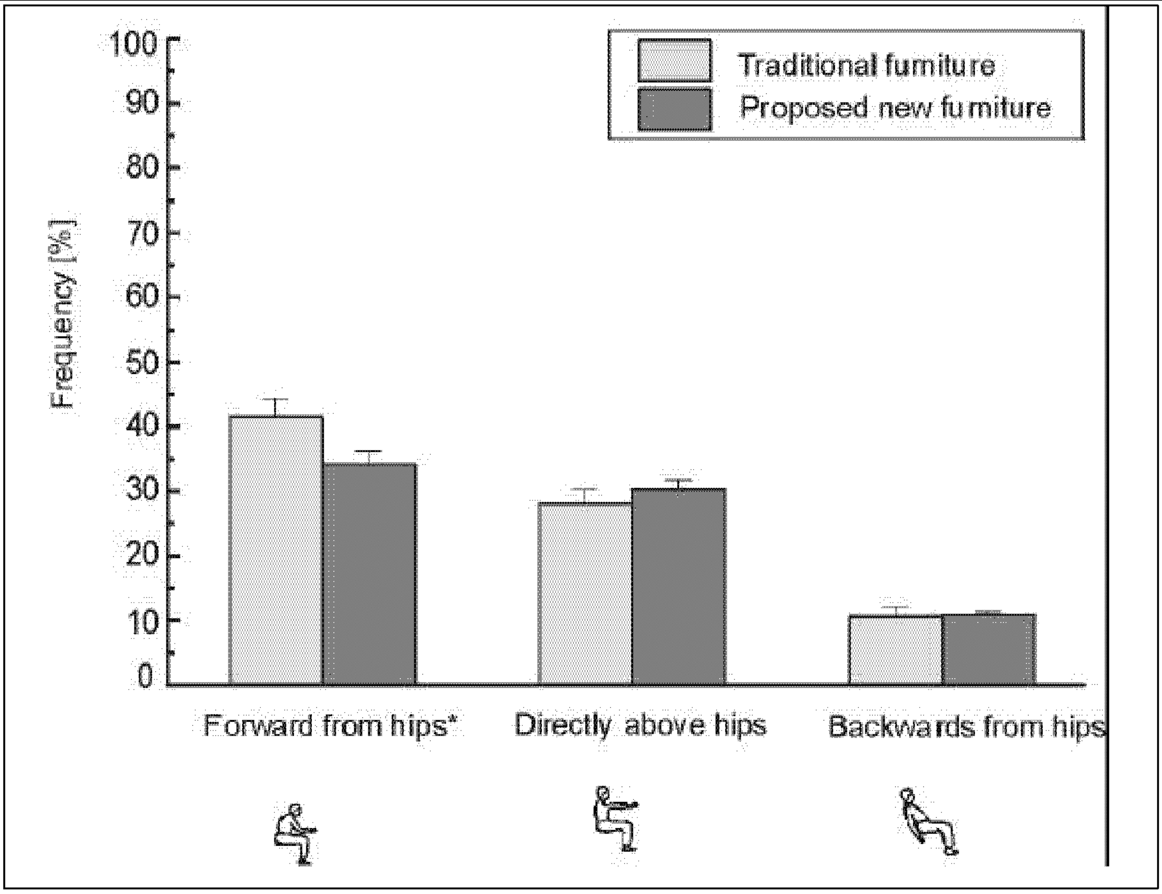



**Figure 7** Seating behaviour according to the upper body posture. The columns show a summary of the results from the four measurement series. For the postures marked with * statistically significant differences (p<.05) were found between the two chairs. The horizontal bars represent the standard variance.

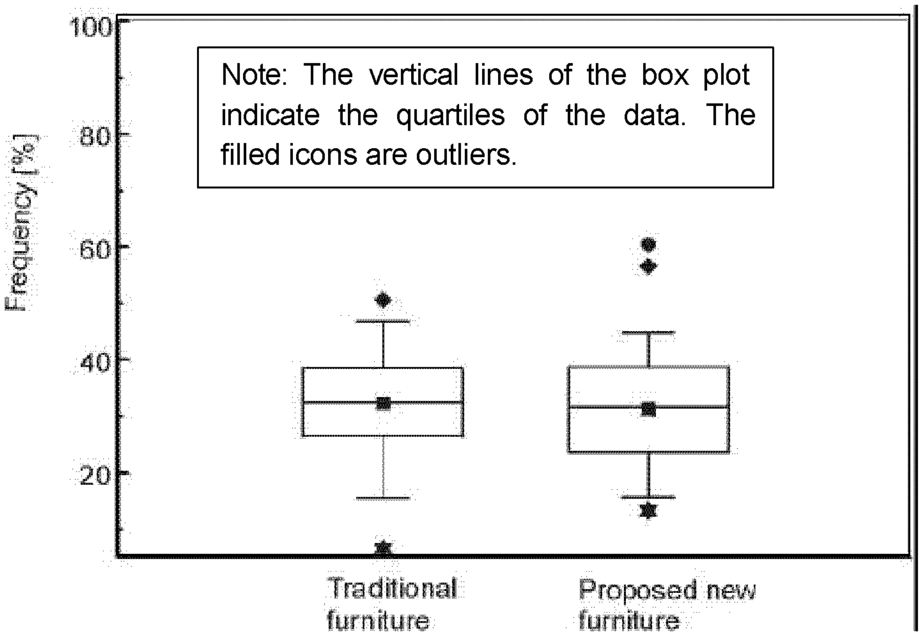



**Figure 8** The frequency of changes in position of the upper body (leaning forwards/in the middle/backwards).

Although the class activities involved primarily seated tasks substantial differences in actual sitting time were demonstrated (see Figure 9). These observations were registered during periods which are described as seated work, for example, learning mathematics, drawing and languages. The first-class children were not seated at their desks 54% of the time. The average time that the primary school (classes 1 - 6) **pupils** spent on their chairs was 65.8% (S.E.= 2.3). The secondary school children sat on average 84.5% (S.E. = 3.5) of the time.

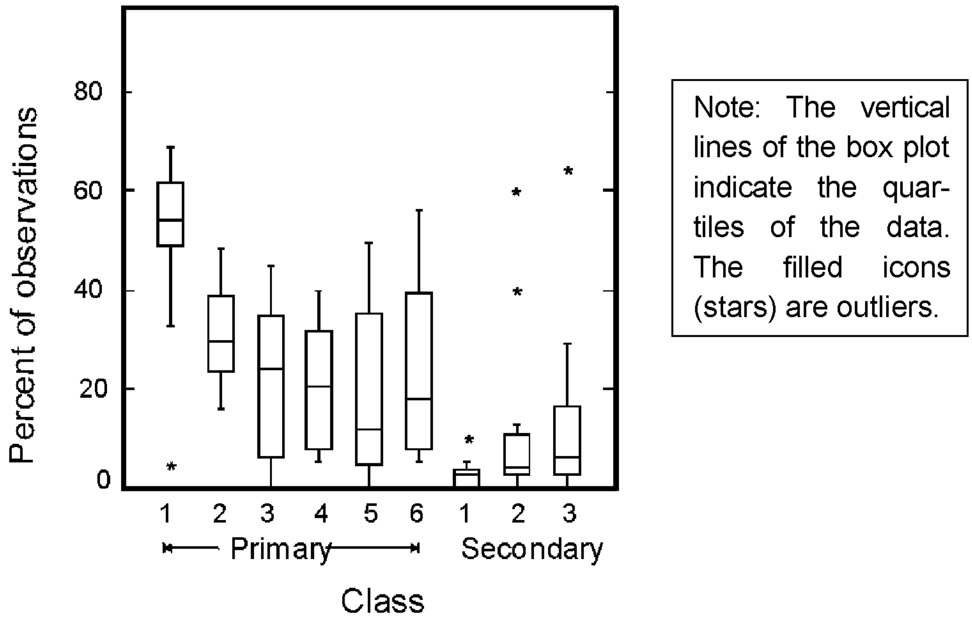



**Figure 9** A comparison of the time in which the pupils were not seated.

### 3.3.2 Questionnaires

In general, the proposed new furniture was preferred in both schools. It was preferred by 82.8% of the respondents with the new furniture at the beginning and by 95% at the end of the study, although 18.4% respectively 26% reported that they slid forwards off the new chair. There were differences between the classes. In both schools, the older children were most critical. Many were of the opinion that the chairs were too hard (25,9% at the beginning, 21,6% at the end).

The springing of the backrest was well accepted. On the first survey, at the beginning of the study, 61% of the users of the traditional furniture and 67% of the new were satisfied with the backrest, that is, they answered positively to the question “How is it with the backrest, do you feel fine when you lean on it?” At the end of the study, 44% respectively 82% were satisfied. The new chairs were on a five star base to improve stability but many of the primary school children spontaneously reported missing the opportunity to rock on the chairs, indicating that they liked the chair to move with them.

The new desks were well accepted. Most of the children appreciated the increased angle of the desk (82% at the beginning, 85% at the end). Several spontaneously welcomed the possibility to adjust the desks to their own needs, independent of their desk partner. Nevertheless, many of the primary children preferred being able to freely choose the desk angle. A substantial point of criticism was the lack of room for school material. Almost half complained that the shelf under the desk interfered in the movement of their knees. This applied to both furniture types.

All the teachers preferred the new furniture. Several found the angle of the proposed seat a bit too steep. The teachers supported the children in their criticism of the lack of storage area for materials. One suggested that only the front part of the desk needed to be angle adjustable. The rear portion could be used for placement of material.

## 3.4 Discussion of the results

Although traditionally the avoidance of a kyphotic posture was viewed as the only measure of a good chair, this view has been revised in recent decades. Quantitative and qualitative movements most probably play a major role in the prevention of back problems (see Grieco 1986). Postural changes lead to physiologically advantageous changes in the loading of the postural muscles. Postural changes might, by changing the pressure distribution in the spinal discs, result in their improved nutritional exchange (Holms und Nachemson 1983). The ergonomic quality of a chair needs, therefore, to be measured on the possibilities it offers for postural change. The basis of the concept of active seating, where frequent postural change is required, lies in this reasoning. Particularly children and youths should not be forced into adopting immobile postures over long periods, as healthy growth requires movement.

On the basis of these criterion, the differences between the traditional and the proposed new school furniture will be evaluated. The tendency towards a more even distribution of the various body postures with the new furniture, particularly the tendency towards more frequent positioning of the torso over the hips (middle position of the body) and towards more frequent postural change can be interpreted positively for the proposed new furniture, even when the differences were very small. The high acceptance of the forward sloping seat supports this conclusion but this needs to be interpreted with caution as acceptance may be determined by factors other than physical load (see Chapters 2 and 9).

It may be that investigations on adaptation to new furniture require longer periods than is generally proposed. Bendix et al. (1985) found that the feeling of comfort on a freely tiltable seat increased in over time in a one-hour study but that the effect disappeared over a longer period. The analysis of the answers to the seating angle questions in this study shows that in the first survey (at the beginning of the study) 100% the children whose seat angle was 4° found this angle to be ideal (n=18), whereas only 25% of the children, whose seat angle was 6° were satisfied with it, that is, they did not wish the angle to be changed. In the second survey (4 months later) the number of satisfied children was substantially changed, namely 78% and 75%.

According to Wachsler and Learner (1960), the evaluation of seating comfort can be reliably ascertained after five minutes of sitting. In view of the changes in comfort ratings found in this study, it appears that longer periods may be necessary to allow for adaptation to new seat angles. They compared an evaluation after five minutes with an evaluation after four hours and their study is often cited as a justification for short-time comfort studies. The number of subjects in their study was very small (6 people). No measurements of posture were included in the study and seat slope was not a variable. Brief trial periods may only be appropriate for measuring the comfort of some chair parameters but not others.

Other postural behaviour can have a moderating effect on comfort. For example, we observed that the children often placed their feet on the bar under the new desk. This probably helped to alleviate the tendency to slip from the chair. The majority of the children stated that they had the feeling they were sliding from the chair but they also felt that the forward sloping seat was more comfortable and felt at ease in the chair at the end of the study.

It is possible that the small changes in seating behaviour and comfort that this study found, were not due to the change in seat angle at all, as multiple changes were made to both the chairs and desks at the same time. The behavioural changes may, for instance, be due to the changes in the seat length and its adjustability. If the seat length is too long, the backrest cannot be used optimally. This means that the backwards-leaning seating position can only be adopted with a kyphosis of the lumbar spine (the so-called coat-hanger posture). With the individual adjustment of the seat length a reduction in the frequency of kyphotic postures would be expected, however this was not found, possibly due to poor use of this adjustment (see Chapter 6).

Good furniture does not automatically lead to good seating postures of children. Amongst other things, sitting posture is probably determined by cultural norms (Bridger, 1987), training and personality factors (See Chapters 7 and 9).

In any case, the results support the findings of the laboratory study (Chapter 3) that seat angle is not a strong determinant of postural behaviour. This might be due to the size of the seat angles investigated. The angles in these studies were smaller than in other studies with school children (Mandal, 1982).

The study awoke an increased interest in, and consciousness of, the importance of seating behaviour in both the children and the teachers. As six studies (4 measurement trials and 2 surveys) were undertaken in each class, a certain amount of disturbance in the classrooms was unavoidable. This was, however, well accepted by all the teachers and almost all the children. However, the frequency of the presence of the researchers in the school lead to the effect that the novelty aspect appeared to wear off fairly soon and, particularly towards the end of the study, it is unlikely that it affected the results substantially. The researchers and teachers felt that the observed seating behaviour of the children, particularly towards the end of the study, was representative of the normal behaviour of the children in the classroom. The “Hawthorne” effect, or the affects of attention to the subjects, can also be evaluated in the light of the comparisons with the control classes, who kept the old furniture but had the same series of investigations.

## 3.5 Conclusions of the field study

The study concluded that slightly forward sloping seats (4° to 6°) are comfortable for children but do not have any substantial effects on their postural behaviour. On the basis of the results of this study, it was possible to support the introduction of the proposed new furniture into other schools and to propose some further improvements.

From this study, it was not possible to draw any conclusions about the relationship between movement and comfort. However, it could be shown that the seating comfort after the introduction of the new furniture changed over the course of several months. Short term studies on chair comfort which cover only minutes or hours need to be interpreted carefully in the light of this finding. Although some pupils spontaneously reported having back pains at times, there were too few to make any conclusions about the effect of the furniture on the frequency of reports of pain or discomfort.

# 4 Seat shape and movement behaviour

Changes to the seat angle are not the only way that the trunk-thigh angle can be opened. The seat profile can be designed to open the trunk-thigh angle similarly to forward tilting seats, but, by making the back area of the seat at a different angle to the front area, the tendency to slip forwards is reduced. In this study the influence of such a seat profile on postural behaviour and comfort was investigated and compared with the effects of a "flat" seat at different angles. It was found that both the seat shape (profile) and the seat angle affect the range of seated body positions adopted, but the seat profile produced a greater effect. Neither the shape nor the slope significantly affects the frequency of posture change. The new profile was rated as more comfortable than the "flat" seats.

## 4.1 Introduction

As mentioned in the previous study a disadvantage of the forward slope is that the sitter tends to slide forwards off the chair. Various different design strategies have been proposed to overcome this problem. The most well known is the knee-support chair. Biomechanically the knee is not in an ideal position to bear weight when it is flexed (Schoberth, 1989). Furthermore, Drury and Francher (1985) found an increase in reports of leg discomfort by VDU users on the knee-support chair. The problem of stress to the musculoskeletal system has therefore not been overcome with these chairs but rather relocated.

It may be possible to open the thigh-trunk angle by another means which avoids the need to brace the body's weight at all. One method is to shape the seat-base such that the area under the ischial tuberosities, where most of the weight from the upper body is supported, is kept horizontal so that less forward thrust occurs. The area under the thighs could be sloped sharply downwards allowing the thigh-trunk angle to be opened. The investigation aimed to test whether this alternative seat-base shape (the modified seat profile) would have similar effects on posture and muscular load to conventionally shaped forward sloping seats, without the disadvantage of the forward thrust. The effect of seat shape on foot pressure was investigated.

But what if the feet and not the knees brace the weight? The feet are designed to bear weight and therefore it is probable that it would be more comfortable to use them to brace the body while seated rather than the knees. Bendix and his colleagues have taken this approach (Bendix, 1984: Bendix et al., 1985). It is not known whether the percent of body weight supported by the feet increases linearly as seat angle increases.

Lesser angles might not require bracing by the feet at all, as friction against the seat surface itself may be sufficient to support the body. Discomfort from continually bracing the body might not, therefore, be linearly related to the seat angle.

In the following investigation, the proportion of body weight which was shifted to the feet at various seat angles was measured and linked to discomfort. The weight force, as transferred to the floor by the feet, operates as a vector having both a horizontal and vertical component. These two components were measured separately.

Measurements were taken continuously to investigate dynamic rather than static behaviour. Studies which have been done in this area before mostly used static measuring techniques, that is, the measurements were taken while the subjects sat in a predetermined posture. A more realistic method of measurement is to average measurements taken frequently over a period of time during which the subjects are performing a normal working task and where they are free to adopt whatever position they choose for their work.

## 4.2 Subjects and methods

### 4.2.1 The experimental chair

An experimental chair was constructed which permitted a wide range of possible adjustment over the most important seat parameters. The backrest unit was taken from a commercially available chair. It was possible to vary its height relative to the seat, the angle of its recline and its distance from the front edge of the chair. This enabled the depth of the seat to be set individually for each subject. The armrests were variable in width apart and in height. These were also individually set for each subject.

The seat itself was composed of 572 screws inserted into a metal plate. See Figure 10). The vertical position (z axis) of each screw-head could he adjusted over a range of 47 mm. The screws were turned by a stepping-motor mounted onto two spindles. The position (on the x and y axes) of the motor was determined by a further two stepping motors which moved it along the two spindles.

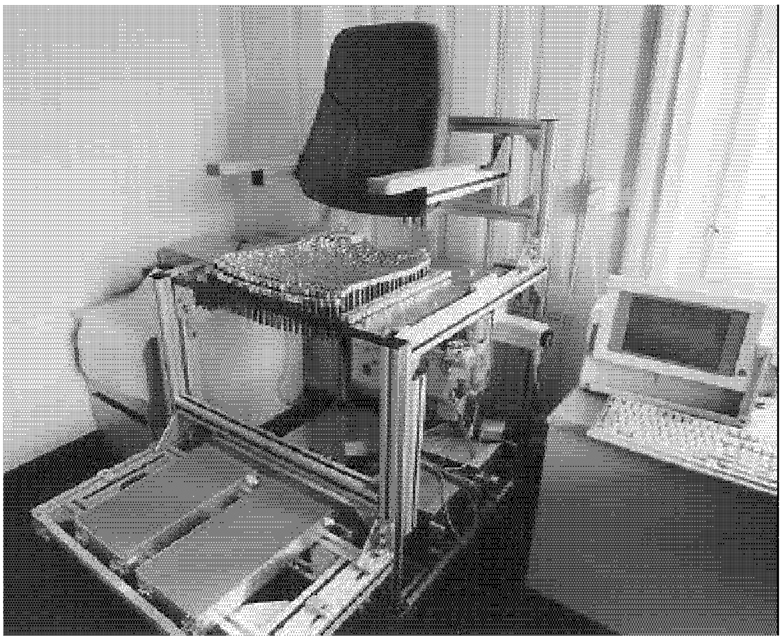


**Figure 10** The experimental chair with seat cover removed to show the screw matrix along with the hardware used to adjust the screws and base plate angle.

The height of the backrest was positioned immediately prior to the experimental session for each subject at a comfortable position as chosen by the subjects themselves. It was set sloping backward at an angle of 100° from the horizontal for all subjects. The armrests were positioned to be at the level of the elbows of each subject when slightly abducted. The distance of the backrest from the front edge of the seat was adjusted according to the buttock inside knee length of each subject (this length less 2 cm).

The height of the seat could be manually adjusted by altering the position of the footplates. For these investigations, the footplates were positioned such that the distance from the front top edge of the seat profile to the footplates corresponded to the seated popliteal fossa height for each subject.

The height of the worktable was adjusted such that for the assembly task it was set at a height of 78 cm from the footplates and 70 cm for the VDU task. These heights are based on the DIN norms for table heights for keyboard work and light assembly work.

### 4.2.2 Seat shape profiles

For this investigation, two profiles were designed for testing the effects of seat shape (see Figure 11). The first was based on the seat of a conventional commercially available office chair. This seat profile conforms to the standard recommendations found in most ergonomics texts in that it is rounded on the front edge and is slightly concave in both axes (Grandjean, 1991; Pheasant, 1986). It was rounded very slightly upwards at the back edge to make a smooth connection to the backrest. The second profile was modelled on the first, and varies only over the front 18 cm. A ramp was created in this region such that the area under the thighs sloped downward at an angle of 8° to the base plate.

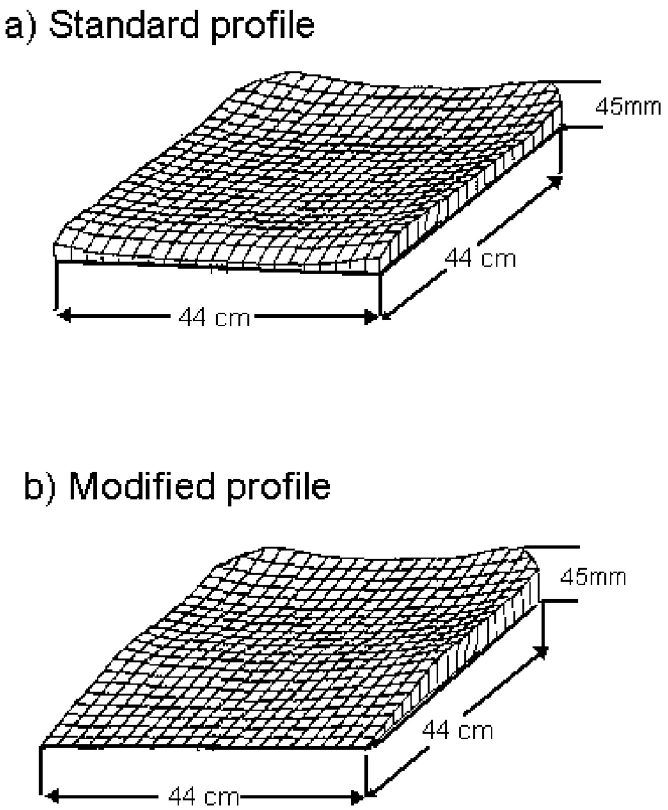



**Figure 11** The two seat base shapes used in the experiment. The modified profile varies from the standard control profile only in the front position where it angles downwards.

The length of the ramp at the front of the seat was based upon anthropometric considerations: The maximum which would still be sufficiently forward of the ischial tuberosities for smaller adults. Its tilt angle was chosen to approximate a similar opening of the thigh-trunk angle to that which is obtained on a flat forward sloping chair at 8°. It is possible that the tilt angle of the front section, and the position of the tilt are not optimised.

Both profiles were produced in sizes which varied according to depth. The profiles extended over 37, 39, 41, 43 or 45 cm such that an appropriate profile could be chosen to suit the buttock inside knee length of each subject (with 2 cm free at the front edge). The two seat shapes were randomly assigned to the subjects.

The seat profiles were produced using a computer programme written in the ASYST[1] programming language. The Position (x, y and z coordinates) of each screw head was determined interactively using a 3-dimensional graphic program. The coordinates were

[1] Macmillan Software Company

then electronically transmitted using two serial interfaces and a digital board (Burr-Brown) communication link to the stepping-motors. The flexibility of this method is obvious. The width and length of the seat can be varied by setting the exterior rows or columns of screws to their lowest position. For comfort, the seat profile was covered by a 4 mm thick mat of upholstery fabric and rubber.

### 4.2.3 Seat slope (angle)

The slope of the entire seat profile, i.e. the plate into which the screws are mounted, was variable from the horizontal to 15° forwards using a further stepping-motor. When the plate is in the horizontal position both of the profiles slope 4° backwards at the region under the ischial tuberosities due to the seat moulding. The seat slopes chosen for the investigation were 0° (baseplate tipped 4° forwards) and 8° forwards (baseplate tipped 12° forwards) at the area on the profile underneath the ischial tuberosities. Subjects were randomly assigned one of these seat slopes for the investigation and the seat base was set at that angle prior to the test.

### 4.2.4 Subjects

The investigation was undertaken using 9 male und 9 female subjects between the ages of 21 and 37 years (median 32), all healthy by self-report. Their heights ranged from 160 cm to 186 cm (median 171 cm) and their clothed weights from 41.5 kg to 87.0 kg (median 63.0 kg). Half were students or academic employees and the remainder were office employees from other occupations. Prior to the experiment, each subject was measured for buttock-inside-knee length and floor to popliteal fossa height in shoes while seated.

### 4.2.5 Tasks

Each subject sat on the experimental chair for two hours, with a twenty-minute break in the middle. For one hour they performed a word processing task on a personal computer, the typing of a text read from a text holder (VDU task), and for the other hour they assembled a model following pictorial instructions and using a variety of different small plastic components which were sorted and arranged in racks of small industrial containers on the workbench (assembly task). The height of the table was adjusted between tasks but the seat slope and shape were the same for both tasks for each subject.

### 4.2.6 Measurements

The subjects were filmed using a video camera positioned three meters from, and at the height of their left shoulder (lateral view). The subject’s posture was analysed from the film and recorded by an observer at one-minute intervals using a seated posture classification system (described in detail in Chap. 3). The position of the centre of gravity of the trunk relative to the ischial tuberosities (forward, middle or backward position), the lumbar lordosis (semi-lordotic or markedly kyphotic posture), any observed twisting or sideward bending of the trunk, and the angle of the thighs relative to the ground were recorded. The data were entered directly into a personal computer.

On completion of each task, the subjects were asked to complete a short questionnaire. This included a body diagram where the subjects were asked to mark any pressure points, areas of stiffness or pain or other discomfort. These were later divided according to body regions (cervical area, thoracic area, lumbar area, sacrum and buttocks, thighs, lower legs including knees) and a marking of any sort within each region was given a score of 1. Four further questions related to the subject's general impression of the chair, the support it offered, the possibility of relaxing in it and how easy it was to change position. They required the subjects to make ratings on a seven-point scale form very bad to very good. These were later totalled giving an approval score with a maximum of 28 points.

Surface EMG electrodes (silver-silver chloride) were used to monitor muscle activity in the trapezius (over the scapula approximately 7 cm from the spinal processes at the level of T7) and the erector spinae (approximately 2 cm from the spinal processes at the level of T3). The electrodes were placed bilaterally, in pairs 2 cm apart, and a reference electrode was placed over the acromion process of' the scapula. Once in place the electrodes were not removed until the investigations for that subject were complete. The signals were filtered, root mean squared, amplified by a factor of 20,000 then A/D converted (Burr Brown).

During the tests, the pressure of the feet was measured using two footplates, which had built-in strain gauges. The gauges were arranged in each plate such that four, one in each corner, measured vertical force and one measured the horizontal force (in the anterior direction).

Readings were taken serially from each of the strain gauges followed by the EMG electrodes (RMS converted signal) at the rate of 10 cycles per second. These readings were later converted into minute averages to give sixty measures per hour for each task.

### 4.2.7 Analysis

All the data from the posture analysis, questionnaire ratings, EMG and footplate strain gauges were analysed using Statgrafics[2]. A multifactorial analysis of the variance was performed for each measure using the factors seat shape, seat slope and task (the independent variables). The dependent variables were the foot force (horizontal and vertical), the EMG (trapezius and lumbar regions), the subjective ratings and the posture analysis. The posture analysis yielded data on the frequency of the various sitting positions (whether forward, middle, backward), the lumbar postures (lordotic, kyphotic), any twisting postures and the frequency of position change.

The data from the footplates were converted to percentages of body weight. The EMG data was converted to microvolts. The posture analysis produces a frequency of each posture and position per hour (maximum for each is 60).

# 4.3 Results

## 4.3.1 Sitting positions and postures

The principal results of the posture analysis are shown in Figure 12. Both seat shape and slope had a significant effect on the frequency of the different positions. When the seat was horizontal (0° angle), the middle position was less frequently adopted than when it sloped backwards, and it was never found when forward sloping ($p = 0.001$). The middle position was more frequently adopted on the modified profile than on the standard profile ($p = 0.03$). The modified seat shape, therefore, encouraged more diversified use of the various body positions than the traditional shape.

There appears to be a tendency for the backwards position to be more frequently adopted on backwards sloping chairs, and the forwards position tended to be more frequent as forward slope increased but the correlation was not statistically significant.

The number of observations which represented changes in body position from the previous observation was used as a relative index of position change. There was an increased frequency of position change on the modified profile (observed frequency 29.3 per hour versus 21.8, $p = 0.05$). No significant effects for seat slope were observed ($p = 0.4$).

[2] Statistical Graphics Corporation

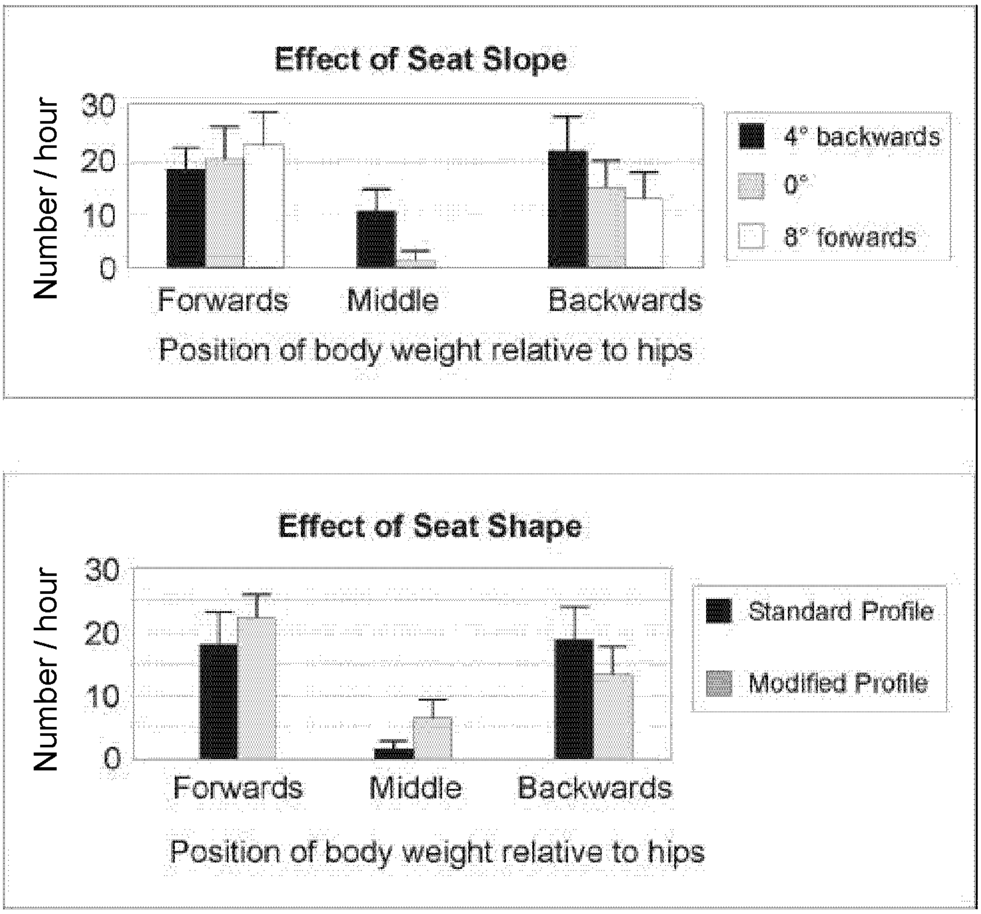



**Figure 12** The position of the torso relative to the hips as a function of seat slope and seat-base shape. Scores represent mean observed number per hour (maximum 60).

No significant difference was found between the various seat slopes in the observed frequency of kyphotic postures, that is, the lumbar posture was not found in this study to be significantly influenced by seat angle (See Figure 13). The tendency, however, was for the standard profile to be slightly more associated with kyphotic postures.

On the other hand, task type was found to significantly affect both body posture and position. See Figures 13 and 14. Generally, the subjects sat more frequently with their weight forwards for the assembly task ($p = 0.0002$) and more frequently backwards for the VDU task ($p = 0.005$). The middle position (torso weight directly over the hips) was adopted least for both tasks. The tendency ($p = 0.1$) was for the assembly task to be more associated with position change (observed frequency 28.8 per hour versus 22.4). For the VDU task, the tendency ($p = 0.12$) was for the modified profile to produce more kyphotic postures than the standard profile when the seat was horizontal, averaging approximately 83% of the recordings, and when the seat sloped forwards.

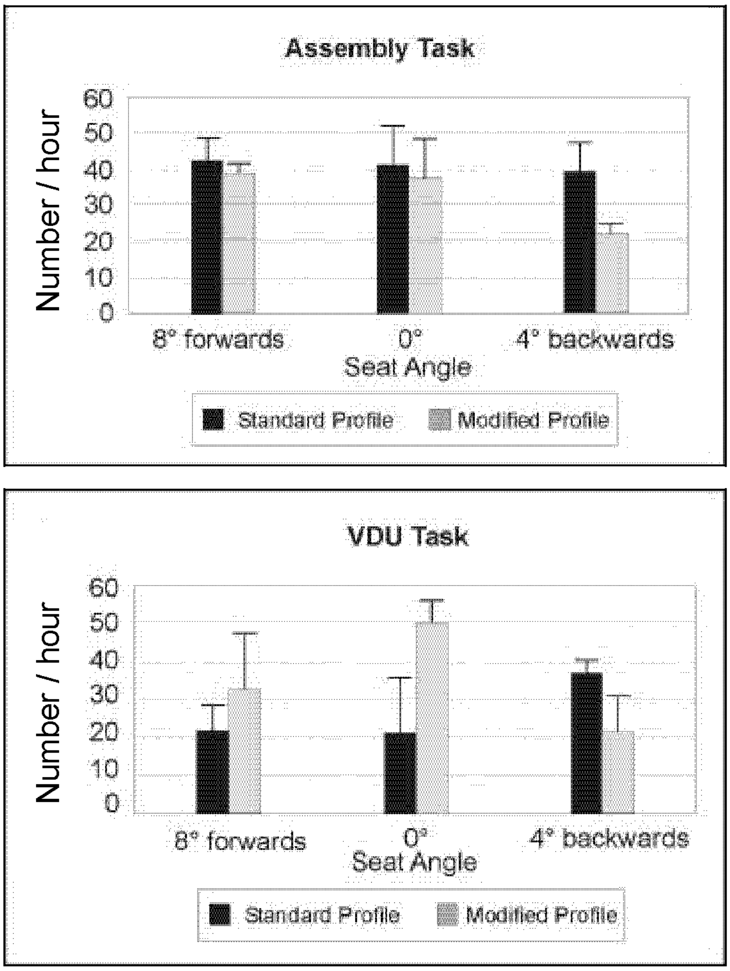



**Figure 13** The mean number of kyphotic body postures observed for each of the tasks at each seat angle and for each seat base profile and task.

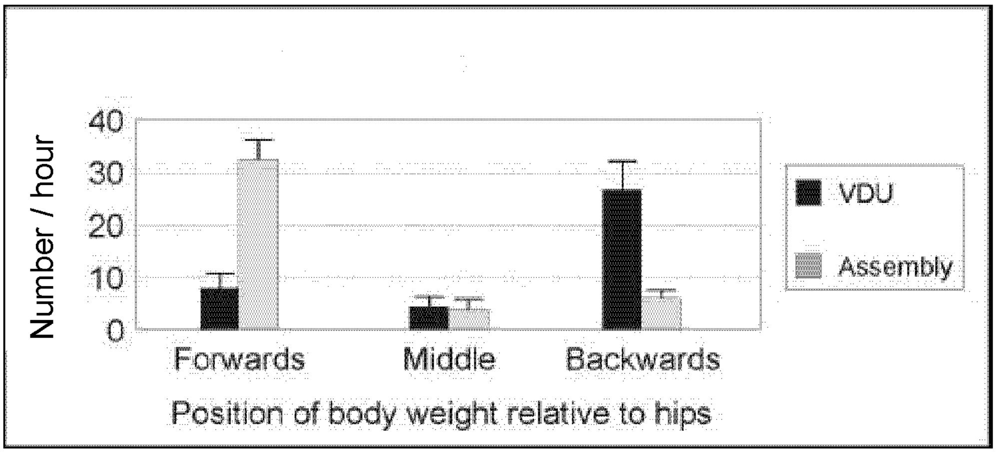



**Figure 14** The position of the torso relative to the hips as a function of task.

A comparison between sitting position on the standard profile when it was tipped 8° forwards under the ischial tuberosities and the modified profile in its horizontal position (thigh area tipped 8° downwards relative to the area under the ischial tuberosities) showed no significant difference in the frequency of the various positions (see Table 1).

**Table 1** Sitting position analysis[3]

| | **Standard profile at 8° tilt** (8°forward tilt under ischial tuberosities) | | **Modified profile 0° tilt** (horizontal under ischial tuberosities) | |
|---|---|---|---|---|
| | **Mean frequency** | Standard error | **Mean frequency** | Standard error |
| Forward position | 21.0 | 10.3 | 22.7 | 8.0 |
| Middle Position | 0.0 | 0.0 | 3.0 | 3.0 |
| Backwards position | 17.8 | 7.8 | 14.7 | 5.6 |

## 4.3.2 Muscle loads

Generally, the modified seat shape produced lower overall lumbar muscle activity ($p < 0.001$). Lumbar activity decreased with forward tilt on the modified profile whereas it increased as the chair tipped forwards for the standard profile. See Figure 15. Lumbar activity did not correlate with the adoption of kyphotic positions ($r = -0.13$).

Contrary to the lumbar activity, trapezius activity was generally higher on the modified profile and for the assembly task ($p < 0.001$ for both). See Figure 16. As for lumbar activity, trapezius activity generally increased as the chair was tipped forward ($p < 0.001$), although the differences were small.

[3] Scores represent the mean observed frequency per hour (maximum 60)

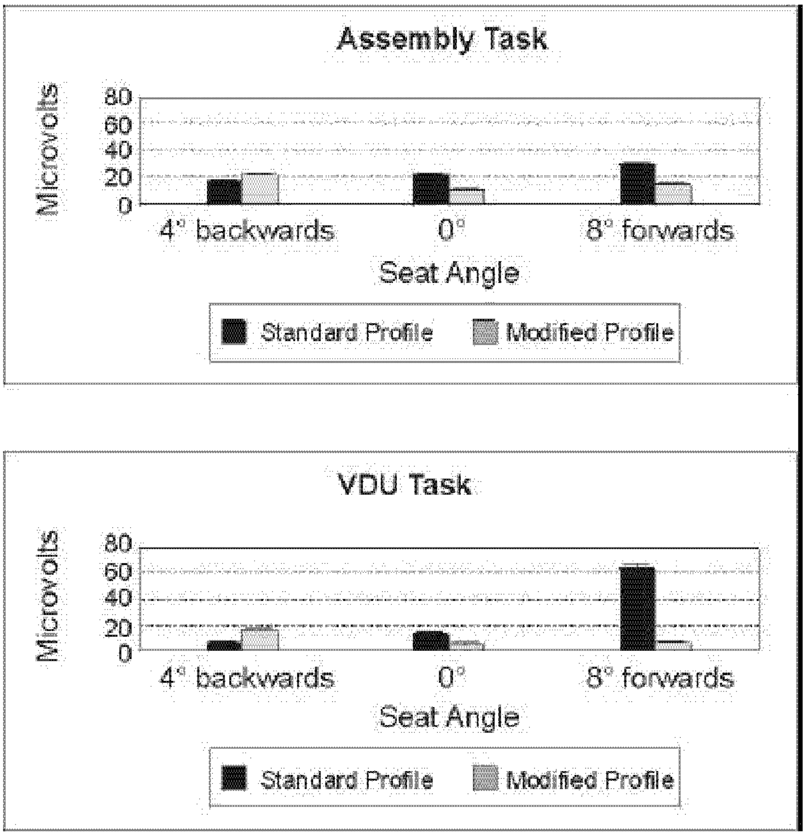



**Figure 15** EMG data from the lumbar region as a function of seat shape, angle and task.

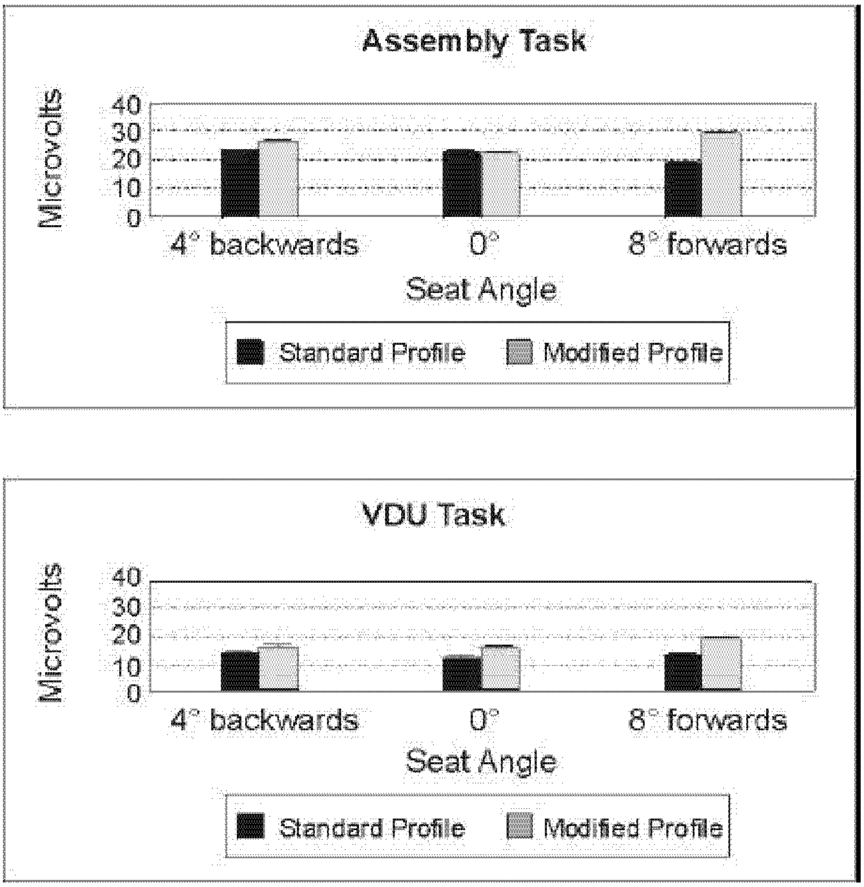



**Figure 16** EMG data for the trapezius muscle activity as a function of seat shape, angle and task.

### 4.3.3 Subjective ratings and comfort

The modified seat shape was judged the most favourably on all questions, however the difference between the profiles did not always reach statistically significant proportions. See details of the questions and results in Annex D. The subjects rated the modified shape as more stable ($p = 0.01$), they reported feeling more relaxed on it ($p = 0.07$) and tended to find it easier to change their position ($p = 0.29$). This was the case while performing both tasks and at all angles.

Figure 17 shows a summary of the total mean scores from each question (maximum 28). The effect for seat slope was non-significant ($p = 0.28$), but the tendency was to favour the backwards and horizontal angles rather than the forward slope. The traditional profile scored better for the assembly task than it did for the VDU task but the effect was not statistically significant ($p > 0.4$).

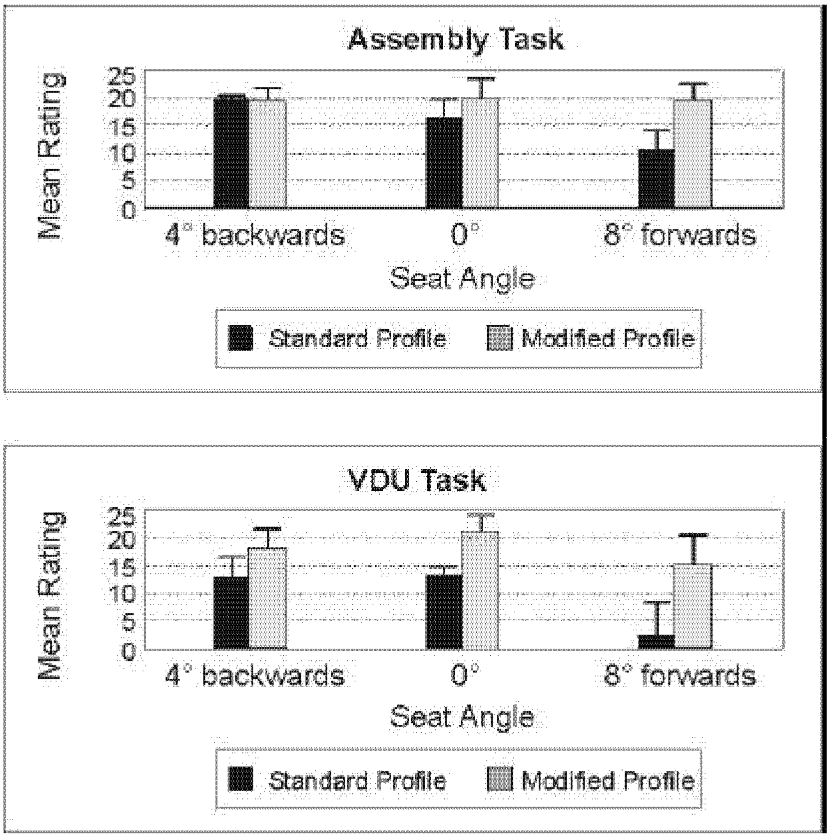



**Figure 17** Subjective ratings of seats according to their shape, angle and the task performed. The scores are mean total scores from the four questions on the questionnaire. The horizontal bars represent the standard error.

The responses regarding discomfort in the various body regions are summarised in Figure 18. The results are based on only a few reports and should be carefully interpreted, particularly for the interaction effects. They indicate that neck discomfort occurred more frequently with the 8° forwards angle on both profiles ($p = 0.01$). The subjects complained less frequently about discomfort in their shoulders on the modified profile ($p = 0.048$). This does not correspond to the trapezius activity data.

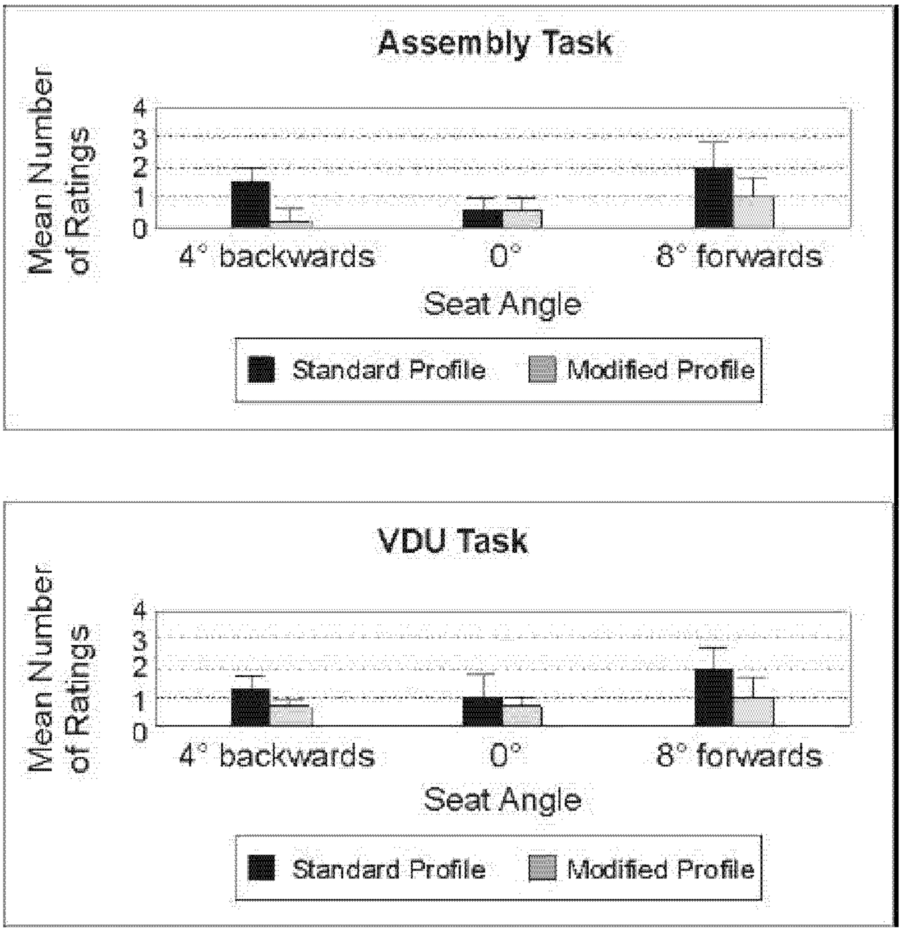
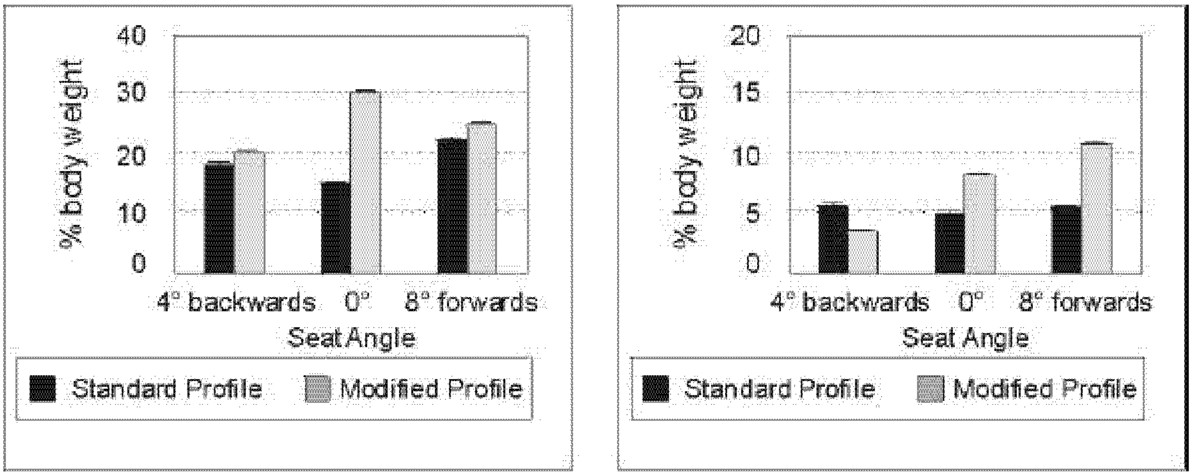



**Figure 18** Discomfort scores from the questionnaire. Any marking of discomfort on the body diagram scored one point. Scores were further analysed according to body part. See text.

No significant overall effect for seat angle was found from the reports of lumbar discomfort ($p = 0.5$). However, there were fewer reports of lumbar discomfort on the traditional profile when it was tilted slightly backwards than forwards, whereas on the modified profile there were fewer lumbar complaints when it was tilted forwards ($p = 0.03$). The traditional chair, when horizontal, was worst of all for the legs.

### 4.3.4 Foot pressure

The body weight percentage that the feet support was only linear for the horizontal component when the modified profile was used, and the vertical component was never linear (See Figure 19). There was a significant difference between the two profiles at all angles ( $p < 0.01$ in all cases), especially at 0°. On the standard profile less weight was transferred to the feet when the ischial support was horizontal, and the relationship between the vertical and horizontal components was similar at all angles. On the modified seat profile, more weight was generally transferred to the feet than on the standard profile. Only when it sloped backwards was a little less weight transferred than on the traditionally shaped seat. When the modified seat sloped forwards, forward thrust was disproportionately increased compared to the standard profile. It comprised about 11% of the body weight.




a) Vertical Foot Pressure b) Horizontal Foot Pressure

**Figure 19** Percent of body weight transferred by the feet to the footplates vertically (a) and horizontally (b) for each seat profile at each seat angle. The horizontal bars indicate the standard error of the mean.

The females supported a significantly ($p < 0.0001$) greater percentage of their body weight with their feet. This was the case with both the horizontal (8% versus 4.9%) and the vertical (24% versus 19.4%) components. There was also a small but significant ($p < 0.0001$) difference in the foot pressure during the two tasks. More force was applied by the feet both horizontally (7.3% versus 5.6%) and vertically (22% versus 2l%) during the VDU task as opposed to the assembly task.

# 4.4 Discussion of the results

## 4.4.1 Sitting postures and positions

The present study shows that task is the most powerful determinant of sitting position. This will be further investigated in the following studies. In this study, the role of the seat shape was also shown to be significant. The results indicate that the modified profile encourages wider use of the various positional possibilities offered by the chair than the traditional profile. The slightly increased frequency of position change on the modified profile also supports the argument that this profile encourages more active seating behaviour. Of course, frequency of position change is difficult to interpret as it may also indicate discomfort. The reporting of discomfort, however, was less frequent for the modified profile than the traditional profile.

The seat slope is also influential in the range of positions adopted. The best distribution of postures seams to be on the seat with a 4° backwards angle. There was a tendency for the torso position to reflect the angle of the chair (backwards on the backwards slope, forwards on the forwards slope). As opposed to seat shape, there were no significant effects found for seat angle in the frequency of position change. The similarity of the postures adopted on the traditionally shaped forward sloping chair and on the modified profile in the horizontal position supports the hypothesis that thigh-trunk angle has a determining effect on sitting behaviour. This supports the assertion by Bridger et al. (1992) and Mandal (1985) that the semi-standing position brings the lumbar lordosis close to the mid-point of its range of motion and therefore poses the least constraint to sitting postures.

The increased frequency of kyphotic postures on the modified profile for VDU work at the forward and horizontal angles is probably due to the table height. The seat height of the subjects was adjusted such that the front edge of the seat profile was at popliteal fossa height. This meant that the modified profile was approximately 1.5 cm higher under the ischial tuberosities than the traditional profile. Table height was adjusted from the footplates so that the table height was lowered relative to the torso as the plate angle altered. The recommended height for keyboard work is possibly too low for this profile. Bendix and his colleagues (1984) generally advocate increased table height for forward sloping chairs. This is supported by this study.

An evaluation of the posture and position data requires a definition of optimal seating behaviour. Unfortunately, no generally accepted definition has yet evolved. As discussed in the introduction to this study, a diversified range of sitting positions and postures is today considered optimal. Generally, kyphotic postures are considered undesirable and a lumbar kyphosis is thought to be optimal (see for example Mandal, 1976; Bridger, 1989). It is supposed that a lordotic seating posture is most like standing: The assumed natural position. The work of Keegan (1953) and Anderson et al. (1979) among others puts this view in question. From their work, it has been shown that some degree of spinal flattening is inevitable in sitting. Adams and Hutton (1985) examined the spinal discs in detail and pointed out that the ability of the discs to withstand pressure is not uniform over their surface (see Chapter 2). The discs are better able to withstand pressure anteriorly than posteriorly. This indicates that the avoidance of mildly kyphotic postures may be unnecessary.

### 4.4.2 Muscular load

In this study, the frequency of kyphotic positions was not directly associated with increased lumbar muscle load as is generally assumed (following Anderson et al., 1979). This may reflect the measurement technique. Static measurements show an association between kyphosis and lumbar muscle load, but under dynamic conditions, other factors might come into play to reduce this load. Bendix et al. (1985) found that lumbar muscle activity was not influenced by seat angle adjustment. They suggested that the iliopsoas might be more important to lumbar posture than the erector spinae. The findings of Bridger et al. (1992) lend support to this explanation.

As previously stated the torso was lifted higher relative to the floor and table for increasing seat angles. The trapezius data probably reflect the resulting mismatch between the seat and the table, which was greater for the modified profile. The neck was most likely more flexed on the forward slope but neck position observations were not included in the study. The readings taken in this study were done over the lower trapezius. The positioning of electrodes on the upper trapezius has been shown to be of great importance (Veiersted, 1991; Mathiassen and Winkel, 1990) so repositioning was avoided.

The task difference in trapezius activity is most likely the result of the increased arm activity for the assembly task. This task required extension of the arms to grasp the components.

### 4.4.3 Comfort

The analysis of the questionnaire answers revealed no general preference for any particular seat angle. Mandal (1991) found maximum comfort on a 15° forward sloping chair with a very high table (92 cm). Bendix et al. (1985) found maximum comfort on a freely tiltable seat but only for one-hour trials, the effect being lost on longer trials. The results of our study indicate that factors other than seat slope and time may interfere in the comfort assessment.

Discomfort even at the 8° forward slope was not very frequently found, nor did the subjects report feeling unstable. There seems therefore no necessity for knee bracing at a forward slope of 8°. Several subjects however complained that the drag on their clothing was uncomfortable at this angle.

### 4.4.4 Foot pressure

The general increase in weight borne on the feet with the modified profile may be accounted for by the differences in shape of the two profiles. The traditional profile, because of the bulging of the front edge behind the knees, may serve to lift the leg more. It may also be due to differences in seating behaviour on the two profiles. The forwards working position was more frequently adopted on the modified seat-base. This position was shown to correlate with increased horizontal foot pressure ($r = 0.23$, $p < 0.001$).

The key to understanding the reduced horizontal foot pressure when the modified profile is tipped backwards, and the increased thrust when it is tipped forwards, possibly also lies in the contouring of the profile. The axis for changing the slope of the profiles is at the rear of the plate. When the modified profile is in the backwards position (as measured under the ischial tuberosities) the anterior portion still slopes 4° forwards and possibly more evenly follows the natural contours of the leg. Whereas, when the rear portion of the seat slopes 8° forwards, the anterior portion slopes approximately 16° forwards, moving towards a semi-standing position.

Horizontal foot pressure is used as an indicator of forward thrust, and therefore it is indicative of the amount of bracing that needs to be done to keep the body from sliding forwards off the seat. This bracing would conceivably be uncomfortable over time due to tiring of the lower leg muscles. However, the reports of discomfort from the questionnaire showed a significantly higher incidence ($p = 0.03$) of reports of discomfort in the lower leg on the standard chair, particularly so when the chair sloped forwards ($p = 0.01$). Weight bracing is therefore not likely to be the cause of the discomfort. It may be due to blood-flow impairment. Bendix and his colleagues (1985) found increased leg swelling in typists on traditionally shaped forward sloping chairs over a working day. This is in agreement with the results of this study. The blood flow in the area behind the knees may be particularly sensitive to pressure.

There was also an increase in discomfort in the upper thighs on the standard profile when the seat sloped backwards. Possibly pressure is more evenly distributed over the thigh area immediately behind the knees on the modified profile, than on the traditional profile which is rounded into a swelling immediately behind the knees. The areas of increased pressure possibly produce the discomfort.

The sex difference can be accounted for by anatomical differences. Females generally have a greater proportion of their body weight in their legs than men. The indication is that females may be more likely to suffer from fatigue and discomfort in their legs, particularly on forward sloping chairs, than their male colleagues. The reports of discomfort were too few in this study to detect any sex difference at particular angles or for particular activities.

The general non-linearity of these seat angle and foot pressure results indicate that bracing and support of the seated human body is more complex than generally assumed, with factors such as seat shape playing an important role. Discomfort is also not directly related to the quantity of foot bracing.

### 4.4.5 Other comments

These results are distinctive in that they were obtained using a measuring technique which takes account of the natural dynamic movement patterns of the sitter as opposed to the usual static methods. All measures, with the exception of the subjective ratings, were made by averaging semi-continuous or continuous readings over a longer period of time, during which the subjects performed a realistic work activity and were free to adopt whatever seated working posture they chose.

It was possible that field trials would produce varying results to those in the laboratory. Three hours on a chair is probably not sufficient time for a person to adapt to a new chair type. Some long-term physiological adaptation and learning effects are to be expected. Seating behaviour is possibly a learned activity (see Chap. 7.) Further studies are therefore indicated to investigate these issues.

## 4.5 Conclusions of the laboratory studies

The results of this study confirm the hypothesis that both seat shape and slope affect the quality of seated postures in that differences were found between the frequency of the various body positions on the different seats and at different angels. However, neither seat shape nor seat slope were found to have a significant effect on the frequency of position change. Seat shape affects comfort whereas seat slope was not found to have any significant effect.

The results indicate that the modified seat profile compares favourably to the traditional shape for assembly work and probably VDU work. A comparison between the modified profile at 0° and the traditional profile angled 8° forward shows the modified profile to produce more acceptable results on almost all measures. At these angles, no significant difference was found between the sitting posture adopted on the conventional forward sloping profile and that on the horizontal modified profile. The modified profile tended, however, to increase the frequency of position change and increase the range of sitting positions used. The comparison is particularly interesting in that the thigh-torso angle is similar when the profiles are in these positions. Neck and leg discomfort occurred more frequently with the 8° forward slope on both profiles, indicating that this degree of forward slope may be undesirable.

The results indicate that it is possible to increase the average thigh-pelvis angle by an alternative means to sloping the whole seat forwards. The seat shape modification tested produced a decrease in spinal kyphosis in the forward and middle working positions. It is particularly desirable for assembly work which principally restricts the workers to the forwards working posture. The disadvantage of leg discomfort found when the seat slopes forwards is decreased by the proposed alteration in seat shape. Generally, the results for the assembly task are also applicable to the VDU task, however kyphotic postures were more frequent on the modified profile for the VDU task. The subjects slumped more often backwards into the chair for the VDU task. This coat-hanger position transfers more weight onto the backrest, which could also in part account for the decreased forward thrust on the modified profile.

# 5 Active seating and spinal load

In theory, seated movements provide relief for the spinal tissues, but they may not substantially affect spinal load at all. The spinal load resulting from the use of chairs with a freely moveable backrest and seat angle facility (synchronized mechanism chairs), spinal load when using fixed non-movable chairs and when regularly standing for short periods were compared using stadiometry. Chairs which fix the posture did not produce more load than chairs which encourage movement. Additionally, comfort and discomfort were not found to be directly related to spinal load. Comfort ratings, however, are increased by movement possibilities.

## 5.1 Introduction

### 5.1.1 The synchronized mechanism and freely tiltable chairs

Chair manufacturers have not been slow in taking up the idea of the benefits of increasing seated movement. The concept has been supported by a number of well-accepted authors (Grandjean, 1988; Pheasant, 1986; Schoberth, 1989) and is widely propagated by sports teachers and physiotherapists. In order to facilitate postural change, chairs have been developed and marketed with various mechanisms which allow the backrest to move forwards and backwards following the upper body movements and the seat angle to be easily changed. On some modern chairs, the backrest angle is coupled with the angle of the seat-pan angle such that movements of the backrest result in movements of the seat-pan angle in approximately a 2:1 ratio in the same direction. The resistance to movement is determined by means of a spring which can be adjusted in tension by the user. In this way, differences in body weight and height may be accommodated. This mechanism has generally been termed the “synchronized mechanism” (or abbreviated to synchro-mechanism) by the chair manufacturers, but some manufacturers use the term “dynamic seating” to describe the mechanism as well as the desired result. The present author recommends the use of the term “active seating” to refer to the activity of the sitter rather than dynamic seating because of this confusion between chair type and seated activity. The term also emphasises that the sitter must make some action. He or she will not have active seating if they are completely passive. Figure 20 shows an example of the movement of synchronized mechanism chairs.

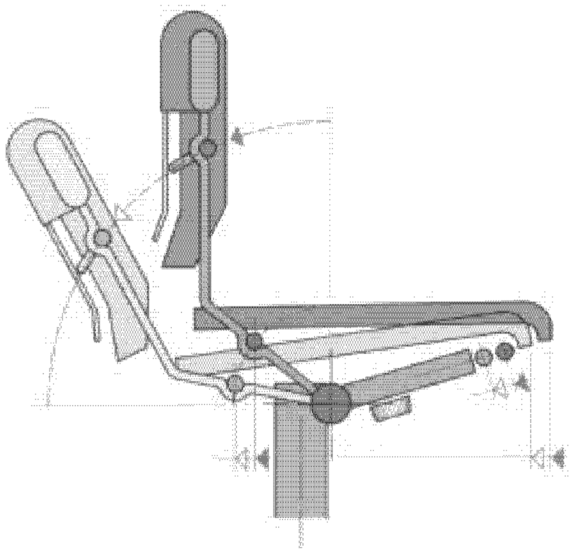


**Figure 20** Examples of an office chair which demonstrates the synchronized mechanism. The backrest and seat are linked together and can be either fixed at a desired angle or left to follow the movements of the body. These chairs are all advertised as top of the range ergonomic chairs by their manufacturers. They were designed with a view to encouraging movement, which is advertised as being beneficial to the spine, and therefore improving comfort.

This type of chair has proved very popular on the market and many large companies in Switzerland offer them as the standard type of chair for their office workers. The effectiveness of such chairs depends not only on the validity of the underlying hypothesis (that movement is beneficial to the spine) but also on whether the postural change possibilities offered are in fact utilised by the users. As has been found in the previous studies, seated posture depends on the task that is being performed. There may be further factors which affect usage, such as personality, training, health and fitness. It is the effectiveness of this synchronized mechanism in terms of reducing seated static spinal load, and possibly therefore optimising disc health, which lies at the core of this study.

A different approach stemming, from a similar desire to increase levels of activity, and which is generally preferred by ergonomics practitioners in industry, is to supply benches where workers can stand to work for short periods during the day. Provision has been made for sit-stand workplaces in several large companies and government departments in Switzerland in recent years. Standing results in a much greater degree of spinal curve change, as has been described above. Mixing standing periods with sitting periods may, therefore, be physiologically better than continuous sitting. Standing, on the other hand, requires more energy than sitting and has various other disadvantages when undertaken long-term, for example, strain of the circulation and the legs. The effect of short regular periods of standing on height change and subjective feelings was also addressed in this study.

### 5.1.2 Previous stadiometric studies on sitting

The effect of sitting has been previously studied using stadiometry. A comprehensive review of these studies is contained in Annex B. Various authors have studied the effect of seat angle on spinal shrinkage (Ericson and Goldie, 1989; Anderson and Helander, 1990; Althoff et al., 1992; Michel and Helander, 1994). Most have found significant differences between various seat slopes on spinal shrinkage in laboratory studies but some were not able to show any effect.

Helander and Quance (1990) compared different sitting and walking about schedules. The chair types were standardised and not tiltable. Significant differences were found between the conditions for the total amount of shrinkage during sitting but not during walking about. The authors suggested that walking about might have a different effect on shrinkage than standing, in that it may facilitate disc expansion. The significant factor to account for the lack of significant differences in the studies on seat slopes might, therefore, have been the amount of movement and postural change which was allowed. The cited experiments were generally performed while subjects remained seated in a specific posture.

In reality, seating generally involves a lot of postural change. The amount of activity that takes place is only partly determined by the design of the chair. It is possible for various postures to be adopted even on the simplest of chairs. For example, even on a stool without a backrest a sitter can change the angle of the pelvis such that the curvature of the spine changes. On a modern office chair, with the possibility of changing the backrest angle, a greater number of comfortable sitting positions are possible. Magnusson and Pope (1996) proposed that hyperextension, a common postural adjustment which temporarily shifts loads from the disc to the facet joints, may provide a means by which disc hydration can temporarily increase. Bendix et al. (1988) compared the effects of sitting on the forward sloping Balans chairs with sitting on chairs with variable seat angles (tiltable chairs) and found no differences, however, they also found that the subjects did not use the tilt possibilities that the chair offered during the experimental period. The amount of actual postural change which takes place while seated depends largely on the task (see Chapter 8.).

### 5.1.3 Spinal load and comfort

A detailed description of pain mechanisms, the relationship of pain to discomfort and the distinction between comfort and discomfort is contained in Chapter 2. Helander and Zhang (1997) argue that comfort and discomfort are not a continuum and should be rated separately. The results of the previous studies in this work support this view. Their method was chosen for this study.

Because the intervertebral discs are not innervated, discomfort is a poor measure of disc health. Nevertheless, if high discomfort ratings are found to be associated with a particularly high spinal load this may be used as corroborative evidence that the load is excessive. On the other hand, muscular effort is often deemed uncomfortable despite the fact that some degree of regular muscular effort is necessary to ensure the fitness of muscles.

Comfort scales are frequently used in ergonomic studies. Comfort is known to be an important factor in the acceptance of health measures and furniture. It therefore seems prudent to include comfort ratings in studies of spinal load and seating. Knowledge of the effects of different seated activity regimes on subjective ratings of seated comfort are important if these activity regimes are later to be encouraged in the workplace.

### 5.1.4 Comfort on tiltable chairs

The comfort/discomfort aspects of tiltable chairs have been investigated by previous authors. Tiltable chairs do not necessarily have a linked backrest and seat such as on the synchronized mechanism chairs, so the results may not apply to the newer systems. Hünting and Grandjean (1976) tested prototype freely tiltable seats, with the seats connected to the backrest, but without a synchronized mechanism, in genuine workplaces and found that the freely tiltable seats were judged more uncomfortable than fixed chairs. They proposed the development of tiltable seats which could be fixed in any position of their range. This is nowadays generally the case. Jensen and Bendix (1992) compared comfort and the amount of movement on tiltable chairs compared to fixed chairs with 5° forward and 5° backward sloping seats. They found no differences between the groups in terms of either comfort or the amount of movement. On the other hand, Lamarche et al (1993) compared freely tiltable seats with fixed seats in two school classes and found that both comfort and the frequency of movements were increased on the tiltable chairs. The subjective reactions may therefore be age dependant.

The comfort/discomfort aspects of regular periods of standing have not received much scientific attention however informal observations and discussions indicate that workers do prefer to stand and walk about from time to time rather than remain seated for their whole working period, if they have the option.

## 5.2 The research hypothesis

The experimental hypothesis is based on the results of previous research from which it is concluded that height change is dependant on spinal loading. It therefore follows that if different activity regimes have an effect on spinal loading then measurable changes in shrinkage will be found, provided of course that these changes are large enough to be detected by the measuring system. It has been shown, as described in the Discussion below, that static seating postures affect shrinkage and spinal loading. If the changes of body posture which are facilitated by the freely moving synchronized mechanism chairs reduce spinal loading then a reduction in the amount of shrinkage will be found compared to static sitting with an upright backrest.

It was hypothesised that continual sitting, with a fixed upright backrest, would result in the most spinal shrinkage over the experimental period. If spinal load is reduced by movement, then the freely tiltable chair and possibly the sit-stand regime will result in less shrinkage than the fixed upright backrest position. The sit-stand regime was expected to produce a similar amount of spinal shrinkage to the freely moving condition. The degree of postural change is greater, but this may be offset by the increased loading during standing. An alternative outcome would be that the freely tilting backrest results in less shrinkage than the sit-stand regime. This would indicate that the load from standing is not compensated during the seated period and that the current trend to sit-stand workplaces should be re-evaluated.

It was further hypothesised that sitting on the fixed upright chairs would be found to produce the most discomfort, due to the static muscle load involved in maintaining an upright posture.

## 5.3 Method

The experiments were conducted in a real workplace with the subjects performing their normal work. Because the aim of the experiment was to test whether the synchronized mechanism has an effect on spinal shrinkage, it was felt that a real workplace would better reflect the genuine usage of the mechanism. Real workplaces have the disadvantage that it is not possible to control the activities that the subjects perform with as much precision as in a laboratory study. On the other hand, they are less likely to be biased by the preconceptions of the experimenter.

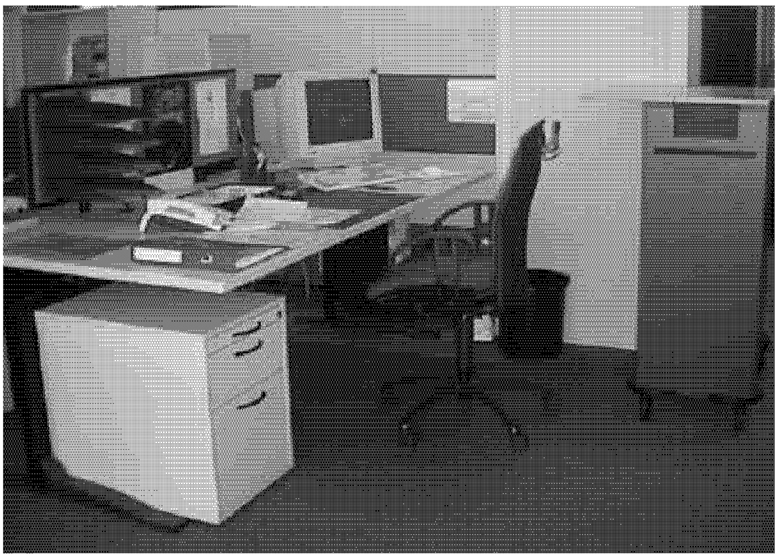


**Figure 21** An example of the workstations at which the subjects worked during the experiment.

A typical workstation where the subjects worked during the experimental period is shown in Figure 21. The tables and chairs were identical for each subject. The height of the tables is adjustable. The seat height, backrest height and armrest position are adjustable on the chair. The synchronized mechanism of the chair, which controls the seat and backrest angle, is operated using a lever on the left side under the seat edge. The mechanism can be either set to freely follow the movements of the body or fixed in any position within its range. The resistance of the mechanism to movement can be adjusted by a knob situated under the front edge of the chair. This adjustment permits persons of different body sizes to feel supported but free to move.

The chairs, which are shown schematically in Figure 22, had moulded seats and backrests covered with firm upholstery. The Figure also contains detailed information about the range of the backrest and seat angle adjustments.

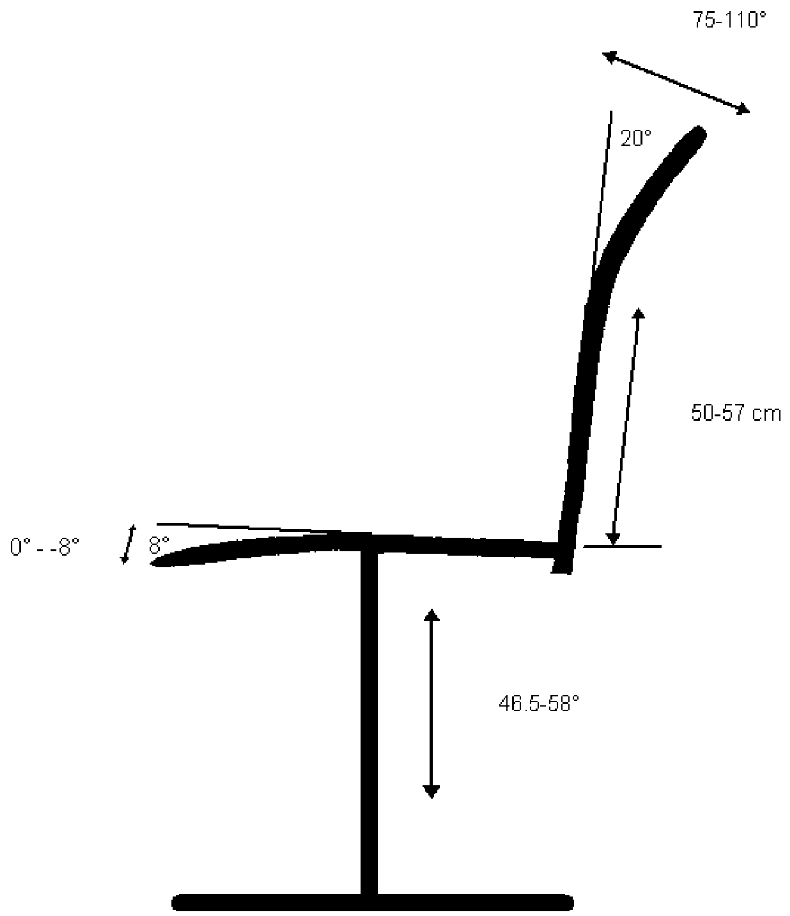



**Figure 22** The chair form and the adjustment ranges of the backrest and seat angle of the chairs used during the sitting periods of the experiment.

### 5.3.1 Experimental variables

The dependent variables for the experiment were:

- shrinkage as determined by displacement of a marker positioned at the base of the subjects' neck relative to the starting height and measured using a stadiometer and,
- the subjects' evaluations of their feelings of comfort and discomfort measured using a questionnaire.

Both of these will be explained in detail later in the Methods section.

The independent variable was seated activity regime. There were three conditions for this variable;

1. **Fixed backrest.** The subject remained seated on his or her own chair at their own workplace for two hours between the measurements. During this time they were free to do whatever work they desired but they were requested not to get up out of the seat. The chair remained fixed in position with the backrest at an angle of approximately 95° to the horizontal. Initially it had been planned to use a 90° backrest angle but the initial subjects objected on the grounds that this was too uncomfortable.
2. **Freely moving backrest.** The subject remained seated, as in level A, but the backrest and seat were left to freely follow the movements of the subject, in so far as the range of movement allowed. The resistance of the synchronized mechanism was adjusted to suit the comfort of the subject. Generally heavier subjects preferred more resistance than lighter subjects. The subjects were told that it should be adjusted such that they can comfortably balance in any position of the range without having the feeling of actively holding the position against a counterforce. The subjects were asked to use the movement possibilities offered by the chair as much as was possible, but no so much that it interfered with their work.
3. **Mixed sitting and standing.** The chairs were adjusted as in level A with the backrest at approximately 95° and fixed in position. The subjects were requested to keep the chair locked in this position during the experimental period. They were then requested to sit for 25 minutes then stand up for 5 minutes in cycles for the two hours of the trial. During the 5 minutes standing, they could continue to work using their high bench or could walk about, not using any stairs. After the fourth sitting period, they should report to the measuring station directly instead of walking about. To facilitate compliance the subjects were given a small kitchen timer which they could set to remind them when to change activity.

Each subject was tested once under each condition. The order of these three conditions was randomised across the subjects such that any order effects would be eliminated. The study was therefore a simple 1 x 3 repeated measures design.

### 5.3.2 Equipment - the stadiometer

The stadiometer used in the experiment is shown in Figure 23. It is the same stadiometer which was used for the experiments conducted by Althoff et al (1992) and is a modification of the original design described by Eklund (1986). See Discussion below.

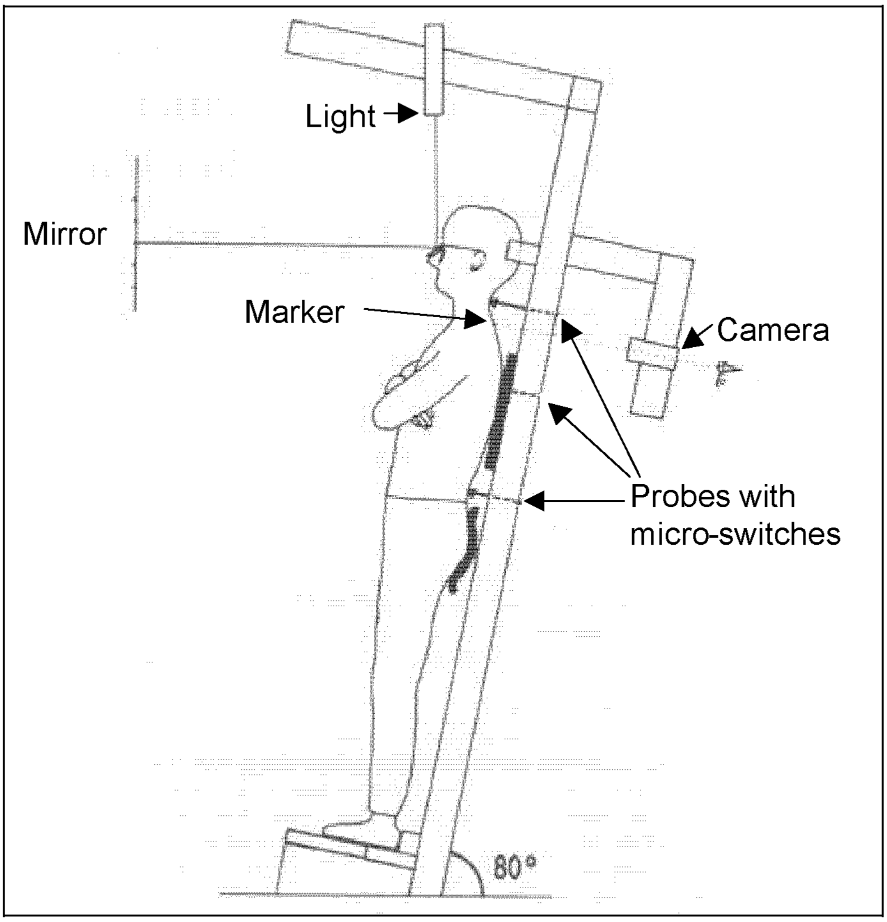



**Figure 23** The stadiometer used in the experiment (Althoff et al, 1992).

The stadiometer stands on a heavy base plate made of wood and metal. It consists of an aluminium frame which slopes 10° backwards. A 10° angled footplate sits at the base of the aluminium frame onto which the subjects stand. According to Eklund, the subjects are better able to relax their muscles in this position and the compressive load on the spine is not substantially altered from that of the standing position. Additionally it serves to help stabilise the body making it easier for the subjects to reproduce their posture and hold it for the duration of the measurement. According to Althoff et al. (1992), leaning backwards unloads the spine in proportion to the sine of the angle of inclination.

On this stadiometer, unloading of the feet amounts to 1.5% of body weight and the unloading of the spine would be even lower. A systematic error from this source is therefore unlikely.

The side supports for the hips are not shown in the diagram. The hips are stabilised by two side supports, which are adjustable for width apart and height, and by the contoured buttock support, which is height and angle adjustable. Individual adjustments of these supports assist in controlling pelvic tilt. In the standing posture, pelvic tilt doesn't play a substantial role in body height, as it is always associated with a change in lumbar lordosis. When the pelvis is tipped forwards the sacrum rises but the lordosis increases. The combined effects cancel each other. Errors from this source should therefore be small. The shoulders rest against two parallel metal plates but no lateral shoulder support is offered.

The head is supported by a height adjustable V-shaped frame into which the head rests. The position of the head is further controlled by reflecting a laser beam onto a mirror mounted over the subject's nose onto a spectacles frame. The subjects have to position the reflected beam onto a line drawn on the wall in front of them. According to Althoff (1992), the head position can be controlled to within approximately 1° in this way. The glasses and mirror can be seen in Figure 24.

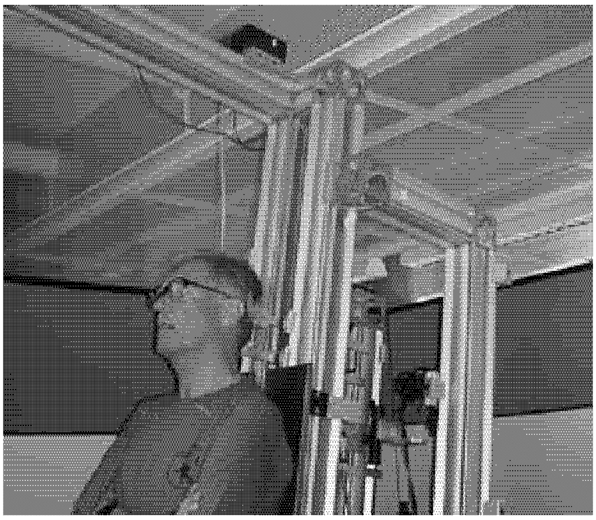


**Figure 24** A subject prepared for a measurement. He is wearing the glasses with the mirror attached over the nose.

Back posture is controlled using three height adjustable probes, which are positioned between the back plates at the level of the lumbar curve, the thoracic curve and the cervical curve at the apex of the respective arches. Two micro-switches with a relative displacement of 0.5 mm are at the end of each probe, where they make contact with the back contour. During the initial adjustments, with the subject standing comfortably within the frame and with the head positioned as described above, the probes are positioned against the back contours. The micro-switches are attached to a light box which is on view to the subjects. When the subject makes contact with the first switch a light is activated. If further pressure is applied, the second switch will be activated and a second light will illuminate. The position of the switches is monitored by the measuring computer. Using the feedback from the lights, the subjects are able to reproduce the contour of their spine to within 0.5 mm. To be able to do this, the subjects need a practice period, during which they step out of the frame then reposition themselves. Stepping out of the frame between recordings is necessary to avoid systematic errors.

The vertical position of all of the supports and the probes can be recorded using a ruler which is attached to the frame on which they are mounted. This ruler is accurate to 0.5 mm. Reproduction of the horizontal position of the probes on which the switches are mounted is achieved by marking onto their shaft the position where they cross the frame support. The markings were numbered for each subject to avoid confusion.

Visible behind the subject is a camera which is used for the measurements. The camera is mounted onto an adjustable base plate. The position of this base plate is monitored by a linear transducer which feeds the plate position into a computer. The computer is programmed such that a measurement of the transducer position can only be made if all the first row of micro-switches are activated but none of the second. That is, the reading would only record if the back contour is precisely reproduced. The cross-hairs in the viewfinder of the camera, a single-lens reflex model, are used to locate a marker, as described below, on the subject's neck. It is the position of the base plate on which the camera is mounted which comprises the height measurement. Shrinkage is measured relatively to the first reading.

### 5.3.3 Subjects

The subjects were recruited from within a large engineering company, which had recently established new offices, and where an active occupational health department had been involved in the purchase and set-up of the office workplaces. The company was initially approached with a request for approximately 20 subjects, preferably of both sexes, who had no previous history of back disorders and who would be willing to partake in the experiment for three consecutive days at the same time each morning. It was further explained that the subjects needed to be engaged in office-type work and that they would not be free to move around at work during the experimental period. The company advertised internally for volunteers by placing notices about the experimental project on various notice boards within a large building where several hundred office workplaces had been set up.

An information leaflet was prepared for the persons who expressed an interest in the experiment. This leaflet explained the purpose of the experiment briefly and elaborated on the experimental design, further emphasising the need for strict control of activities within the two-hour experimental period, for constancy of the experimental time each day and activity prior to beginning work. The leaflet (in German) is attached in Annex D. The last page contains an agreement to the conditions and this was signed by each subject prior to the first experiment.

Seventeen subjects were recruited in this manner, 14 male engineers and 3 female administrative workers. All worked at identical workplaces doing mixed office activities such as writing, telephoning, VDU work and filing. A further campaign to recruit more females proved unsuccessful, presumably because it was more difficult for the secretarial staff (the majority of women in the company) to meet the conditions which were necessary, namely not to leave the workplace during the experimental period. Further details on the subjects used in the experiments are contained in Annex D.

During the experiment, the subjects wore their normal work clothes. Originally they were asked to wear a T-shirt but most objected to this on the grounds that it made a poor impression on uninitiated others. The women chose to wear closely fitted cotton tops over their brassieres whereas the men wore a shirt over a singlet. Particularly with the men, it was important that the experimenter checked that no folds were underneath the micro-switches as these were found to disturb the reproduction of the posture.

### 5.3.4 Measuring technique

The stadiometric measurement method used in the study is based on the procedure described by Corlett and Eklund (1986). The subject stands within the frame of the stadiometer during the measurements, leaning on the adjustable supports which are positioned to follow the contours of the body such that posture is reproduced as accurately as possible for each measurement. The subjects are trained in obtaining a consistent posture prior to the experiment. Changes in stature are measured relative to the first measure and not absolutely. At least three readings are taken for each measurement and the measurement is the average of the readings. Varying from the original method, there was no control of the weight distribution on the feet. The contribution to the variance by changes in weight distribution does not seen to be significant and later authors have discarded it without increasing the variance of their measures (Althoff et al, 1990).

At the first visit an indelible mark was made on a piece of non-allergenic sticking plaster one finger width above the vertebra prominens on the cervical spine (C7) of the subjects. Experiments undertaken by Althoff et al (1992) indicated that this position was easily located and least affected by changes in cervical lordosis. The subjects were told that the plaster was very important and that it should remain in place until the end of the experimental series. The position of the plaster was below the top of the collar and, as the experiments were conducted in winter, was not generally visible to others or likely to be washed off by swimming activities. It was explained to the subjects that they should not be too enthusiastic about washing the back of their necks for the duration of the series, so as not to dislodge the plaster. Nevertheless, because several of the subjects were not able to participate in the experiment on three consecutive days, the plaster on these subjects was replaced, making a comparison of the starting position on separate days impossible for these subjects. The issue of the reliability of the starting measure will be discussed further in the Discussion section. The camera position needed to be altered in several cases between trials, which had the same result.

The supports were adjusted before the first trial to approximately correspond to the body proportions of the subjects. The subjects removed their shoes then they stood on the footplate of the measurement apparatus with their feet facing to the front and with their heels against the fixed surface at the rear. With their knees locked straight against the knee-support and their hands either clasped together at the front or folded across their chest they were requested to roll onto the other supports. The subjects were asked in advance which arm position was most relaxing for them, and they were then instructed to consistently use that position for the following measures. Next, they were asked to inhale and exhale a few times and get themselves relaxed. The supports were then adjusted such that they fitted comfortably against the body contours and their positions were noted. The lights attached to the contact micro-switches were then switched to their reactive mode and the subjects were shown how their posture determines whether the lights on the apparatus are activated. It was explained to the subjects that the measurements could only be made if the first row was activated but not the second. They could therefore practice altering their posture slightly until they could get the necessary sequence of lights. Once the subjects were able to do this, the measurement-training period could proceed. During this phase, the subjects were practised in reproducing their posture reliably and quickly. To finish this practise period they had to be able to reproduce three measurements to within 0.1 mm. This preparatory period took a maximum of 20 minutes including the practice trials. It was found that the subjects learnt the procedure very quickly and no subject required more than 10 practices to fulfil the requirements. Most needed no more than 5.

For the remainder of the experimental series the subjects were measured as soon as they arrived at the location of the stadiometer. The position of the supports and probes was adjusted, prior to the subject's arrival, according to the positions recorded during the initial training period. The subjects would remove their shoes, step onto the apparatus, take a breath, and role onto the probes and supports. They checked that the laser lamp was reflecting onto the marker on the wall. They then made any fine adjustments of their posture that were necessary to get the signal lights into the correct constellation then they announced themselves ready. The experimenter would then line up the marker on the subjects' neck with the hairline of the camera viewfinder, check the lights and laser beam, then take a measure. Up to this stage, both the experimenter and the subject were blind to the actual readout of the measurement apparatus. Initially three readings were taken with the subject stepping off the stadiometer and repositioning him- or her-self between each. The actual measurement for the trial was the mean of these three readings.

After the first week of the experiments, a difficulty was detected. The variability of the three readings was greater than expected. Afterwards four readings were taken and the subjects were left to rest in the stadiometer for approximately 1 minute before the first reading was taken. The reason for this was that, although it had been assumed that any influence of footpad swelling would have subsided during the walk to the stadiometer, it was noted that there was a tendency for the recordings to decrease during the brief measurement period. If the measurement was delayed for a minute or so after the subject stood in the stadiometer, the recordings were much less variable.

Height change was evaluated by determining the difference between the mean of the readings taken at the beginning of the workday with the mean of the readings taken at the end of the 2-hour experimental trial.

### 5.3.5 Subjective evaluations

A questionnaire (see Annex D) was designed which integrated elements of the Nordic Questionnaire (Kuorinka et al, 1987) and German translations of most of the questions used by Helander and Zhang (1997). The questionnaire was given to the subjects at the end of each activity trial, that is, at the completion of the 2-hour sitting activity regime after the final measurement for the day. On the questionnaire, the subjects were requested to judge the level of comfort or discomfort of the activity program which they had just completed. They had to mark the score which best reflected their feeling or impression on a 9-point scale with 1 corresponding to “not at all” and 9 corresponding to “extremely”. As it is not possible to perfectly convey the meaning of particular phrases from one language to another, it is possible that some changes were made on the meaning of the questions posed by Helander and Zhang. The questions translated into English are shown in Table 2.

The first five questions relate to levels of discomfort whereas the last four relate to comfort factors. The order of the questions follows that developed by Helander and Zhang but one of their questions was excluded as it was designed for comfort comparisons of different types of chairs and was therefore inappropriate for this study.

**Table 2** The questions that were used to evaluate the subjective responses to the activity regimes.

| Discomfort questions | Comfort questions |
|---|---|
| I had muscle pain | I was relaxed |
| I had heavy legs | I felt refreshed |
| I felt cramped | I felt good |
| I felt unsettled | I was comfortable |

I felt tired

The subjects were then asked to look at a drawing of a figure where different body regions are marked. The figure corresponds to the figure used in the general Nordic Questionnaire. The subjects should consider whether they had any discomfort during the trial period and, if so, to make a mark on the diagram next to the name of the appropriate area. If they had discomfort on the front side of their body, they should likewise mark by the appropriate body part name.

### 5.3.6 Procedure

The subjects had to attend on three separate days, one for each experimental condition. Because the company had a flexi-time arrangement for working hours, each subject was able to choose when they wished to start work. The subjects therefore elected when they preferred to attend the experiments, with the provision that it had to be the same on each day. They were requested to report to the measuring station before they commenced work on the experimental days for the first measurement to be taken. In order to standardise as much as possible the beginning measurements each day, the subjects were asked to keep to a strict routine on the mornings before work, that is, to get up at the same time, do the same things, come to work the same way, etc. Because of the variable starting times it was possible to schedule up to three subjects on any particular day, provided that they started work no closer together than half an hour. The experiments were scheduled for subjects to start between 7 am and 8.30 am. The second measurement was taken 2 hours after the first, irrespective of starting time. The stadiometer was calibrated prior to the arrival of the first subject each day.

At the beginning of the first day, the subjects were asked whether they had read the description of the study and understood everything. The important aspects were repeated and a consent form was signed. The stadiometer was then set up as described above and the settings recorded. Once the preliminary trials were complete, the subject went immediately to their workstation and the experimental trial began in accordance with the randomised activity plan. The subjects returned to the measuring station, avoiding the use of the stairs, directly after the 2-hour activity program was complete and a second measurement was made. The subjects then completed the questionnaire on their subjective feelings during the trial and any questions were answered. On subsequent days the first measurement was made as soon as the subject arrived for work, otherwise the same procedure was followed.

On the second day, after the experimental trial, measurements were taken of the subjects' right wrist, elbow, ankle and knee diameter using an anthropometer. These measurements were taken according to the method described by Colombini et al (1989). The purpose of this was to be able to make an estimate of the disc area of each subject for later comparison with the rates of shrinkage. The subjects' age, height and weight were also recorded at this stage. Colombini et al's formula for estimating bony structure weight (SW) is shown in Equation 1.

$$SW(g) = ((a + b + c + d)/4)2 \times h \times 1.1 \qquad \text{(Equation 1)}$$

where a, b, c and d are the diameters of the wrist, elbow, ankle and knee and h is height.

Once SW is obtained the disc area at the levels L4-L5, L3-L4 and L5-S1 can be calculated according to regression formula. For example, the equation for disc area the level L3-L4 was found to be:

$$L3\text{-}L4\ (cm2) = 0.95 + 0.002 \times SW(g) \qquad \text{(Equation 2)}$$

There was some variability in the time that it took the subjects to get from their workplace to the experimental station and the distance that they had to cover. The workplaces were between approximately 10 and 100 meters from the stadiometer and some subjects had to change floor. These were requested to use the lifts rather than the stairs. The maximum time between standing up and reaching the stadiometer was approximately 2 minutes. This introduces an unavoidable but systematic bias in the results. Althoff et al (1992) calculated that the absolute values of stature change would be approximately 5% larger than the measured values under similar conditions and concluded that this source of error is small in relation to the overall error. Each subject was told about the results of their individual measurements at the end of their third experimental day.

### 5.3.7 Data evaluation and tests

The raw data were collated, group means were obtained and the shrinkage per square centimetre of the discs was calculated. Weighting of the results according to the variability of the measure, more fully described in the Results section, was also done. To investigate the distribution of the data, to perform the inferential statistical tests of variance between the groups and the correlations between the results the program Statview® was used.

## 5.4 Results

### 5.4.1 Height changes

Initially the raw data obtained from the stadiometer was analysed. The height changes did not follow a normal distribution in any of the activity conditions, as can be seen from the frequency histograms in Figure 25. The closest approximation to a normal distribution was in the activity regime with the fixed upright backrest. In all conditions, some subjects shrank while others grew. In both the condition with the freely moving backrest and the mixed sitting and standing condition there appears to be a bipolar distribution.

An analysis of the variance was conducted using the Kruskal-Wallis procedure. This is a non-parametric statistical procedure used when data are not normally distributed, as in this case. No significant differences were found in the amount of shrinkage between the three activity regimes (p = 0.30). The means table from the Kruskal-Wallis test are shown in Table 3.

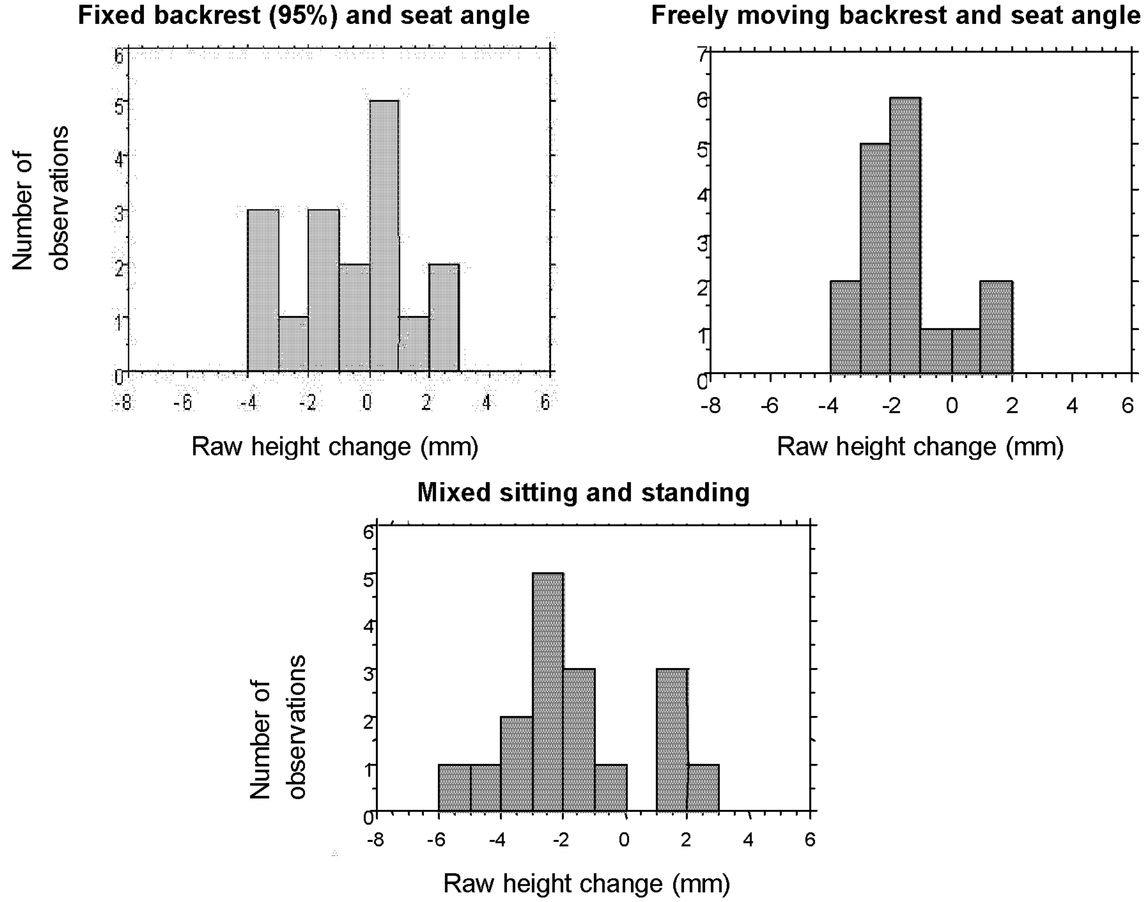



**Figure 25** Frequency histograms showing the distribution of height changes for each activity condition compared with a normal distribution.

**Table 3** The raw height change data for each regime.

| | Fixed | Free | Mixed |
|---|---|---|---|
| Mean | -0.60 | -1.45 | -1.70 |
| Std. Dev | 1.93 | 1.47 | 2.19 |
| Minimum | -3.77 | -3.42 | -5.47 |
| Maximum | 2.20 | 1.28 | 2.07 |

The box plots in Figure 26 illustrate the distribution of the data for each activity regime. From the box plots, it can be seen that the distribution of the data is too widely spread to conclude that any differences exist between the means of the activity regimes. As it is possible that some of the variance in the data is due to confounding factors within the experiment, further analyses were conducted. A Mann-Whitney test of the combined height change data revealed a significant relationship between the raw height change and sex (p = 0.01). The mean height change for the females was -2.58 mm compared to the mean male height change of -0.96 mm indicating that females shrink more. This needs to be interpreted carefully as there were only 3 females in the study, however it is in agreement with other studies. Removing the females from the data set did not change the result of the Kruskal-Wallis test for differences between activity regimes substantially (p value = 0.51). Other factors which may have contributed to the variance in the data were examined.

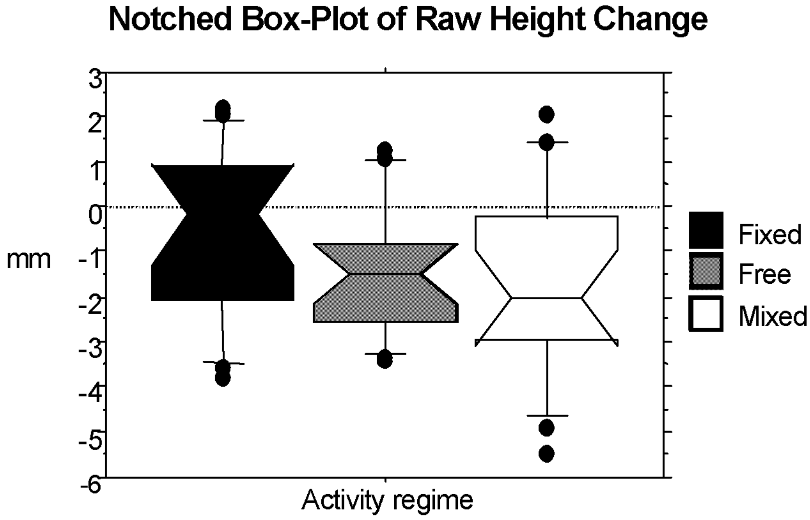



**Figure 26** The means and distribution of each activity regime. [The box plot shows the 10th, 25th, 50th (median) and 90th percentiles of the variables. Values above the 90th and below the 10th percentile are plotted as points. The notching shows the 95% confidence interval around the median.]

The differences may be due to differences between disc areas. It is possible using the formula developed by Colombini et al (1985) to calculate the bony structure weight (SW) for each subject from their wrist, elbow, ankle and knee diameters and heights. According to Colombini et al this relates well to disc area, with a correlation of 0.84 at the level of L3-L4 in the spine. Using the regression formula obtained by Colombini et al the disc areas at the level of L3-L4 were calculated for each subject. The amount of height change was then adjusted to reflect the relative sizes of the subjects' discs. The raw height change was converted into height change per square centimetre. The adjusted height change results for each activity regime can be found in Annex D.

A Kruskal-Wallis test on the adjusted height change data again failed to reveal significant differences between the activity regimes (p = 0.28). The amount of raw height change across all activity regimes, however, was found to be positively correlated to disc area (Spearman's rho = 0.38 with p = 0.007). A positive correlation indicates that shrinkage decreased (height relative to the first measurement was greater) as disc area increased. Correlations for disc area, age, height and weight with the raw and adjusted height change in each of the activity regimes are shown in Table 4.

Age did not correlate, at the level of significance (p =0.05) used in this study, with the raw height change data (p = 0.06), however it correlated weakly but significantly with the adjusted height change data (r = 0.3 and p = 0.03) indicating that shrinkage tends to decrease as age increases. When the data were separated into activity regimes differences were found between the correlations for age. The correlation was strong in the freely moving regime (r = 0.5 and p = 0.045) but non-existent in the fixed backrest (r = 0.02, p = 0.9) and mixed sitting and standing regimes (r = 0.36, p = 0.15).

**Table 4** Correlations (Spearman's rho) of the amount of raw height change and the height change per square centimetre with anthropometric data using combined data from all activity regimes.

| Raw Height Change | r | p |
|---|---|---|
| Disc area L3-L4 | .382 | 0.007 |
| Age | .264 | 0.064 |
| Height | .337 | 0.018 |
| Weight | .294 | 0.038 |
| **Adjusted Height Change** | **r** | **p** |
| Disc area L3-L4 | .456 | .001 |
| Age | .309 | .030 |
| Height | .395 | .006 |
| Weight | .364 | .010 |

When the height change data were divided into two age groups, those under 40 years and those over 40 years, there is still no significant difference between shrinkage under different activity regimes according to the Kruskal-Wallis tests. Only when the subjects over 60 are removed from the data is there a tendency to a significant difference between the groups (p = 0.058). Figure 27 shows the means of the adjusted height change data on the subjects under 60 separated into activity regimes. It can be seen that there is no significant difference between the freely moving backrest regime and the mixed regime, but the fixed backrest regime results in less height loss (less spinal shrinkage).

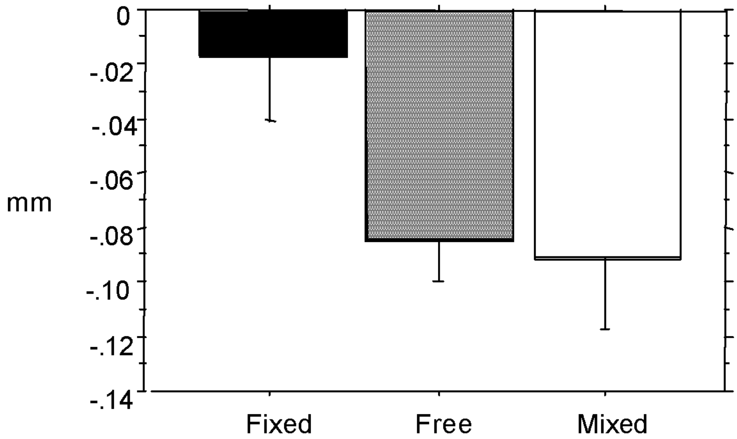



**Figure 27** Height change per $cm^2$ for subjects younger than 60 years shown according to activity regime. Thin lines indicate the standard error of the means.

There was a strong positive and significant correlation between disc area and height change in the mixed sitting and standing regime (r = 0.7, p = 0.005) and the freely moving regime (r = 0.5, p = 0.04) but in the fixed backrest regime the relationship was non-significant (r = 0.07, p = 0.7). The same pattern was found in the relationship of height to shrinkage. Height is a parameter in the calculation of disc area so these results are not independent of each other. Weight correlated significantly with the adjusted height change only in the mixed regime (r = 0.6, p = .02).

These results indicate that disc area, height, weight and age all affect the dependant variable, shrinkage, in combination with the activity regime.

### 5.4.2 Variance weighting

In the above analyses, the variability in the initial measurements has been ignored, as the analyses were undertaken using scores obtained from the means of the 3 or 4 measures taken during each measurement period. The standard deviations within each measurement period can be found in Annex D. The mean standard deviation was 0.52 mm but in some cases, it was much larger, with the largest being 2.49 mm.

The standard deviations from the original measurements can be used to weight the data obtained according to the procedure described by Bevington (1969). This procedure takes into account the fact that some data points have been measured with more precision than others. Each data point is weighted inversely by its own variance. The method permits some control of instrumental variance during the measurements. Following this procedure, comparisons between the three activity regimes show no statistically significant differences between the regimes either for the raw height change data or the adjusted height change data.

### 5.4.3 Subjective evaluations

For each subject a mean was obtained of the scores for the questions relating to comfort and those relating to discomfort. Notched box plots of the subjective responses under each condition are shown in Figures 28. The results for each subject can be found in Annex D. From the box plots, it appears that the fixed backrest regime differs more from the other two activity regimes than they differ from each other. The apparent tendency is for discomfort to be rated higher with the fixed backrest regime and comfort to be lower. This is a similar pattern to the tendency observed in the height change data, where the fixed backrest regime also appeared to differ from the other two regimes but the difference generally did not reach statistical significance. The distributions of the subjective data also do not appear to be normal and contain substantial variation. A Kruskal-Wallis test of the variance between activity regimes failed to reveal significant differences between the groups for either the discomfort ratings ($p = 0.19$) or the comfort ratings ($p = 0.34$). Individual variability is substantial in all cases.

A summary of the body areas marked on the questionnaire as being uncomfortable is to be found in Annex D, however only 4 subjects indicated an area of discomfort on the diagram. Three of these subjects reported pain in multiple areas. Most complaints related to neck discomfort, followed by shoulder and upper back discomfort. Neck discomfort was always paired to another area, mostly upper back or shoulder discomfort. Two persons reported neck discomfort under all three conditions and two subjects reported shoulder discomfort under the fixed backrest condition and the mixed sitting and standing condition but not under the freely moving condition. Because of the scarcity of responses to this question, further analysis was not conducted.

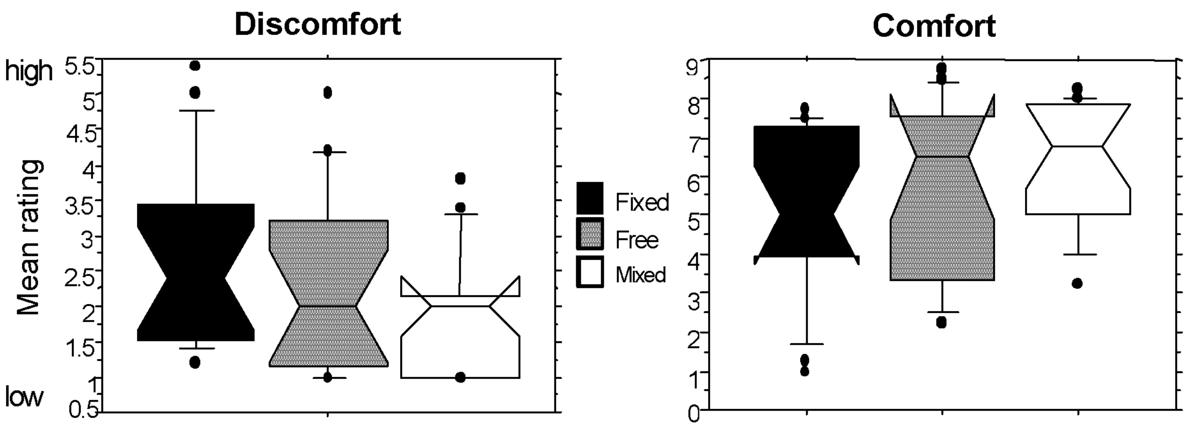



**Figure 28** The distribution of discomfort and comfort ratings under each condition. [The box plots show the $10^{th}$, $25^{th}$, $50^{th}$ (median) and $90^{th}$ percentiles of the variables. Values above the $90^{th}$ and below the $10^{th}$ percentile are plotted as points. The notching shows the 95% confidence interval around the median.]

The relationship between the subjective factors and height change was investigated by testing for correlations between these factors but in all cases, no correlation was found. The correlation matrix is shown in Table 5.

**Table 5** Correlation matrix showing the relationship between subjective factors and height change.

| | Discomfort | | Comfort | |
|---|---|---|---|---|
| | r value | p value | r value | p value |
| Raw height change | -0.11 | 0.46 | -0.04 | 0.79 |
| Adjusted height change | -0.11 | 0.44 | -0.04 | 0.77 |

The analyses of the subjective ratings therefore did not reveal any substantial differences between the activity regimes in terms of either comfort or discomfort. Furthermore, there appeared to be no relationship between shrinkage and either comfort or discomfort. There was no meaningful difference found between the results of the comfort ratings and those of the discomfort ratings.

# 5.5 Discussion

## 5.5.1 Critical evaluation of the experimental method

Before conclusions can be made from the results of the study, it is necessary to examine the experimental method for possible sources of error.

## 5.5.2 Methods for determining spinal load

Ideally, the health effects of working conditions are investigated by longitudinal epidemiological research. The results of the studies described in previous chapters indicate that multiple factors are involved in back discomfort at seated work places. Because of the diagnostic complexity and multi-causality of back pain, epidemiological studies are problematic, as many factors have to be included in the studies. Causality is therefore generally inferred from measuring the effects of workload on functional load. Models describing this process need to be multi-factorial (Van Dieen and Toussaint, 1993), and include physical load (strain) as well as other factors, which moderate the effects of the load, resulting in the functional load (stress).

Different methods have been used to measure the functional load on the back. These include direct measurement (e.g. Andersson and Nachemson,1974; LeLong et al, 1992), biomechanical computational methods (e.g. Eklund, 1986) and spinal shrinkage (Althoff et al, 1992). Direct measurement methods and biomechanical models have practical limitations in terms of field applicability, personnel required and equipment. (see Chapter 2 for more details).

The precise measurement of body-height shrinkage was chosen for this study because it may be the most valid. It fulfils the requirements of the model described above in that it measures functional load directly from workload and individual capacities can be compared. The method has been used by numerous authors such as Fitzgerald (1972), Kraemer (1973, 1980), Eklund and Corlett (1984, 1986), Foreman and Troup (1987), Boocock et al (1988), Brisland and McGill (1989), Garbutt et al (1990), Althoff et al (1992), van Dieen and Toussaint (1993), Reilly and Chana (1994), Fowler et al (1994, 1997), Hutchinson et al (1995), Schultz et al (1995) and De Looze et al. (1996).

Kraemer proposed that the height loss took place in the spinal discs as a result of loading and concluded that it resulted from pressure dependant fluid shifts. A detailed description of previous studies and a mathematical model of disc height change (Burns and Kaleps, 1980; Eklund and Corlett,1984) were described in Chapter 2. It is known that height losses from a given spinal load depend on circadian variation as well as the isometric strength of the back muscles (Wilby et al., 1987) and age (De Pukys, 1935; van Dieen et al, 1993).

It is known that height loss is not linear to load (Tyrrell et al, 1985; Köller et al, 1984). The rate of deformation is greater in intermittent (sine wave) loading as compared to equally large continuous loading. This indicates that changing posture does not “pump” fluid into the discs but rather that the discs recover by passive diffusion during periods of decreased load. Conversely, the load on the disc pushes the fluid actively out of the discs. Van Dieen and Toussaint (1993) have suggested that the overall effect may be due to the cumulative effect of subsequent peak loads with insufficient recovery time. They noted that the initial deformation at loading seems to be larger than the initial recovery at unloading so that if a further load was applied before recovery was complete an increased effect may be found. Assuming that some postures and positions load the spinal discs more than others, then this indicates that the time between changes of posture should be sufficient to allow full recovery.

### 5.5.3 The reliability and validity of stadiometric methods

Following a review of the literature on spinal shrinkage as a parameter of spinal load van Dieen and Toussaint (1993) concluded that the method showed promise as a means for providing more insight into the relationship between workloads and their physiological consequences. They concluded that the method appears to be sufficiently sensitive and accurate for comparing different workload situations and that it has some advantages over other methods. It nevertheless has some limitations in terms of reliability and several questions remain open concerning its validity.

A large degree of unexplained inter-individual variation has been found in most studies. The age and sex of the subject play a significant role in this variation. It is therefore necessary to control for these factors. It has been suggested that the inter-individual variation may reflect the discs’ state of degeneration. It would therefore be a useful diagnostic tool (Eklund, 1988), in combination with other information, and could shed light on the differences between the capacities of different workers.

A further source of measurement error arises from the subjects' inexperience in reproducing their posture. This is the most serious potential deficit of the stadiometric technique and various methods have been devised to reduce this source of error. Most of the methods used in the last decade are based on the method developed by Eklund and Corlett (1984). The method used in this study is based on their method and modified by recommendations from Althoff et al (1992), who removed head posture as a source of measurement error by measuring height at a point marked on the neck. Various criteria have been used to train the subjects until they were able to reproduce measurements with sufficient reliability but Van Dieen and Toussaint (1993) report that all authors eventually achieved a reproducibility of error below 1 mm.

Concern has been voiced that inclusion of the lower limbs results in an overestimation of the length changes (Hol et al., 1992) but Foreman and Linge (1989) found that heel compression occurs very quickly (under 2 mins) and Althoff et al (1992) found that the contribution of the lower limbs was comparatively small. This indicates that pressure induced fluid shifts are more marked in the spinal discs than in other structural tissues.

There is also a methodological difficulty when the effects of different postures on spinal loading are investigated. This is particularly relevant in seating studies. With standing stadiometers, the subject has to change posture to be measured, and this postural change results in changes to the pressures on the spine which may affect the measurements. The height change which was measured in the study resulted from the effects of the experimental regime plus the effect of standing up and walking to the stadiometer. This means that the amount of height change measured does not accurately reflect only the change due to the activity program. In order to minimise this source of error the time between the experimental condition and the measurement must be kept as small as possible and should be the same for all subjects. Because of the non-linear nature of the shrinkage and recovery, the greatest effect is evident within the initial period (Ericson and Goldie,1989), however recovery takes longer than shrinkage. The measurement is, nevertheless, always of the residual effect after the period in which the subject leaves the test situation, walks to the stadiometer and positions themselves in it. The findings of Jafry and Haslegrave (1992) indicate that the standing stadiometer systematically underestimates the amount of shrinkage that takes place and results in more variability of the measures compared to seated measurement. Ideally, measurements should be done before the subject gets out of the chair. This was not possible with the apparatus used for this experiement.

Nevertheless, as activities between the experimental regime and the measurement were, for each subject, very similar on each day of the experiment, the variation should be the same on each day and therefore comparisons of the relative height change would not theoretically result in changes to the findings. At present, no methods are available which permit measurement at real workplaces but it is conceivable that a suitable technique could be developed in the future.

Ericson and Goldie (1989) used spinal shrinkage to study the effects of different types of chairs used during 8 hours of real VDU work. In their study, it was not possible to strictly control the amount of loading. The relative measurement difference between groups was used rather than absolute measurements. The method nevertheless proved sensitive enough to detect differences between different sitting conditions.

According to van Dieen and Toussaint (1993), the stadiometric method correlates well with comparisons of subjective ratings of load. As has been mentioned it also fits well with the previously described model which includes loading factors, capacity and health consequences. Anderson and Helander (1990) found that disc pressure and EMGs of the erector spinae were highly correlated with spinal shrinkage. This gives it construct validity, but a quantitative precise relationship between load and stature loss has not yet been conclusively established. More detailed notes on the validity and reliability of the method can be found in Annex B. In spite of the drawbacks, the technique of stadiometry has been shown to be a valuable indicator of the compression forces acting on the spine.

### 5.5.4 The conduct of the experiment

The experiment was designed to keep the known sources of error, such as postural variation during the measurement, to a minimum but as is generally the case with real subjects and workplaces, several unexpected events intervened.

The most important of these was that the starting height of the subjects was not found to be consistent across the three days of the experiment. Because the rate of shrinkage is greatest in the morning, this means that the reference measures, taken at the same time in the morning for each subject, may not have been sufficiently similar for comparisons to be made. For six of the subjects no comparisons between days were possible because of unavoidable alterations to the measurement (the marker on the neck was replaced or the camera mounting had to be repositioned). A comparison of the first measures of the remaining eleven subjects across the experimental days revealed that the differences in starting height were non-significant in only two cases. It would be expected that if the starting heights are different, the rate of shrinkage or height recovery would also be different.

This possibility was considered during the planning stage of the experiment. One method of reducing error from this source is to check the height reading at the beginning of the morning against the previous days first readings. It was felt that this procedure would introduce a source of experimenter bias into the measurements, as there was no reason to believe that any one morning was more representative of the real height at that time of day than any other. Having the measurements taken under double-blind conditions, although increasing the variance of the data, has the advantage that it is less susceptible to bias.

Another method of reducing this source of error into the results is that used by Althoff et al (1992), where the measures are referenced to the expected height loss when standing. From the variation in the starting measures found in this study the Althoff et al method seems superior to trying to standardise activities prior to testing, as has otherwise been done. In planning this study, the time constraints precluded the use of the Althoff et al method, as the study would have extended over an unacceptably long period.

In any experiment using subjects, care must be taken to ensure that the sample is representative of the population that is under investigation or only limited generalisation of the results is possible. The population which this sample were chosen to represent, were general office workers with mixed tasks. In Switzerland today, the physical tasks of most engineers would be similar to those in the study and most office workers would perform similar types of tasks. They work principally on a desktop computer but the work also involves speaking to each other, speaking on the telephone and consulting notes or books. It was felt that the subjects used would perform physically very similar types of tasks to those employed in the banking and insurance sectors as well as in the public service. It could, however, be argued that, because the sample contained predominantly males, the results should not be generalised to female workers. As females respond more to spinal load than males it is possible that significant differences were missed. The fact that some subjects grew while others shrank, in each of the conditions and for both sexes indicates that this is unlikely.

There is a further source of potential subject bias in the fact that all of the subjects were volunteers. This probably means that they represent a sub-group for whom health issues and back disorders are particularly important. They may have preconceived ideas about what is good seating and appropriate activity regimes. It was felt that as the subjects were blind to the measurements it was unlikely that any potential bias arising from their expectations would be minimal, at least on the height change parameter. A bias from this source in the subjective results is possible.

During the study, the activities of the subjects were prescribed by the experimental condition. In reality, it would be rare for the subjects used to remain seated for as long as two hours without standing. This particular provision excluded many of the workers at the site chosen for the study, particularly the administrative and secretarial workers (mostly women) as they were not able to guarantee that they could remain seated at their workplace. From this point of view the types of activities regimes used in the study were somewhat artificial of real workplace conditions.

The high level of education and the subjects' experience with research served to maximise compliance by the subjects with the experimental conditions. They were all very interested in the outcome of the research and understood why the defined procedures needed to be closely followed. Many offered suggestions for further studies or improvements in the apparatus.

On the other hand, there was no control over the subjects' compliance built into the study. Although the subjects understood the importance of sticking to the activity regimes several reported that they had soon forgotten about the experiment once they became immersed in their work and therefore some variability may have been introduced into the experimental activity regimes. For example, there was no guarantee that the subjects used the backrest during the study, although they had been asked to do so as much as possible. The differences between the activity regimes, particularly the fixed and freely moveable backrest regimes, may therefore not have been substantially different. Hünting and Grandjean (1976) noted that the subjects on fixed chairs were in contact with the backrest only 62% of the time. The experiment has the advantage, therefore, that it more closely includes the real pattern of activities which occur in office work on these types of chairs than would a study where activity levels are more closely controlled. Nevertheless, recording the subjects' activity patterns would have been advantageous. It may have been possible to determine whether the lack of significant differences between the two, seated, experimental regimes was due to a lack of real activity difference.

### 5.5.5 The significance of the spinal shrinkage results

The results obtained from this study do not support the hypothesis that the use of freely tiltable chairs, such as those with the synchronized mechanism used in this study, results in decreased loading of the spinal discs. The loading of the discs was not sufficiently different with these chairs to that found with fixed upright chairs. There are several reasons why this result may be the case. It may be that the difference was too small and the variability too great for a difference to be detected by this experimental design and measuring apparatus. On the other hand, there is good reason to conclude that there is no real advantage in terms of spinal load from these types of chairs.

The experimental hypothesis was based on several underlying assumptions. The first assumption was that height change results from spinal loading. From the review of the literature there seems to be adequate evidence that loading does produce spinal shrinkage, at least where higher loads are involved such as when carrying weights. There also seems to be sufficient evidence that decreasing the compressive load on the discs below that incurred by the effects of gravity on the body, such as when lying down, results in height gain up to a point of equilibrium. Studies on astronauts confirm that reduced gravity results in height gain.

The studies which have been done on shrinkage, where seated postural differences were the only loading factor involved, have not produced consistent results. The differences may be due to the amount of movement which was made while seated. Althoff et al (1992) found that sitting resulted in less shrinkage than standing regardless of chair type. Their subjects were not encouraged to change posture during the study. On the other hand, Helander and Quance (1990) found that of the six subjects tested, five shrank while seated but gained height while walking about. Walking may therefore load the spine less than static standing postures and less than sitting, indicating that movement reduces spinal load. In support of this, Van Deursen et. al (2000) used spinal shrinkage to compare static chairs with passive forced motion while seated and found that when sitting on the dynamic chair (forced motion) spinal length increased in comparison to the static chair (without motion). This supports the view that the lack of differences in height change between the chair types in this study is due to lack of sufficient movement while seated. Despite the fact that the chairs allowed more postural change, it is possible that too few changes were actually made. No measures were made of how much movement the subjects made on the chairs. Additionally, the periods of standing may have been too static or too short to produce any substantial recovery.

It is also possible that the amount of load variation produced by common postural variations is not sufficient to have a significant and predictable effect on height loss. Other factors such as disc health, body build and muscular tension may have a much greater influence.

### 5.5.6 Consistency with other results

Ericson and Goldie (1989) found a significant increase in shrinkage on a Balans chair, which had no backrest, compared to on a Old chair, which had a backrest and armrests. They did not control backrest angle and did not mention in their description of the study as to whether the backrest and seat angle were freely moveable or fixed. They concluded that the backrest was the determining factor in this difference. The fixed upright chairs used in the present study may provide more backrest support than is provided by the freely moveable backrests. If this is so then the non-significant trend found in this study would be in agreement with Ericson and Goldie's (1989) conclusion. In the upright position, the synchronized mechanism chairs provide less support than fixed chairs because as soon as a critical pressure level is reached the backrest tips with the body. The backrest resists all of the weight that is transferred onto it only at the end of the tilt range. On the other hand the freely tiltable backrests permit the subjects to tip more of their weight onto the backrest as they lean further backwards, thus the support which they offer is greater than that of fixed upright chairs over most of their tilt range. The support that they offer therefore depends on how they are used. If the subject kept the backrest tilted continually to the end-point of its range then the result should be the same as on a fixed backrest at 118°. This is approximately the same as the easy chair condition in Althoff et al's (1992) study, although the influence on muscular load would be different. If the backrest was not used at all, then the result should correspond to the result that Althoff et al found for unsupported sitting on a stool. Depending, therefore, on how the mechanism was used, it would not be expected, during the two continually seated activity regimes, that height change would be outside the range that Althoff et al obtained in their study for the stool and for the easy chair.

The measurements in Althoff et al's experiments, however, were related to the expected shrinkage if the subject remained standing. They found an increase in height in all of their conditions compared to the expected standing loss. In this study, no comparison was made with expected standing height loss but 8 subjects showed an increase in height during the fixed regime and 3 showed an increase during the freely moveable regime. The maximum height loss found in the fixed condition was -3.8 mm and in the freely moveable condition, it was -3.4 mm. The maximum height gain in the fixed condition was 2.2 mm and in the freely moveable condition 1.3 mm. Althoff et al found a statistically significant difference between the easy chair condition and all of the others but none of the other conditions differed significantly from each other. The results of this study are therefore in accordance with their findings once allowance is made for the way that the differences were calculated.

Michel and Helander (1994) found significantly greater shrinkage on fixed upright Old chairs than on sit-stand seats, where the subjects sit high on a forward sloping perch without back support but are not standing. In Althoff et al.'s study the Balans chair with no backrest showed a tendency to produce less height gain than Old upright chairs whereas adding a backrest to the Balans chair showed a tendency to increase height gain. Because they did not include an equivalent to the sit-stand seat, and because the measurements in Althoff et al.'s study were related to expected height loss, no direct comparison between the two studies can be made. On the other hand, it is possible to compare Michel and Helander's (1994) results from the fixed upright chairs with those obtained in this study. The mean shrinkage that they found on these chairs was just below 5 mm after 2 hours of VDU work. This is more than the maximum found in this study. The chairs which they used did not have armrests and this may account for the difference. The use of armrests is believed to reduce the compressive forces on the spine and it would therefore reduce the amount of shrinkage. It is not known whether the armrests were in fact used during the experimental period.

Ericson and Goldie (1989) concluded that the difference found in their study was due to the presence of the backrest but their Old chair was equipped with armrests whereas the Balans chair was not. The difference that they found could equally well be attributed to this difference. Michel and Helander (1994), when comparing their findings with those of Ericson and Goldie also suggest that the differences in the results of the two studies could be explained by the presence or absence of armrests. In Althoff et al's study the only chair which had armrests was the easy-chair and this chair was the only one which significantly reduced shrinkage compared to the others. In the present study, all of the chairs had armrests.

Bendix et al (1988) failed to find a significant difference in terms of shrinkage between sitting on a Balans chair and sitting on a chair with a variable seat angle. Subjects were not permitted to stand and both chairs had no armrests. They noted that the subjects did not to use the movement possibilities that the chair offered and no difference was found in the movement patterns of the two groups. They concluded that the result represents more a comparison between sitting on a Balans chair and sitting on a chair with a fixed seat. The results of the present study can more readily be compared with the results of Helander and Quance (1990) who also included a regime of 25 minutes of sitting and 5 minutes of standing, but with a minimal fixed lumbar support and no arm-rests. They found that all six subjects shrank but individual variability was great. Shrinkage after two hours varied between 0.5 mm and 5.5 mm. The maximum shrinkage in the present study under the same regime was also 5.5 mm but four of the subjects increased in height (maximum 2.1 mm). The difference is probably due to the greater number of subjects included in the present study.

### 5.5.7 The postural change and subjective feelings results

According to Helander and Zhang (1997), comfort ratings do not change over time but discomfort may. The reason for this is that comfort depends more on aesthetic factors and feelings of well-being, whereas, discomfort depends on fatigue factors. In the present study, no differences were found between the conditions either for comfort or discomfort. The subjective ratings were made only at the end of each experimental regime but it appears that the amount of fatigue was not sufficiently or consistently different enough for general conclusions to be made about the discomfort levels under the different regimes. The non-significant trend in the data was for discomfort to be least under the mixed sitting and standing regime, but individual variation was substantial. Each of the regimes was found to produce most discomfort by at least five of the subjects. This result is surprising because other authors have found that tiltable chairs are generally preferred over fixed chairs (Bendix et al, 1988; Hünting and Grandjean, 1976). Helander and Quance (1990) found that all of their subjects preferred to sit and stand at regular intervals rather than remain seated for three hours.

It would be expected, according to the theory of Helander and Zhang (1997) that comfort would be rated the same for all conditions by each subject as no changes were made to the aesthetics of the chairs. This was not the case. The rating scores from some subjects varied across almost the entire possible scale. One subject, for example, had a mean comfort rating of 1.0 for the fixed backrest but 8.0 for the freely moving backrest. Another subject had a rating score of 2.5 for the freely moving backrest and 8.0 for the mixed condition. Only in a few cases were the rating scores relatively consistent between regimes. It may be that the subject's expectations in terms of spinal health have an effect on their sense of well-being, which have resulted in the variations in the comfort scores. In any case, no pattern emerged which would indicate that there was any commonality in perceptions about the comfort of the different regimes.

It was concluded that discomfort was not a significant element over this period, possibly because the activity regimes did not last long enough for tiredness to be felt. In respect of the period chosen for the activity regimes, there is a difference between the expected occurrence of spinal shrinkage and tiredness. Shrinkage mostly occurs during the initial stages of a load until a point of equilibrium is reached, whereas tiredness builds up over a length of time and is least at the beginning. It is conceivable that if the period of the experiment had been extended differences in discomfort may have been found, whereas it is unlikely that further differences would have been found in the amount of shrinkage.

### 5.5.8 Postural change and the development of back pain

In the light of the more recent findings described above there is good reason to question whether, and if so to what extent, spinal shrinkage is affected by unloaded movements and therefore to what extent the freely moving, synchronized mechanism on modern office chairs affects shrinkage and by inference also disc degeneration. There are several, as yet unproved, links in the model which underlies the development of these chairs. There is no concrete evidence that spinal loading at these low levels actually leads to disc degeneration.

There is also insufficient evidence to conclude that too little movement causes lower back pain. The NIOSH (1997) study found sufficient evidence to conclude that lifting and forceful movements contributed to the development of back disorders along with awkward postures and heavy physical work but not static postures. Magora's (1972) oft-cited review and Grieco's review of the literature in 1986 may apply to workplace conditions which no longer widely apply. The type of work that is done in offices has changed dramatically over the last twenty years with the advent of computerisation and increased public awareness of ergonomic issues. There are many examples of workplace ergonomics interventions where older furniture was replaced by more adjustable models and most industrialised countries have developed standards for office furniture which make adjustable swivel chairs mandatory. It is conceivable that the health problems which resulted from poorly matched workers and workplaces have now become much more rare.

On the basis of the results of the present study, and in the light of the above comments, there is serious doubt as to whether static seated work postures result in back disorders. Before making any claims on the basis of the present results, however, it is necessary to establish how likely it was that a significant difference between the groups may have been missed. A post-hoc test of the power of the experiment using the actual variance of the whole set of data and the maximum mean difference that was found between the groups (the fixed regime and the mixed regime) reveals that the probability of missing a significant difference between these groups, given the high variance, was relatively high. For a two tailed test with $\lambda$ = .05 the probability of missing a significant result was 33%. To be 80% sure that there were no differences between the groups with the same variance it would be necessary to test 47 persons (a further 30 subjects). It is therefore necessary to treat the result of no difference between the groups with some caution as a significant difference may exist which has not been detected.

On the other hand, even if a real difference of this magnitude existed (1.1 mm) it is reasonable to question whether such a small difference is of any real importance. In the normal course of a day, the normal fluid loss in a disc is 10-12%. Considering that other, common, loading conditions result in greater disc height loss and that the individual variation was so great it seems reasonable to conclude that even if a difference did exist between the groups it would not be of any clinical significance.

It may be that movements during sitting are not enough to affect the supply of fluid into and out of the discs. Adams and Hutton's (1985) studies have shown that pressure inside the disc alters as a result of postural change, but because of variations in the strength of the posterior and anterior annulus, it may be that the total fluid content of the disc is little affected in real life by movements in the middle of the movement range. The amount of fluid which is pressed out on one side may be compensated by simultaneous uptake on the other side. The increase in osmotic pressure in one part of a disc which results from water being squeezed out may also result in water being actively sucked into the other side. The biochemical mechanisms which exist within the disc are not yet well understood.

### 5.5.9 The role of the cervical spine and other structures.

It is possible that the back problems found in epidemiological studies are cervical disorders rather than lumbar problems. In many studies, particularly older studies, there is little definition of the location of the back pain and therefore it is difficult to know whether the problems encountered were low back problems or cervical problems or mixtures of both. The measurement method used in this study was aimed at evaluating shrinkage in the lower back. If the shrinkage were principally in the cervical spine then it would not have been detected. A similar study to this with a focus on the cervical spine would be useful to determine whether this is the case.

Various other structures may be more important in the aetiology of back pain than disc lesions. The spinal ligaments and muscles are well innervated and are susceptible to injury and degeneration. Disorders of these structures are difficult to diagnose because they are not readily seen on X-ray or ultrasound imaging. Ligaments repair only very slowly and muscles which are continually used do not repair quickly. It is at least plausible that many of the episodes of back pain lasting less than three months are due to damage in these structures rather than degenerative disc disorders.

The effects of muscular tension need also to be considered in more detail. It is well known that muscles which are suddenly exposed to increased use respond by becoming painful. Additionally, when an area is painful, the body generally responds by increasing muscle tension in the area. This serves to stabilise the affected area and therefore enhance healing of the affected structure. On the other hand the sudden great increase in the use of generally neglected muscles results in them becoming painful, creating circularity in pain generation which may prolong the period of incapacity. It has been suggested by other authors (Althoff et al, 1992) that antagonistic muscle function may contribute to spinal loading and that this may arise from constrained postures, vibration or psychological stress.

Psychological stress alone is sufficient to increase muscular tension such that in periods of high workload, for example, it is probable that the increased tension on the muscles makes them more susceptible to injury and may predispose people to muscular overuse disorders. This would be more likely if the general level of muscular fitness was not very high and this may be one reason why exercise programs have been found to be so successful in the treatment of back disorders. Fitness programs are also promulgated as being beneficial in reducing psychological stress.

The results of this study should not be interpreted to mean that there is no physiological advantage in increasing seated movements. The spine is not the only body structure which responds to movement. There are many advantages to interspersing periods of sitting with periods of standing. For example, the incidence of varicose veins is reduced, cardiovascular strain is reduced, digestion is facilitated, muscular effort is more evenly distributed, etc. Because of these advantages, movement should be encouraged and the positive effects of tiltable chairs on other body systems should not be ignored.

## 5.6 Conclusions

It was concluded from the study that chairs with the freely moveable backrest and seat angle facility, the so-called dynamic or synchronized mechanism chairs, provide no substantial advantage in terms of the total compression over a two-hour work period on intervertebral discs. A two-hour period is arguably sufficient to conclude that there will be no difference at the end of a working day, as most shrinkage occurs during the initial period of a load and in real workplaces, seated work is generally interspersed with other activities and breaks. The advantages of these chairs, however, is not limited to their effects on the discs, as movement has a positive health effect on various other body systems. It is also very likely that, although the freely moving option did not show any significant difference to the fixed upright seat or to regular periods of standing, the facility to be able to alternate between periods of leaning backwards and sitting upright may have more positive effects than those found in this study. It has been shown in previous research, for example, that a fixed backrest angle of 120° increases disc hydration compared to sitting upright.

The effects of circadian rhythm, age, sex and body proportion outweigh the effects of the synchronized mechanism and individual variation was found to be substantial even when these factors were controlled. It was concluded that the presence of armrests on chairs might be more important in reducing compressive load than has otherwise been assumed.

# 6 Use of chair adjustments

Avoiding painful postures and optimising seated comfort depends on the correct adjustment of furniture. However, providing adjustment possibilities e.g. the adjustment of seat height to individual needs, does not guarantee that correct adjustments will be made. This study investigated how well chair adjustments are made without training. The provision of adjustable chairs was not found to substantially improve the matching of furniture to body proportions compared to non-adjustable furniture. Although the subjects understood how the mechanism for adjustment worked, they did not how to determine the correct settings.

## 6.1 Introduction

The correct matching of chairs to the size of the user is essential to ergonomic seating. In the laboratory study, chair adjustments were made by the experimenter to ensure that these factors did not have an influence on the experimental results. In the real world, people have to make their own chair adjustments. Inappropriate choices will affect postural behaviour because using the whole available range of postural possibilities depends on correct adjustments.

This paper describes a comparison study which was undertaken to systematically investigate the advantages to be gained by the provision of individual adjustment possibilities for school furniture.

Because of the rapid growth of children, the range of sizes is larger than for adults and a larger variability is evident in the relationship between body dimensions. A significant advantage of adjustable chairs is that variations in body shape are more easily accommodated. Additionally, the need for pupils to keep track of their own individual chairs is eliminated. Individual chairs are generally impractical in secondary schools where the classes change rooms frequently. The need to keep a stock of spare furniture in the classrooms to allow for variability between classes is also limited.

Two questions which are often raised concerning adjustability, however, are whether people actually use the available adjustment possibilities, and how well they use them. It may be that adjustability, by improper use, produces more mismatches between pupils and their chairs than having a proportioned range of sizes available for distribution. The alternative to adjustable furniture is to supply a range of furniture sizes which are allocated to each pupil according to their size such as prescribed in most European countries (BS 5873; DIN ISO 5970; NF D 60-602; ÖNORM A 1650). The question which arises is whether adjustability results in any real improvement in matching between pupils and their furniture.

The traditional chairs used by Zurich school children consist of a moulded wooden seat and backrest on a metal frame (see Chapter 3). The seats are height adjustable by means of a key which is generally held by the class teacher. The teachers are therefore responsible for the correct adjustment of the chairs. The backrest has no method of adjustment nor is there any way of adapting the seat depth to the thigh length of the pupils. New chairs were proposed with backrest height adjustment and a seat depth adjustment. The new chairs also provide some additional mechanical springing to the backrest and an increase in backrest depth. For the secondary schools, the backrest and seat height of the new chairs can be adjusted at any time by the pupils themselves. Seat height is controlled by means of an integrated spring and lever mechanism such as generally found on office furniture. For the primary schools, all adjustments remained under the control of the teachers.

New tables were also included in the study. Chairs and tables should be viewed as a complete unit, as height changes in the chairs need to be matched to table height. The traditional tables were height adjustable and had a continual angle adjustment range between the horizontal and a maximum of approximately 10°. The new tables had a similar height range adjustability but had only two angle positions, namely horizontal or tipped 16° forwards.

This study was conducted in parallel with the study on postural behaviour described above (Chapter 3), but further aims were to determine:-

1. Whether the additional adjustment possibilities are used?

2. Do the changes result in improved adaptation of the furniture to the individual pupils?

# 6.2 Method

For details of the subjects and furniture involved in the study, see Chapter 3.

## 6.2.1 Anthropometric measures

Two anthropometric studies were undertaken: One was done shortly following the introduction of the new furniture and one four months later. Measurements were taken according to the procedure described by Pheasant (1988). On each occasion, measurements were taken of each pupil's height, and then while seated, the distance was measured from the underside of their knees to the floor (with shoes) and from the rear angle of their knees to their buttocks. The distance from the floor to the inside of their elbows was similarly recorded. The height of their chair surface was then measured, the depth of the seat from the front edge to the perpendicular drop from the foremost portion of the backrest, and the height and angle of the table surface.

These measurements were then used to establish how frequently mismatches occurred, and in what direction these most frequently deviated. The criteria used for correct chair height set a maximum of 5 mm more than the floor to inside knee distance and a minimum of 5% of this length. As seat depth was measured from the foremost portion of the backrest, a correction (2 cm) needed to be made to account for fitting of the buttocks into the gap beneath the backrest in the backrest measures. All measures between a maximum of the thigh length minus 2 cm knee clearance and a minimum of 20% less than the thigh length were scored as correct. The maximum table height accepted was 5 mm more than the internal elbow height and the minimum was 5% less than this height.

### 6.2.2 Questionnaires

Six pupils were randomly selected from each of the classes on both occasions and a structured interview was given (see Annex D). The interviews were designed to assess how well the pupils understood the adjustment mechanisms of their chairs and the underlying ergonomic principles, that is, whether they knew how to correctly adjust the furniture for themselves. A similar questionnaire was distributed to all of the teachers asking for their comments on the use of the furniture.

## 6.3 Results

### 6.3.1 Anthropometric studies

The anthropometric studies revealed generally poor adjustment of all the furniture. Table 6 lists the percentage of correctly adjusted chairs and tables divided into schools, furniture type and time of study. It was found that only about 30% of the chairs were set at heights within the defined limits. The new furniture was generally slightly more likely to be correct than the traditional, the notable exception being for the secondary pupils with the new furniture, as more adjustments that are incorrect were found with the new furniture. These pupils were able to adjust the chairs themselves.

An analysis of their errors revealed that the pupils tended to set their chairs too high. This was the most common error in all groups and no significant difference was found between the old and new furniture types (see Figure 29).

Approximately 60% of all the chairs fulfilled the seat depth criteria. On the old furniture, the most frequent depth error was that they were too long. On the new furniture seat, depth was adjustable and the most frequent error was setting them too short.

**Table 6** The percentage of correctly adjusted chairs and tables by schools, furniture type and measurement series

Seat height

| Type | % correct | Time | Type | % correct | School | Type | % correct |
|---|---|---|---|---|---|---|---|
| New | 32 | Beginning | New | 26 | Primary | New | 41 |
| Old | 28 | | Old | 22 | | Old | 30 |
| | | End | New | 37 | Secondary | New | 17 |
| | | | Old | 34 | | Old | 24 |

Seat depth

| Type | % correct | Time | Type | % correct | School | Type | % correct |
|---|---|---|---|---|---|---|---|
| New | 58 | Beginning | New | 52 | Primary | New | 66 |
| Old | 63 | | Old | 63 | | Old | 55 |
| | | End | New | 65 | Secondary | New | 46 |
| | | | Old | 62 | | Old | 79 |

Table height

| Type | % correct | Time | Type | % correct | School | Type | % correct |
|---|---|---|---|---|---|---|---|
| New | 33 | Beginning | New | 28 | Primary | New | 34 |
| Old | 24 | | Old | 20 | | Old | 27 |
| | | End | New | 39 | Secondary | New | 33 |
| | | | Old | 28 | | Old | 17 |

The table height measures were also disappointing, with generally less than 30% correct. The new tables were, however, more likely to be set correctly in all groups than the old tables. As opposed to the old furniture, too low settings were observed with the new furniture. The old tables were more often much too high.

The angle adjustment of the new tables was well utilised in the primary school (73% on the first series and 93% on the second). This was not the case for the old furniture (20% used with a maximum angle of 6°). The secondary school pupils were found to angle the new tables much more frequently on the second series (29% increased to 49%).

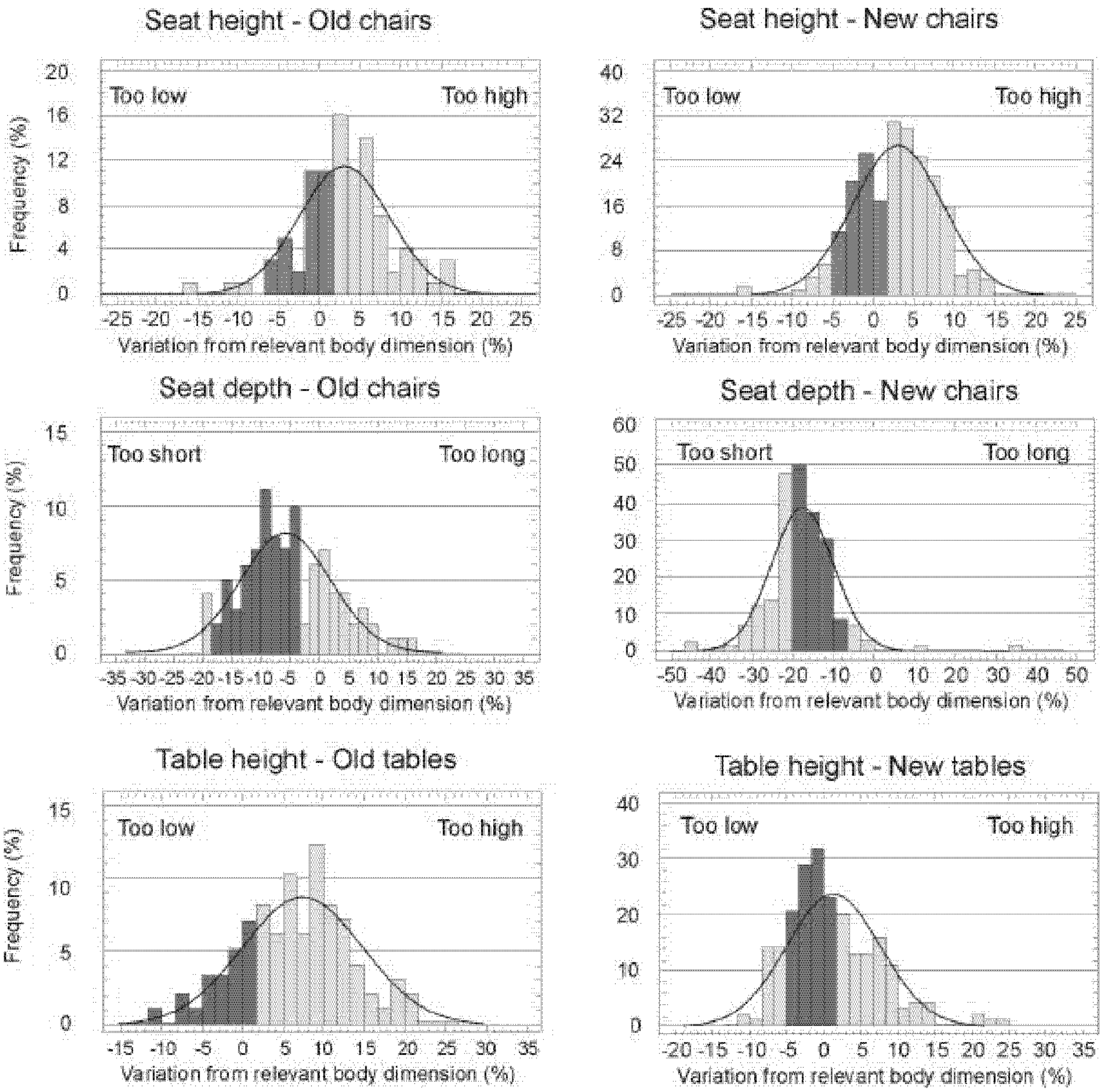



**Figure 29** Results of the anthropometric measurements. The darker columns approximately indicate the correct settings

### 6.3.2 Questionnaires

Generally, the pupils showed a good knowledge of the mechanics of their chair operation. The very young children had, as would be expected, the least knowledge. Chair depth adjustment was the least understood, mainly in the primary school. Nevertheless, 71% of the pupils had a good understanding of the mechanism even when they themselves were not able to use it.

The actual criteria used for correctly adjusting the furniture were very poorly understood at all levels. Very few pupils were able to adequately state what the correct height was for themselves (27% at the end of the study, notably almost exclusively new chair users). It was expected that they would know that the chair should be high enough to reach their knees but not lift their feet from the floor and that the chair depth should not be so long that it pushes into the back of their legs. The principle of the table slope was well understood and most pupils knew how to adjust the table height.

The teachers generally favoured the new furniture. The use of the keys was questioned in the primary school. It was suggested that a locking mechanism, not easily used by the pupils, could be integrated into the design of the primary school chairs. The accessibility of the adjustment mechanism was also criticised.

## 6.4 Discussion

It is generally well accepted that habits acquired during childhood tend to be the most resistant to change. Working postures in adult life are largely determined by seating behaviour acquired during the period of our preliminary education. What sitting postures we prefer and our willingness and ability to utilize chair adjustments are all conceivably learned behaviour patterns. For this reason ergonomists should not limit their thoughts on workplace furniture only to adult workplaces. Children also „work“ for long periods, five or six days a week at their school benches.

In this study, it was found that a significant amount of mismatching was present very shortly after the introduction and fitting of the new furniture. This was also the case with the non-adjustable furniture. From the results, mismatching was common in both the adjustable and non-adjustable features of the furniture. This did not appear to result from lack of knowledge about how to use the mechanisms but rather how to determine the correct adjustment.

The study confirmed the phenomenon which has been previously observed with school pupils; that they set their chairs too high (Bendix, 1986). The new furniture did not improve the situation. If the seat is too high or too long, the backrest cannot be properly utilised and therefore static loading of the postural muscles is increased and kyphotic positions are more likely to result. With the old chairs, the seat depth was more frequently too long, whereas with the new chairs, it was frequently too short. From an ergonomic viewpoint, this is less serious than too long as it should not affect postural behaviour. Accordingly, the results indicate that postural behaviour did not change substantially.

The results indicate that continual education and checking are probably necessary for good furniture adjustment. Generally, the new adjustment mechanisms produced some improvements in the matching of the pupils to their furniture, however, they by no means guaranteed it. The need for more education of the pupils and teachers on how to determine correct seat adjustment was indicated. Training alone may, however, not be enough to ensure a permanent behaviour change. The study described in Chapter 7 investigates this aspect with adults.

# 7 Effectiveness of training

The previous studies indicate that the synchronized mechanism may not be used as intended, in that subjects do not necessarily change posture more frequently than with fixed seats. Various factors are important in determining how well chair adjustments are made and used, such as the subjects' knowledge and beliefs (cognitive aspects) about their chair mechanisms and ergonomic seating or their moods (affective aspects). Postural behaviour while seated on tiltable chairs therefore depends on training in the importance of movement and on how to use the mechanisms of the chair. Training empowers people to make their own decisions about their seating behaviour.

## 7.1 Introduction

Over the last decades, many companies have purchased new furniture with the aim of improving the ergonomics of their workplaces. The emphasis on „ergonomic“ furniture has been most noticeable in office workplaces where chairs with individual adjustment possibilities have now become the standard and height and angle adjustable tables are increasingly common. The chairs usually allow the user to adjust the seat height and backrest height to their own body proportions. They also often have inbuilt mechanisms whereby the backrest angle automatically adjusts to the seat angle, which itself tilts over a specific range in accordance with body movements and posture, the so-called synchronised mechanism. In most cases, this mechanism can be fixed, whereby the seat and backrest remain in the position where it was engaged, or it can be left to freely tilt through its range.

The experiences that companies report have not, however, always been positive and chair manufacturers report that the adjustment options are rarely used correctly. There have been few studies of whether adjustable furniture is used correctly and if not why not. In the study of school children, described in Chapter 6, it was found that the provision of individually adjustable chairs and tables does not necessarily improve compatibility between furniture and child. Whether chairs and tables are used correctly may depend on whether the users are aware of how to operate the furniture and what they have to gain by doing so. Increasing user knowledge may therefore be the key to improving the use of the adjustment options.

Schute and Starr (1984) felt that continued reports of discomfort after the introduction of adjustable furniture could be due to lack of training, difficulty in using the controls or „antiquated working conditions“. After a workplace-training program and with considerable support of their subjects, they compared the subjects' comfort using adjustable chairs and tables with the same subject's comfort using non-adjustable furniture. They found a significant reduction in reports of discomfort using the adjustable furniture after up to five weeks. Dainoff and Mark (1986) tested whether subjects (10 females) would actually use an adjustable and tiltable chair correctly if trained. They were aware that „misuse of ergonomic adjustments in the field is common“ so they felt that training was essential. The subjects were very closely monitored for the whole of the study (half-hourly measures and continual video recording for a week). They found that their subjects adjusted the chairs whenever they changed tasks. They suggested that the effectiveness of alternative training approaches should be investigated. Both of these studies, although supporting the need for training in the use of the furniture, do not attempt to test how persistent the change in behaviour was.

This study aimed to evaluate a program which had been implemented in a large banking company to improve the use of chairs which are supplied as standard within the company. This company has a relatively long tradition of investment in ergonomic furniture and has sought to emphasise healthy working practices. Traditionally all new employees are given a brochure explaining the methods for individually adjusting their workplaces and explaining what benefit is to be gained by ergonomic workstations. It also emphasises the importance of users taking responsibility for their own well-being. Recently, in response to continuing complaints to the ergonomic department about discomfort, the ergonomics department decided to incorporate a face-to-face talk on the importance of ergonomic workplaces and training in the use of the furniture whenever a new office was established. The effectiveness of this procedure was evaluated in this study.

### 7.1.1 The research hypotheses

The first hypothesis was that the training program about the benefits of ergonomic seating and how the furniture works, alters the attitudes of the subjects in respect to their assessment of the importance of ergonomic seating and their knowledge of it (cognitive attitude).

The second hypothesis was that the quality of matching between furniture and user depends on training in furniture adjustment and understanding of how it works. The testing of this hypothesis evaluated the effectiveness of the training program in terms of behavioural change. The assumption being that attitude change proceeds, and contributes to, behavioural change.

## 7.2 Methods

### 7.2.1 The workplaces

The workplace chosen for the investigation had been established in a new building for six months. During the first three months, the employees were transferred to the new building in groups, or as individuals from other workplaces within the same company.

The transfer took place as part of a restructuring of the credit department. The company has placed a lot of emphasis on workplace ergonomics over the last decade and therefore, although the furniture in the new building was new, it did not represent a substantial change ergonomically from the other worksites. All worksites within the company are equipped with relatively new adjustable chairs and tables. At this worksite, the tables and chairs were identical for all employees, regardless of rank. Routinely a brochure containing an introduction to ergonomic seating and instructions (with illustrations) about how to manipulate the furniture adjustments is placed under the glass inset of the tabletops (or similarly) at all workplaces. This was done at all workplaces in the new building.

### 7.2.2 The furniture

The chairs supplied at each workstation had facilities for continuous adjustment of seat height and stepped (1 cm) adjustment of backrest height. They had a synchronised seat and backrest angle tilting mechanism which could be engaged (fixed) at any angle within the range (0° to 5° seat angle corresponding to 90° to 110° backrest angle) or disengaged to freely tilt with body movement. The seat could not be forward tilted. There was an adjustment for the resistance of the synchronised tilting such that it could be adapted to suit larger/stronger/heavier persons or smaller/weaker/lighter persons (all three factors are assumed to play a role).

The table could be height adjusted over a continuum using a crank handle and it could be tilted to three different positions; 0°, 2° or 4°.

### 7.2.3 The training

As part of the induction, training to the new building and work structure the first group (about half of the final occupants) was additionally given a one-hour face-to-face training session about the importance of workplace ergonomics to health and the operation of the furniture in the building. This was conducted by personnel from the ergonomics specialist unit within the company. The aim was to improve the use of the furniture. Personnel from the ergonomics unit were concerned that the furniture was not being optimally utilised, as they often found that complaints about workplace discomfort were easily corrected by better adjustment of the furniture that was already available. They felt that further training might alleviate the frequency of furniture adjustment-employee mismatching.

### 7.2.4 The subjects

Two lists were drawn up which contained all the employees in the new building - one list for those who had been trained and one list for those who had not. Twenty-two subjects from each list were then randomly selected for inclusion in the study. In the final data analysis, 41 subjects were included (20 trained and 21 untrained). One subject requested to be excused due to work pressures and two subjects were excluded due to unresolved confusion about whether they had been trained on induction or not. Two of the untrained group stated that they had been trained by other persons, so they were kept in the sample. The demographic data collected for both groups are shown in Table 7. The untrained group turned out to be slightly younger; otherwise, the groups were well matched on the factors checked. The sex distribution in both groups corresponded well to the distribution within the workplace.

**Table 7** Demographic data of the subjects.

| | | Total | Males | Females |
|---|---|---|---|---|
| **Sex** | Trained | 20 | 14 | 6 |
| | Untrained | 21 | 16 | 5 |

| | | Median | Min. | Max. |
|---|---|---|---|---|
| **Age** | Trained | 32.5 | 21 | 56 |
| | Untrained | 26.0 | 21 | 44 |
| **Height (cm)** | Trained | 180.0 | 160 | 194 |
| | Untrained | 175.0 | 160 | 184 |
| **Weight (kg)** | Trained | 70.0 | 46 | 87 |
| | Untrained | 68.0 | 49 | 84 |

### 7.2.5 The measures

Subjects were given a brief explanation of the purpose of the study (ie. to evaluate the ergonomic training process) and were then asked to complete a two-page questionnaire. The questions were designed to establish how confident the subjects felt using the adjustment mechanisms, how frequently they used them, their attitude to seating ergonomics and whether they felt comfortable. It was hypothesised that the ability to alter posture would correlate with comfort. This is a view accepted by other authors (Bendix, 1986; Grandjean, 1987; Hagberg, 1982).

The final question was open-ended to try to ascertain whether any important factors had been missed. While the subjects were answering the questionnaire, measures were taken of the workplace anthropometrics. The measures included popliteal height, floor to internal elbow height, seat height, backrest height, table height and angle. A recording was made as to whether the seat was currently fixed in position and, if so, its angle was measured. To standardise measurement error as much as possible all of the measures were taken by the same person using the same equipment.

## 7.3 Results

### 7.3.1 The anthropometric measurements

The quality of the match between popliteal height and seat height was determined according to the following criteria. Firstly, the absolute difference between the two measures was calculated. The result was then graded as good (score of 1) if the difference was 1 cm or less, acceptable (score of 2) if the difference was 2.5 cm or less and unacceptable (score of 3) if it was more than 2.5 cm. The mean scores were then calculated for each group and the results compared using a $\chi 2$ test. A significant difference was found between the groups (p= .0014). The results are displayed in Figure 30.

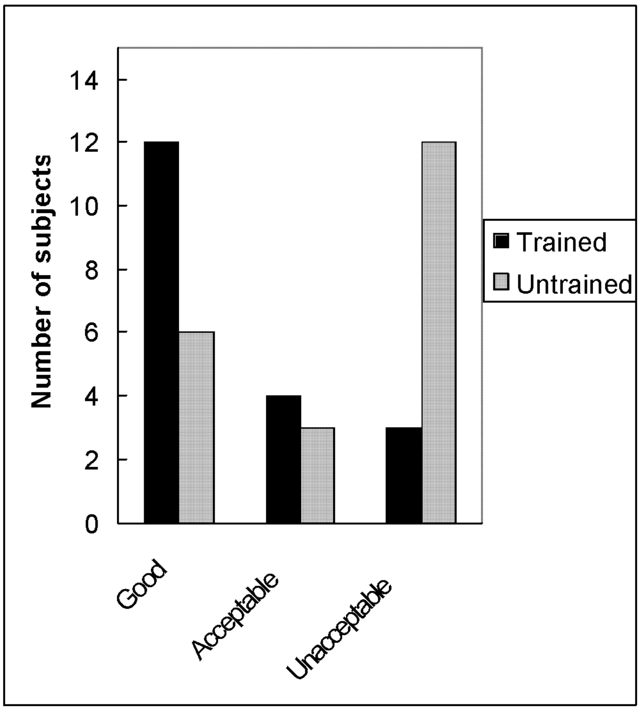



**Figure 30** Matching of seat height to popliteal height.

A similar method was employed to score the matching of elbow height and table height (Figure 31). Good matches were classed as those with 2.5 cm difference or less, moderate those with 4.5 cm or less difference and any more was unacceptable. A significant difference was found between the groups (p=0.0041). 70% of the subjects in the trained group were found to have tilted the table-top and 42% of the untrained subjects, with subjects in both groups to the maximum angle of 4°.

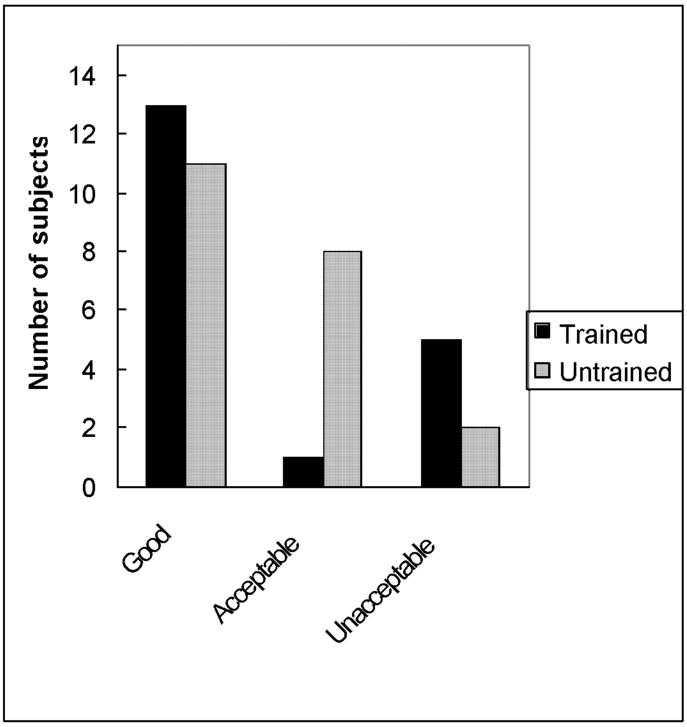



**Figure 31** Matching of table height to elbow height

Most subjects (65%) had the chairs in the fixed position when the measures were taken, however a significant difference was found between the trained and untrained groups ($\chi 2$ P-Value=0.02) in that more of the trained subjects had the chair freely tilting (see Figure 32).

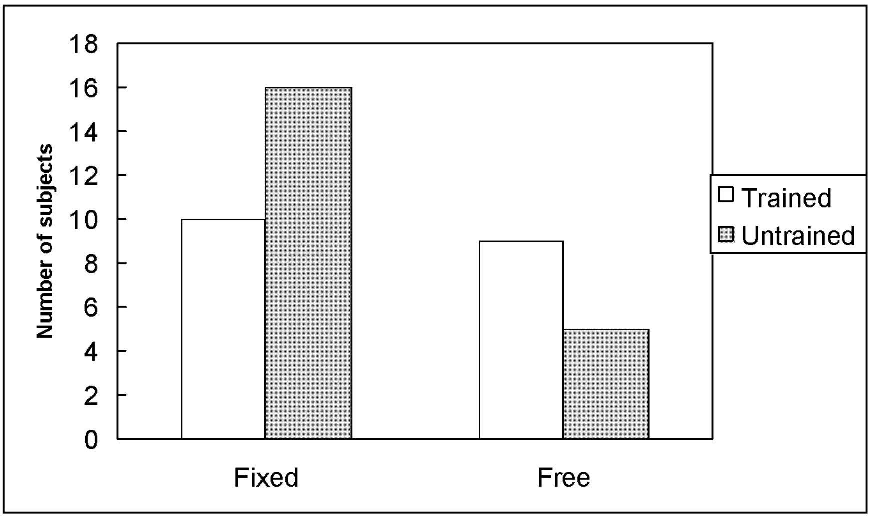



**Figure 32** Actual use of the synchronised tilting mechanism.

No significant difference was found between the groups for the mean preferred fixed angle but the tendency was for the untrained to prefer slightly greater seat slope (see Figure 33). The seats could be tilted between 0° and 5° backwards.

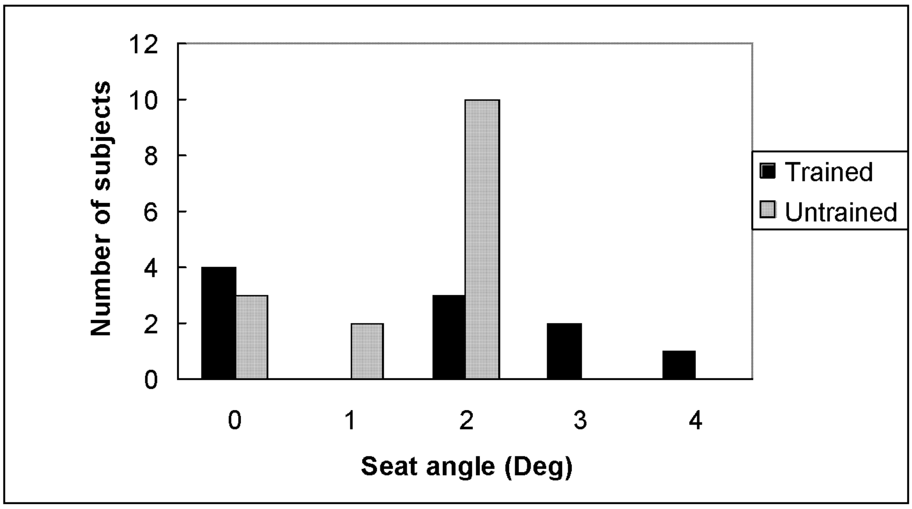



**Figure 33** Frequency of fixed seat angles for each group.

Backrest height was measured as the distance between the seat and the top edge of the backrest. The mean height for the trained group was 50.4 cm and the untrained group 49.2 cm. This was not a significant difference. The range of adjustment was 48 to 55 cm for the trained group and 48 to 54 cm for the untrained group.

### 7.3.2 The questionnaire

Several questions were intended to elucidate how confident the subjects felt using the adjustment mechanisms, that is, to test their own perception of their knowledge. Almost all subjects reported feeling confident at being able to use the chairs. There was a non-significant tendency for more of the trained subjects to answer positively (100% vs 85%). Slightly fewer of the trained subjects felt confident that they understood how to use the synchronised tilting mechanism than untrained subjects (68% vs. 76%), however the difference was not significant. The difference between groups was accepted as significant when p ($\chi 2$ Test) < 0.05. A comparison between the reported use of this mechanism and that which was actually found during the study showed good agreement, indicating that the self-assessment was valid.

There was a highly significant difference between the trained and untrained subjects in their understanding of the resistance adjustment but, even within the trained group less than half of the subjects claimed an understanding of how to use this mechanism (42% vs 10%).

One question related to how frequently the subjects used three of the adjustments; seat height, backrest height and backrest angle. The frequency of use of these adjustments was not found to vary between the groups (see Table 8). The most frequent response for the frequency of use of all of the adjustments was “rarely”.

The subjects were additionally asked how easy it was to use these same adjustments. The results of the analysis of variance are shown in Table 9. No significant differences were found between the groups. All mean scores were on the „easy“ side of the scale with the backrest height scoring lowest.

**Table 8** Frequency of use of the mechanisms.

| | | Several times per day | Several times per week | Several times per month | Rarely | Never | Significance |
|---|---|---|---|---|---|---|---|
| **Seat height** | **Trained** | 0 | 1 | 0 | 16 | 3 | NS |
| | **Untrained** | 0 | 2 | 0 | 14 | 5 | |
| **Backrest height** | **Trained** | 1 | 0 | 0 | 10 | 9 | NS |
| | **Untrained** | 0 | 0 | 0 | 10 | 11 | |
| **Backrest angle** | **Trained** | 3 | 2 | 3 | 11 | 1 | NS |
| | **Untrained** | 2 | 2 | 1 | 12 | 4 | |

**Table 9** Ease of use. Anova results

| | | Mean | F-Value | P-Value | Significance |
|---|---|---|---|---|---|
| **Seat height** | **Trained** | 6.316 | 0.175 | 0.678 | NS |
| | **Untrained** | 6.450 | | | |
| **Backrest height** | **Trained** | 5.000 | 1.122 | 0.297 | NS |
| | **Untrained** | 4.294 | | | |
| **Backrest angle** | **Trained** | 6.105 | 0.012 | 0.912 | NS |
| | **Untrained** | 6.158 | | | |

The current level of comfort of the subjects was examined by three questions and three further questions related to the result of the subject's efforts to improve comfort. Most subjects found their chairs comfortable (95% of the trained subjects and 76% of the untrained, p=0.52). The untrained subjects tended to be less likely to accept the actual setting as comfortable, but the difference was not statistically significant. Of the five subjects who reported not being comfortable, only one was trained and they reported having tried to improve the adjustment with limited success. Of the untrained respondents one had not tried to improve the adjustment, 3 had had no success, and one had had limited success. Most subjects reported feeling able to easily change posture and that the resistance offered by the backrest, when in the freely tilting mode, was rated as comfortable. See Figure 34. The differences between the groups were not statistically significant.

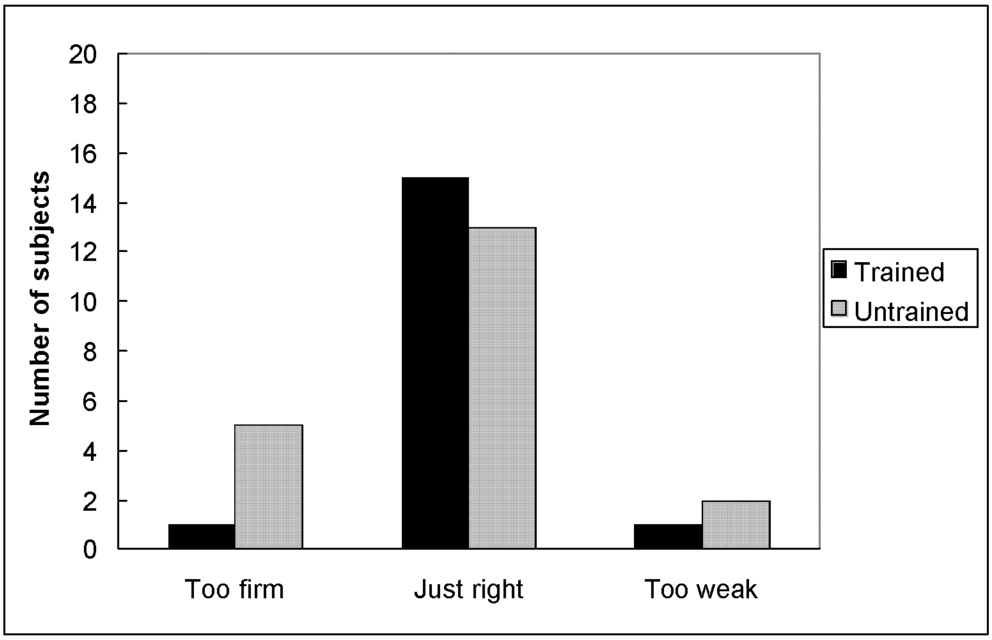



**Figure 34** Evaluations by the two groups of the amount of resistance to movement offered by the synchronised tilting mechanism

There was no significant difference on any of the cognitive attitude questions between the groups (i.e. how important they felt that various factors were in respect to their chair). Comfort and health had the highest average ratings of importance, but all of the other factors also had mean scores which were over the middle position on the scale. The results are summarised in Table 10.

**Table 10** Subjective ratings of the importance of chairs to various factors (maximum importance score=7)

| | | Mean | SD | 95% C.I. | Significance |
|---|---|---|---|---|---|
| Comfort | Trained | 6.26 | 0.78 | 0.35 | NS. |
| | Untrained | 6.33 | 1.21 | 0.52 | |
| Health | Trained | 6.05 | 1.32 | 0.59 | NS. |
| | Untrained | 6.43 | 1.18 | 0.50 | |
| Concentration | Trained | 5.37 | 1.60 | 0.72 | NS. |
| | Untrained | 4.90 | 1.41 | 0.60 | |
| Work quality | Trained | 5.47 | 1.63 | 0.73 | NS. |
| | Untrained | 4.90 | 1.41 | 0.60 | |
| Work quantity | Trained | 5.11 | 1.77 | 0.80 | NS. |
| | Untrained | 4.38 | 1.84 | 0.79 | |

The final question was open ended. It asked the subjects whether they had any suggestions for improving the furniture. From the trained subjects two suggestions were received. The first suggested that the lumbar support should be increased and the second suggested that the adjustment levers should be labelled. From the untrained subjects four suggestions were recorded. One echoed the above comment regarding increasing the lumbar support, one suggested that the height adjustment should be „finer" and two suggested that operating instructions should be supplied.

## 7.4 Discussion and conclusions

Individual control is known to be an important element in workplace health promotion (Kuhn, 2003). Central to workplace health promotion is the empowerment of people through training and their participation in the decision-making processes. The effectiveness of training may, however, still depend on affective attitudes or mood. This may also be influenced by participation in the decision-making process.

The first hypothesis was to test whether the training program altered the attitudes of the subjects in respect to their assessment of the importance of ergonomic seating. The assumption is that matching of furniture and user depends on motivating factors, that is, the perceived gain (an attitude). Attitudes have cognitive (knowledge and beliefs), affective (feeling) and behavioural components. From the results of the questions, the first hypothesis could not be verified as no change in attitude was found. The most likely explanation is that the level of knowledge of potential gain was already sufficient before the training program. The training showed no effect because the affective component was closely associated with the cognitive component (a desirable situation for trainers).

Attitudes are learned through social interactions, including training, and by other influences, such as experience. The success of any training program will be determined largely by the prior attitudes of the pupils. For training to be successful, the training must be matched to their attitudes (prior beliefs and feelings). In this case, there was a mismatch between the assumed level of knowledge, and that which was included in the training. Most untrained subjects in both groups believed that they had sufficient knowledge to correctly adjust the furniture. One question relating to knowledge, however, showed a significant difference between the groups; the function of the resistance mechanism. This did not seem to be known before the training. The training in the less well-known aspects of the chair mechanism, namely the resistance adjustment and tilting mechanism, resulted in reduced confidence by the subjects. The most likely explanation is that the untrained subjects were unaware of the mechanism and therefore did not realise that they did not know how to work it.

Knowledge is only one component in attitude formation and attitudes do not necessarily change behaviour. The second hypothesis tested was that the quality of matching between furniture and user depends on training in furniture adjustment and understanding of how it works. The testing of this hypothesis evaluates the effectiveness of the training program in terms of behavioural change. Is know-how an important factor in the correct use of ergonomic furniture? From the results of the study, this hypothesis has been supported. A significant improvement both of seat height adjustment and table height adjustment was found in the trained group. The aim of the study was to evaluate how effective the face-to-face training was in comparison to the distribution of brochures. Obviously, the more direct approach is more effective in achieving behavioural change in this area.

Although the difference was not statistically significant, slightly fewer of the trained subjects reported feeling confident in using the synchronised tilting mechanism. On the other hand, fewer of the untrained subjects were using it at the time of the test. This may indicate that the untrained subjects only thought they knew how to work the mechanism, but actually did not. There was found to be quite a bit of spring in the backrest even when the mechanism was fixed such that it would be possible to imagine that the mechanism was already free if one had not had the opportunity to compare. A comparison of the reported use of this mechanism with that actually found, however, did not reveal any contradictions. From the results of the questions on frequency of use of mechanisms, it can also be seen that most subjects in both groups reported rarely changing the backrest angle. It is possible that subjects who generally left the chair freely tilting would respond that they rarely changed the backrest angle, as a change would require no actual manipulation on their part.

An examination of the table mismatches revealed that of the five trained subjects with mismatches four had the tables well over the recommended level. This is of interest in that other authors have found that subjects prefer higher tables and they may, in fact, be better for some types of work (Bendix, 1986; Mandal, 1991). It is possible that once the subjects know how to adjust the table they tend to adjust it over the recommended height. It would be interesting to follow up on whether these subjects do, as would be expected from the theories, experience more discomfort in their shoulder and neck region, or whether they have a behavioural compensation strategy to avoid the need to continually lift the elbows to clear the table.

The results of this study have supported the conclusions from the Schute and Starr (1984) and Dainoff and Mark (1986) studies. In both of these studies, the amount of experimenter support and contact with the subjects was high. In this study, contact with the subjects was minimal - one hour three months before the study by different persons. This decreases the likelihood that the results are due to experimental effects (particularly Hawthorn effects) rather than the experimental variable, the training.

From the open-ended questions, it did not appear that any significant factor had been missed in the study. The request for documentation indicates that the policy of placing brochures at the workplace is not always effective.

In terms of the effectiveness of the training program, several suggestions can be made. Emphasis should be placed on the less well-understood aspects, especially the synchronised tilting mechanism.

It would be possible to evaluate the effectiveness of the training program by other means. For example, by measuring the frequency of grievances from the workplace. The degree of involvement of the trainees is important. Written communications are less effective than face-to-face training. It could also be predicted that hands-on training is the most effective. Real chairs should, therefore, be used for demonstrations and the trainees should be encouraged to try out the adjustments themselves during training.

An additional aim of the study was to collect empirical data: To measure and evaluate how adjustable chairs and tables are actually used. The results indicate that most of the subjects felt confident using the modern ergonomic chairs. Comfort was highly correlated with confidence in the use of the mechanisms, however, their level of knowledge of the potential benefits of seated workplace ergonomics was high. Once the subjects made initial adjustments, they seldom change these. From the results, this is not due to lack of knowledge. On the other hand approximately a quarter of the subjects had some difficulty in the use and of the synchronised tilting mechanism, and more than half of the trained subjects still had difficulty using the resistance adjustment, which is poorly located under the seat. Less than 10% of the untrained subjects discovered it for themselves.

In summary, it was found that although attitudes to the value of chairs to various ergonomic factors did not change, seating behaviour was found to be different between the groups. The trained group showed better adjustment of the furniture to their body proportions and indicated that they were more confident in using the other ergonomic options that the chairs offered.

# 8 Postural behaviour and task factors

Apart from chair characteristics and training postural behaviour while performing seated work may be determined by task characteristics. This study comparatively evaluated the sitting behaviour of workers who were engaged in various different seated work tasks. Additionally it compared the effects of fixed seat angles with tiltable seat bases. Task was found to be a more powerful determinant of seated posture and position than the type of chair. Task also significantly affected the frequency and pattern of position change. In comparison, the type of chair did not show substantial differences on these variables. Postural behaviour on tiltable seats (with a synchronized mechanism) was not found to be significantly different from on fixed seats for VDU work, however the tiltable seats were judged more comfortable.

## 8.1 Introduction

It would seem obvious that task requirements would significantly affect sitting behaviour, that is, the person's postural range and movement frequency, but few studies have been done to investigate this relationship. The study was undertaken to collect some base data on normal seated movements which could be used for benchmarking in other studies. These are required for future comparisons of work tasks and equipment designs. The effect of different types of chairs on postural behaviour of adults has also not been studied over longer periods of time (more than a couple of hours) so it is not known to what extent variations in chair design affect movement patterns over longer periods.

Additionally the study aimed to compare two different chair designs at the one workplace, namely, chairs with fixed seat angles and chairs with tiltable seats. The tiltable seats had a mechanism which adjusts the backrest angle to the angle of the seat (synchronized mechanism). This type of chair is common in office furniture today and is often called "dynamic seating". It has an advantage over independent seat and backrest adjustments in that separate adjustment is unnecessary. Separate adjustments require additional manipulation by the users and have the potential for several undesirable combinations, such as, forward sloping seat and forward sloping backrest. This combination would make the sitter very unstable on the chair. However, no scientific studies have been reported on the comparative use and comfort of these chairs.

# 8.2 Method

## 8.2.1 Measuring seated postural behaviour

The seated postural behaviour was analysed using the seated posture classification method described in Chapter 3.2.2.

## 8.2.2 Workplaces, tasks and equipment

Five different workplaces with a variety of chair types were studied using similar methods. The working tasks studied, subject details and the chair types are shown in Table 11 and Figure 35.

**Table 11** Workplaces, subjects and chair types included in the study.

| Task type | Subjects | | | Chair |
|---|---|---|---|---|
| | Males | Females | Ages | |
| Light assembly work | 1 | 5 | 17-46 | A |
| Office work | 5 | 1 | 26-37 | A |
| Listening-lecture attendance | 6 | 0 | 25-45[a] | C |
| VDU work | 2 | 4 | 20-40[a] | A and B |
| Cashier work | 1 | 5 | 20-40[a] | B |
| **Total** | **15** | **15** | | |

[a] Estimated

The tasks varied according to how much manual work is required, but they are all generally carried out while seated. All require concentration and visual attention. The VDU work involved programming tasks in a bank. The workplaces were designed in consultation with an ergonomist and fulfilled all standard ergonomic principles of size and adjustability. The cashier workstations had also been designed to incorporate modern ergonomic principles. The cashiers registered purchases in the grocery section of a large department store. The office work involved varying periods of VDU work interrupted by telephone calls, searching through papers, writing of notes, thought pauses, etc. The assembly work involved welding micro-components onto an electronic circuit board. The lecture was for post-graduate education and included a short video presentation.

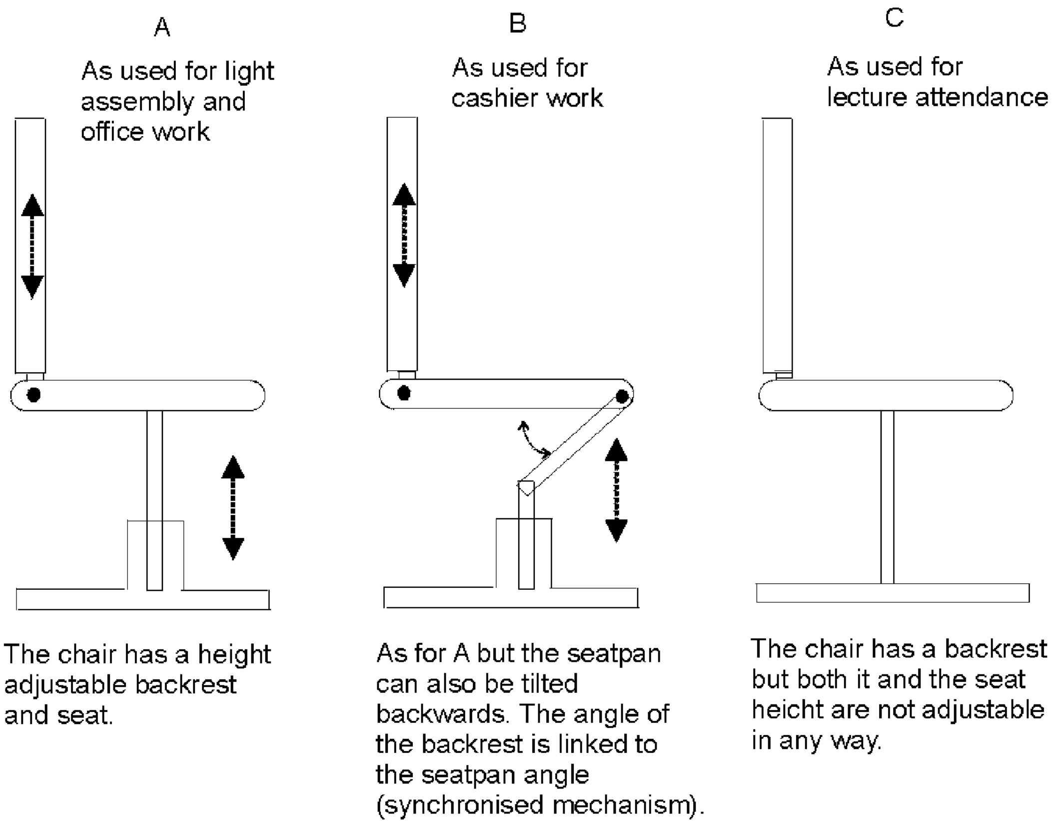



**Figure 35** The types of chairs used at the various workplaces in the study.

### 8.2.3 Observation periods

For validation purposes (see 8.4 Discussion below), the cashiers were observed for two hours each. All the other subjects were observed for one hour at their normal workplace. The position of the observed person was recorded by either direct input into a laptop computer using a barcode reading pen or by manual listing using numeric coding for the positions. Only the last fifty observations for each session were analysed, to avoid the worst of the complications arising from the subjects' awareness of being observed. For the lecture attendance, leg positions and the curve of the back were not recorded due to viewing difficulties.

The VDU workers were given Type A chairs (backrest and seat non-synchronised) a few days before the trial so that they had a little time to accustom themselves to them. The first observation period, was done with the Type A chairs and, after a short pause, they were given back their usual Type B chairs (synchronized mechanism) and observed again for a further hour. Short questionnaires containing subjective rating scales were additionally given to the VDU workers after each chair trial. These questionnaires contained rating scales for comfort and body diagrams for marking any areas of discomfort.

The other subjects performed their usual work on their usual chairs during the whole observation period.

The cashiers were each observed over two hours by two independent observers such that the reliability of the measuring system could be checked. Where appropriate an analysis of variance was performed on the data followed by t-test comparisons. The results should be interpreted carefully as there is confounding by chair type in the experimental design (see 8.4 Discussion).

## 8.3 Results

### 8.3.1 Forward, middle and backward positions

The frequencies of the various sitting positions during the five tasks are shown in Figure 36. The assembly workers, VDU workers and cashiers were found to sit principally in the forwards or middle sitting positions, rarely leaning backwards, whereas the general office workers lean back more often than forwards. The general office workers utilise their seating position options more than the other workers. The listeners at the lecture rarely adopted the middle position. They were noted to sit most frequently with their upper torso weight supported either on the table in front of them or leaning on onto the backrest. There was unfortunately no facility in the matrix for systematically recording the use of arm or back supports.

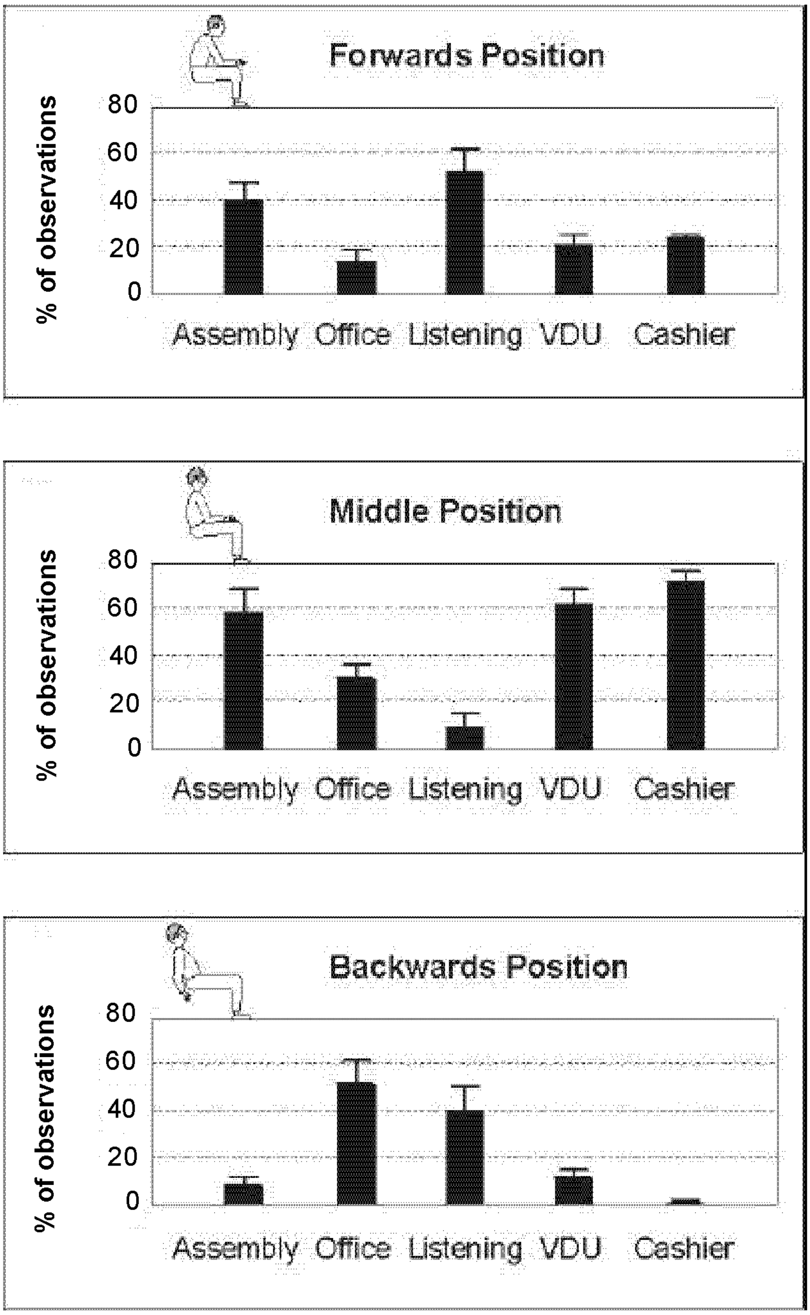



**Figure 36** The frequency of the various trunk positions for the different workplaces. Columns indicate the mean number of observations made during the measurement period. Bars indicate the standard errors. The maximum number of observations for each workplace was 50 during the measurement period.

## 8.3.2 Kyphotic and twisted postures

A comparison of the frequency of kyphotic and twisted postures can be seen in Figure 37. Differences were statistically significant ($p<0.05$) for all comparisons except between assembly and office workers. The general office workers were frequently in kyphotic postures (approximately 80% of the recordings). A common work posture observed in this group was the 'coat-hanger' position, sitting on the front of the chair but leaning the shoulders on the backrest with the back falling into the hollow space at the base of the backrest. This posture was rarely observed in the other groups, who were also less likely to lean backwards. Markedly kyphotic positions were most rarely observed in the VDU and assembly groups. The cashiers were most often observed in twisted positions; however, twisting was still found relatively often at the other work tasks; between 15-20% of the recordings. Statistically significant differences ($p<0.05$) were found between the groups with the exception of the assembly workers and the office workers.

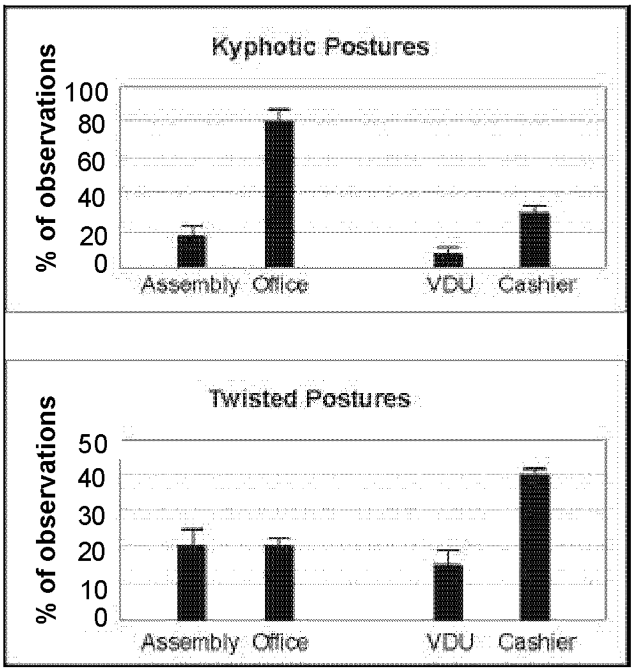



**Figure 37** The relative frequency of kyphotic and twisted postures for the different workplaces. Data was not collected for the listeners due to visibility difficulties. Column height indicates the mean number of observations made during the measurement period. Bars indicate the standard errors. The maximum for each column was 50 readings.

## 8.3.3 Leg position

The position of the thighs is important because this may affect the spinal posture (see Mandal, 1981). In Figure 38 it can he seen that the only thigh position that the cashiers adopt while sitting is position 3. The clearance for their knees at their workstations is very narrow, due to the transport belt installed in the counter, and it does not permit the knees to be crossed, thus virtually eliminating the possibility for positions 1 and 2.

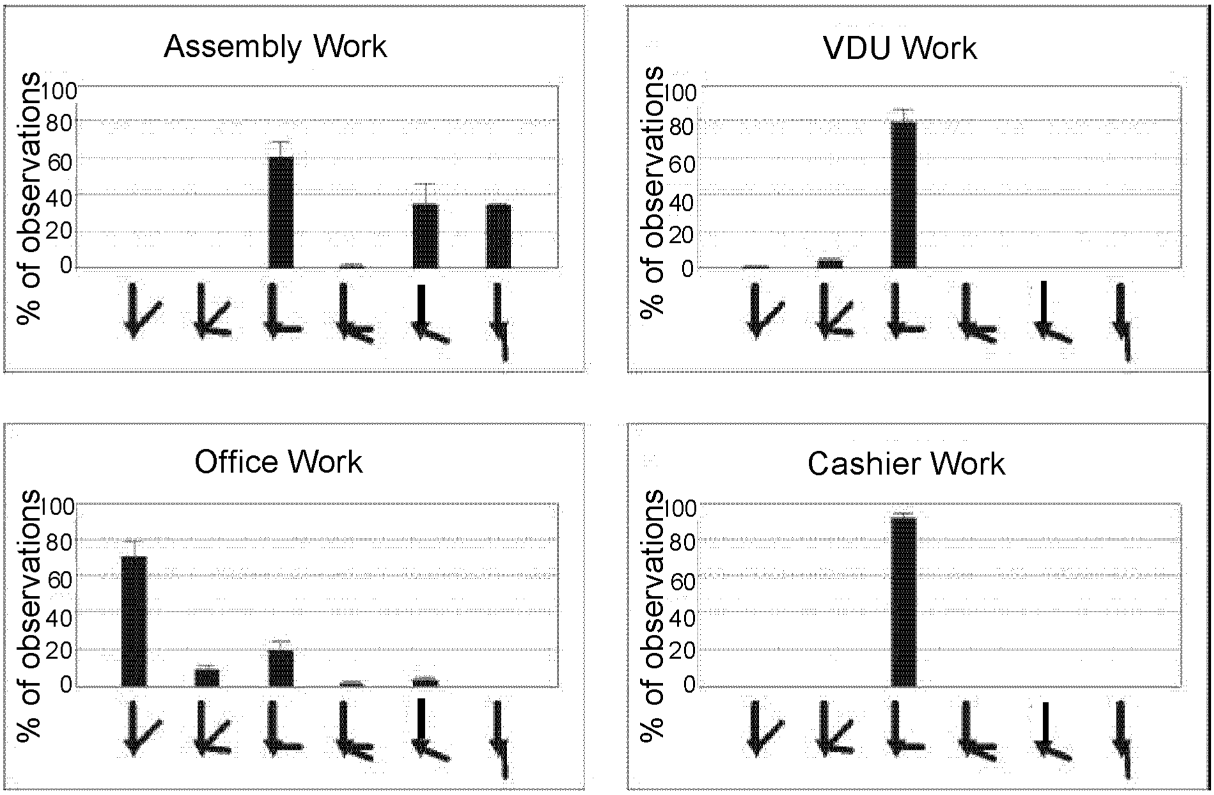



**Figure 38** The frequency of the various thigh positions at the different workplaces. A total of 50 recordings were taken during the measurement periods. However, some data is missing due to visual obstructions which occurred in the workplaces.

Again, the general office workers showed the greatest flexibility with leg position. The assembly workers did not lift their knees above the horizontal but instead moved forward on the seat to tip them downwards. The VDU workers did not do this, but it was seen in the office workers. The assembly workers were the only subjects who were observed to stand during part of the observation period (position 6).

## 8.3.4 Movement frequency

The relative frequency of position change can be seen in Figure 39. The office workers and cashiers changed position most frequently, the listeners least. This result needs to be evaluated in the light of the type of the postures that are adopted, as the degree of movement may be important.

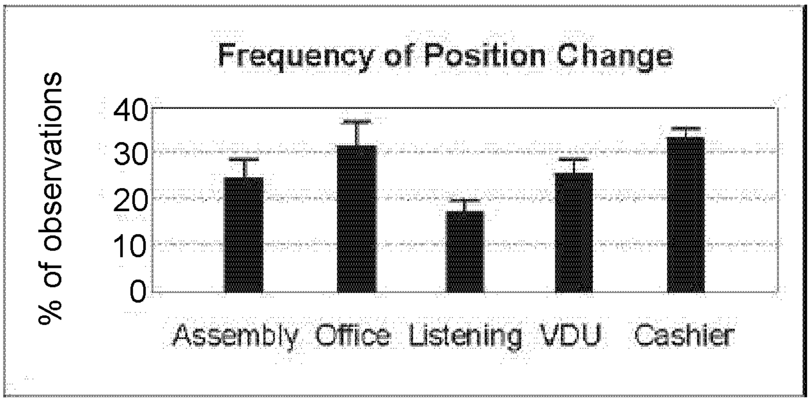



**Figure 39** The relative frequency of position change for the different workplaces. A change of position was recorded when the trunk posture (forward, middle or backward) was altered from the previous recording. Columns indicate the mean number of changes made during the measurement period (maximum 50). Bars indicate the standard errors.

### 8.3.5 The tiltable seats

The comparison between the two different types of chair used by the VDU workers revealed no significant differences ($p = 0.3$) in the observed sitting behaviour for position, lumbar curve or movement frequency. There was, however, a significant difference in the acceptance ratings of the two chairs. The results revealed overwhelming support for the subject's usual chairs, that is, the chairs with the synchronised backrest and seat angle mechanism. All subjects preferred them. They reported feeling more comfortable on them, better supported, and they felt freer to change position.

### 8.3.6 Reliability of the observation method

No significant differences were found between the ratings from the two observers used simultaneously for the cashiering study ($p < 0.001$). In fact, the inter-observer reliability was over 98% on all factors. As a comparative tool the observation matrix, therefore, proved to be quite reliable.

## 8.4 Discussion of the results

It was concluded that task demands have a significant effect on sitting position and posture. General office workers with more varied tasks are more able to make use of multiple sitting options than those whose work is restricted only to VDU work. Seated inactivity eventually produces discomfort. It is unlikely that this could be engineered out with a better distribution of pressure, because of the need to maintain posture by some muscular effort, even in the best of chairs. But how detrimental is the inactivity to health? The epidemiological data available (see Annex A) indicates that prolonged seating is linked to musculoskeletal disorders particularly in the cervical region (see also Grieco, 1986). Coupled with this is the continual mechanical strain on the supporting tissues of the spine and trunk and the nutritional requirements of these structures. Grieco describes a possible process in which protracted work, such as that done by the postural muscles in inactive seating, results in reduced blood flow which eventually results in inflammation, which in time leads to a scaring reaction of both the muscles and surrounding tissues. Pain is furthermore both a consequence of this process and a factor in maintaining it, as pain tends to produce further muscular tension and immobility. Furthermore, as has been mentioned, the spinal discs themselves may rely on movement for their nutritional exchange, as they have no internal blood supply. This is also the case with other postural supporting tissues such as the articular cartilage along the spine. Kraemer (1985) has argued that there is a threshold load limit for disc nutrition processes and that an immobile posture, where the lumbar spine and arms are well supported, prevent this load form being reached (see Chapter 2 for a detailed discussion on this point).

From these and other studies (Andersson et al., 1974; Grandjean and Burandt, 1962), the possibility of relieving spinal loading by bracing of the upper body appears to be very important in seating behaviour. Where the work task permitted, this seating option always appears to be used. The listeners were able to reduce the load on their spines and muscles by almost continual support of their upper body on their desks and backrests. The office workers also relied heavily on the backrest, however, the frequency of the coat-hanger posture in this group calls into question its benefit. These kyphotic postures provide relief for the upper torso but are associated with increased loading of the upper spine, which may offset the gain. This group did not have seats which could be tipped backwards, or angle adjustable backrests. In 1962, Grandjean and Burandt used multi-moment photography to record the postural behaviour of general office workers and found that they most frequently leant backwards and most rarely leant forwards. From the results obtained in this study, this behaviour does not seen to be typical for intensive VDU work, possibly because of the influence of the use of the mouse. The difference, however, may be due to the type of chair used.

Theoretically the synchronised backrest-seat mechanism on the VDU workers' chairs should support the body better in the backwards position. It is furthermore designed to permit easier position change between the backwards and the middle positions; however, the backwards posture was seldom adopted for the VDU task. The VDU workers were significantly less likely to show kyphotic or twisted postures than the office workers. Differences in seated behaviour between the chair types may be found in tasks where the backwards position is more frequently used and kyphotic postures are common, such as in general office work. This question needs to be further investigated. It is, however, possible that the reason for the high comfort and acceptance rating of the synchronised chairs is due to the very short time which was available for the subjects to accustom themselves to the different chairs, or due to aesthetic considerations. The Type A chairs ware not as stylishly designed. Comfort may, therefore, in part be determined by the perceived aesthetic quality of the chair.

Some of the twisting postures of the cashiers may be due to the limitation in their leg movements. The cashiers have swivel chairs and therefore, in theory, do not need to twist their bodies. A small push with a foot would theoretically suffice to turn the whole body and avoid these awkward twisting movements. It is, however, more probable that this activity reflects a biomechanical bias. It requires less effort to twist the upper body than to lift and push with the leg.

It can be seen that the cashiers and office workers change their position most frequently; however, the changes by the cashiers are mainly between only two very similar positions. Their posture is therefore much more static than the office workers who move between all three positions. In this light, the frequency of position change alone cannot be seen to accurately reflect the fixed or active nature of the work. Information is also needed about the degree of movement. The listeners move less often but the change is more significant in that they swap from forwards to backwards.

VDU workers and cashiers are particularly at risk for musculoskeletal problems compared to the other groups (Krueger et al., 1988; Hünting et al. 1981; Ong, 1984) and there is some indication from these results that the reason may be linked more to the restriction in their movements than to the frequency of the position change. Larger movements are likely to be of more value than frequent small changes.

How often should the sitting position change? Movements may be dictated either by the task requirements or by a physiologically driven need for position change. They can therefore be a measure of discomfort rather than mobility. If it is true that people seek to minimise their physical workload, then in an ideally comfortable chair at an ideally designed workplace, no postural changes should take place, but, as has been discussed, this is physiologically undesirable. Is there a mechanism which drives people to change position or is postural activity determined primarily tasks? A suitable range of movements has not yet been clearly defined, nor has the border between dangerous and beneficial movement types or the optimum frequency of change.

From this study, it has been shown that the VDU workers move the least. From other studies, it has been found that they are also the most prone to musculoskeletal problems. It can therefore be assumed that they do not move enough. But can there be too much movement? Very frequent movement probably indicates discomfort or instability. A suitable range needs to be agreed. In this study, there were too few reports of discomfort to make any conclusions relating discomfort to amount of movement, however restrictions to the range of movements, as with cashiers, appear to result in discomfort.

What is the optimal sequence of the changes, or rather, what range is necessary? From this study it seems that the use of all three body positions is necessary - or at least the alternative to move between the forwards and the backwards postures.

# 9 Psychosocial factors

Environmental and psychosocial factors influence back pain associated with seated work. A comparison of the relative importance of these factors to comfort and discomfort at seated workplaces is complicated by little consistency in ergonomics literature about what is meant by the term psychosocial factor.

Musculoskeletal complaints are the highest reported ill-health problem in the European workforce (Paoli and Merllié, 2000). They are closely followed by stress. Several authors have suggested that there may be a connection between the two (see Devereux, 2002). Similar psychosocial factors seem to increase the risk of both, for example, perceived work demands and job control. Although there seems to be an association between stress and musculoskeletal disorders, it is difficult to conclude whether stress reactions are significantly involved in the development of musculoskeletal disorders or whether those with musculoskeletal disorders simply experience stress reactions due to the experience of pain and functional impairment.

To some extent the issue is confused by a lack of definition of the term “psychosocial factors” in the literature. It may be used to describe perceptual differences between subjects, personality, interpersonal relations in the workplace or organisational aspects, amongst other factors (Theorell, 2000). For the purpose of this brief summary of some of the factors that may play a role in seated back pain, these are divided into individual and psycho-organisational factors.

## 9.1 Individual Variations in Comfort Perception

As was discussed in Chapter 2, comfort and discomfort should be considered as separate parameters. When users compare different chairs, differences in comfort and aesthetics are easy to perceive but differences in discomfort are not easy to distinguish (Helander, 2003). Differences in spinal loading are difficult to perceive due to poor proprioceptive feedback from ligaments, joints and the spine. The joints are relatively sensitive to small changes in angle, and the spine cannot sense differences in pressure due to different body postures. On the other hand, two design features are easily detected by users and have a profound effect on comfort. The first, is that the size of the chair must fit the user’s size, and the second is that the front edge of the chair must not hinder the blood circulation to the lower legs. The ease of adjustability has a significant influence on user preference, probably because it is perceived to directly influence comfort, however small differences in seat angle (less than 3°) and height (less than 2 cm) cannot be perceived by normal users. Helander found that ratings of comfort (well being, relaxation, easy of movement, etc.) do not change over time whereas discomfort (pain, stiffness, tiredness, etc.) builds up over a day of work. The results in this paper support Helander's findings. He also found that people with lumbar disc disorders are much more sensitive to discomfort than healthy users, presumably because they get more "powerful and painful feedback" when the spinal pressure increases.

There may also be personality variables which influence perceptions of comfort. Ergonomics research has largely ignored the emotional values of design, although it has recently attracted sufficient attention for an International Conference on Affective Human Factors Design (Singapore, 2003) and a special issue of Ergonomics[4]. Seated comfort may be further improved through research in this area. In any case, positive user impressions, emotions and satisfaction seem necessary to the acceptance of ergonomic measures and in the use of ergonomic features.

## 9.2 Psycho-organisational factors

In a review of risk factors for back disorders Burdorf and Sorock (1997) concluded that gender, height, weight, exercise and marital status do not seem to be consistently associated with back disorders whereas job dissatisfaction and low job decision latitude appear to be important but the evidence is not consistent. Other reviews (Bongers et al, 1993; Bernard, 1997) have concluded that a relationship exists between low back pain and monotonous work, a high workload, time pressures, lack of control, and lack of social support at the workplace. Hollmann et al. (2001) found that the influence of control depended on the level of the physical load. Increasing control was only effective if physical load was low. As spinal load in seated work is low, this indicates that, the effect of individual control, and possibly other psycho-organisational factors may be crucial in the development of back discomfort.

Jensen et al. (2002) studied over 5000 VDU workers in Denmark. They found that high quantitative job demands and low possibilities for development at work were predictors for neck and hand and wrist symptoms. Although they did not investigate lower back pain, they found that repetitiveness was the only factor that could partly explain the associations between symptoms and duration of VDU use, the dose-response relationship. The psychosocial factors appeared to be associated with symptoms independently of the duration of VDU use. This may also be the case for lower back pain.

The incidence of lower back pain in the Swiss population can be analysed according to branch of employment (see Annex A). Unfortunately, the available data (Schweiz. Gesundheitsbefragung, 1997) cannot be analysed for occupation, which would provide more information on the tasks that are most related to higher risks. Nevertheless, it is

[4] Ergonomics. Special issue: Hedonomics – Affective Human Factors Design. 2003. Vol 46. Nr. 13/14.

clear that back disorders are not distributed evenly amongst the population and the distribution does not seem to be clearly related to the amount of movement or spinal loading generally associated with these branches. For example, the frequency of disorders in the building trades is the same as in commerce and marketing. Obviously, other factors, probably many, are involved. A more detailed analysis of the data reveals strong and highly significant correlations between back pain and shift-work, former shift-work, frequent disturbances to work, workload, monotonous repetitive work, noise from co-workers, dusty and dirty workplace, air-conditioning at work and work satisfaction.

The implication of these research findings is that psychosocial factors need to be considered in further studies on seated back pain. Research into biomechanical mechanisms and chair design should not ignore the influence of work organisation and individual factors on lower back discomfort.

# 10 General conclusions

The principle conclusion of this work is that comfort at seated workplaces is dependant, among other factors, on the amount of movement that is possible. This is largely determined by task factors. Chairs, which have a synchronised mechanism that permits the seat angle to be changed, were consistently rated as more comfortable than fixed seats, although people do not always use the mechanism. The use of the mechanism depends on training. Postural behaviour differences were found for seat shape more than for seat slope. The studies indicated that discomfort results from lack of movement but this is probably not due to any increase in spinal load, rather to the load on the musculature of the body and stress on other body systems. Future research is necessary to clarify the effects of organizational factors that influence the perception of comfort at seated workplaces.

## 10.1 An evaluation of the synchronised mechanism

From the above experiments, it can be concluded that freely tiltable synchronized mechanism chairs are generally perceived to be more comfortable by the users but they were not found to result in less spinal loading. The effects on spinal load of circadian rhythm, age, sex and body proportion outweigh the effects of the synchronized mechanism and individual variation in spinal load was found to be substantial even when these factors were controlled. It was concluded that the presence of armrests on chairs may be more important in reducing compressive load than has otherwise been assumed. The advantages of these chairs, is not limited to their effects on the spinal discs, however, as movement has a positive health effect on various other body systems, particularly the spinal muscles. It is very likely that, although the chairs with the freely moving option did not show any significant difference to the fixed upright seats or to regular periods of standing, the facility to be able to alternate between periods of leaning backwards and sitting upright may have more positive effects than those found in this study. On the other hand, it was found that synchronised mechanism chairs often are not used in the freely tilting mode, nor were they shown to substantially improve postural behaviour, so it cannot be concluded that the comfort relates directly to the increased possibilities for movement which they offer. The reason for the greater comfort probably relates to their association with a sense of well-being, convenience or fun rather than any biomechanical advantage. The mechanism may be perceived as comfortable because of the greater control that users feel that they have for altering their position. This perception is based on beliefs and attitudes rather than the real possibility for postural change, as work tasks largely determine postural behaviour.

Back discomfort arising from seated work is multi-factorial in origin and chair design characteristics, although important, cannot be considered the primary factor in its genesis in workplaces today as most office chairs meet basic ergonomic design criteria. These are defined in international standards. Many chairs may be "over-ergonomic" in that they aim to reduce discomfort where users would not perceive the difference. Task demands are more important for the prevention of back pain than chair design characteristics and other psycho-organisational aspects the workplace may be more important.

The conclusion is that chair features such as the seat angle adjustment and the synchronised tilting mechanism may not be as important to the discomfort of normal users as has been assumed. These aspects are probably much more important to users with back disorders, however the responses of subjects with back disorders were not investigated in these studies. The implication of the findings is that a chair needs only to meet some basic ergonomic requirements for avoiding discomfort. The indirect findings in this paper support Helander's view (2003) that these basic requirements are:

- The seat should not be substantially too high or too low for the user.
- The front edge of the seat should not interfere with the circulation to the lower legs.
- The seat back should provide lumbar support.
- The chair should allow an opening of the thigh-trunk angle to more than 110°.
- Pressure should be evenly distributed on the seat as well as on the backrest.

Other aspects are a matter of the user's taste and personal preferences, which depend on beliefs and attitudes. These aspects are incorporated into their perception of comfort. Comfort also depends on perceived control of the chair characteristics.

## 10.2 Implications for future research

The results indicate that future ergonomic studies on seating should focus less on the mechanical and design aspects of the chair and more on the environment in which the chair is used. Training and task organisation are at least as important as the provision of modern adjustable chairs.

At least two further studies are clearly necessary to answer questions which have been raised by the results of this study. The first relates to the involvement of armrests in reducing spinal load. This needs to be investigated further as the results of this study and comparisons to other studies indicate that armrests may be more important than generally believed. Shrinkage due to compression at the level of the cervical spine should also be further investigated, particularly as it relates to activity levels. It is conceivable that larger differences occur in this region in response to movement than occur in the lumbar spine.

The synchronized mechanism chairs are not fully utilized in real workplaces. A further study is indicated to find out why this is the case.

# Annex A. Incidence of back pain and social implications

Traditionally it has been known that back pain may result from heavy lifting or from accidents such as falls or collisions. The results of the European Foundation Study conducted in 2000, (Figures 40 and 41) support this view in that agricultural and craft workers, machine operators and persons in elementary occupations show a higher than average frequency of reporting of backache. In this survey, occupations which are generally associated with seated work show a lower incidence of back disorder, however even in this “low risk” group approximately one in five persons report backache.

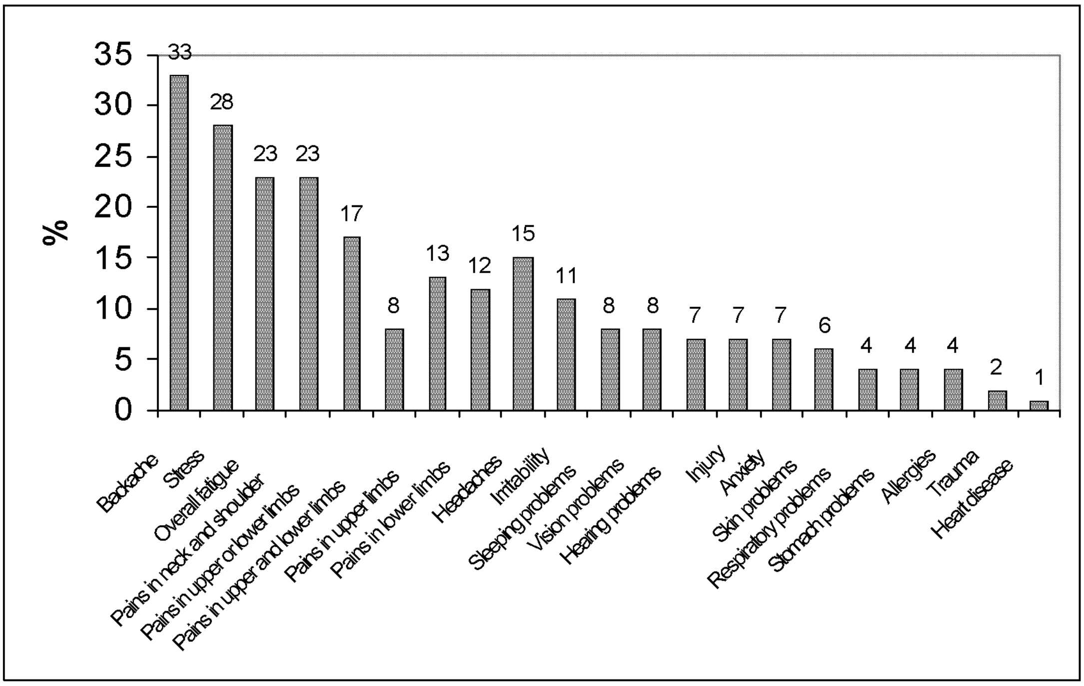



**Figure 40** Frequency of reports of health impairment of workers due to specific problems as found in the Third European Survey on Working Conditions, 2000.

Once the amount of heavy manual work declined, it was expected that the incidence of back disorders in the community would be reduced. This has not proven to be the case although a great deal of effort has been put into the regulation of heavy work and into prevention campaigns aimed at reducing the frequency of accidents. These efforts have had little effect on the incidence of back pain in the industrialised world (see Grieco, 1986) and the subject of compensation for back pain sufferers is a sensitive issue in many countries. The overall costs to the community are enormous both in financial and social terms.

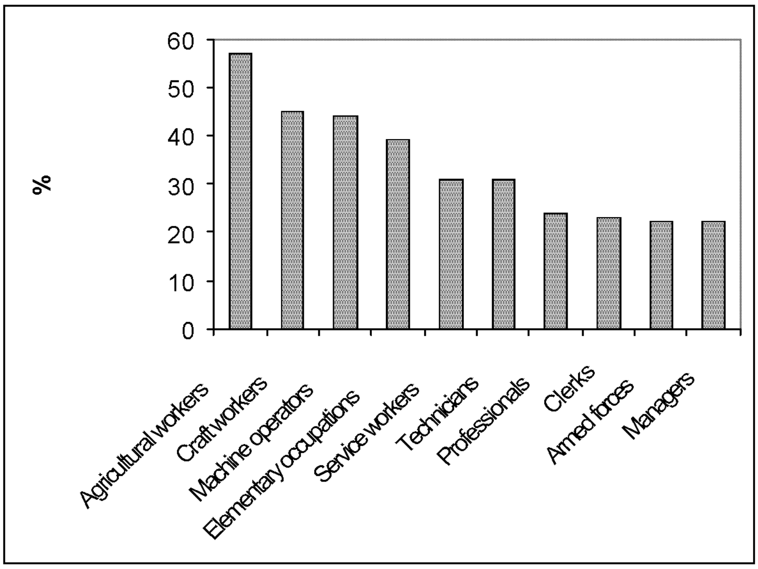



**Figure 41** Frequency of reports of back pain by occupation (European Foundation Survey. 2000)

Figure 42 shows the incidence of lower back pain in the Swiss population according to branch of employment (Schweiz. Gesundheitsbefragung, 1997). Unfortunately, the data cannot be analysed for occupation, which would provide more information on the tasks that are most related to higher risks.

The compensation and health care system in Switzerland demonstrates how this country has distributed the cost of back disorders over a wide base which makes it hard to obtain accurate statistics from which the causal mechanisms could be inferred. In Switzerland the Workers Compensation Act (Unfallversicherungsgesetz) obliges insurers to compensate and provide for the livelihood of workers who are injured as a result of accidents and occupational diseases from the time of disability until death. Workers Compensation insurance is compulsory for all workers with contributions being equally levied on employers and employees. This insurance covers both workplace and non-workplace accidents. In the case of diseases, a distinction is drawn between disorders due to workplace and non-workplace factors. Only the former are covered.

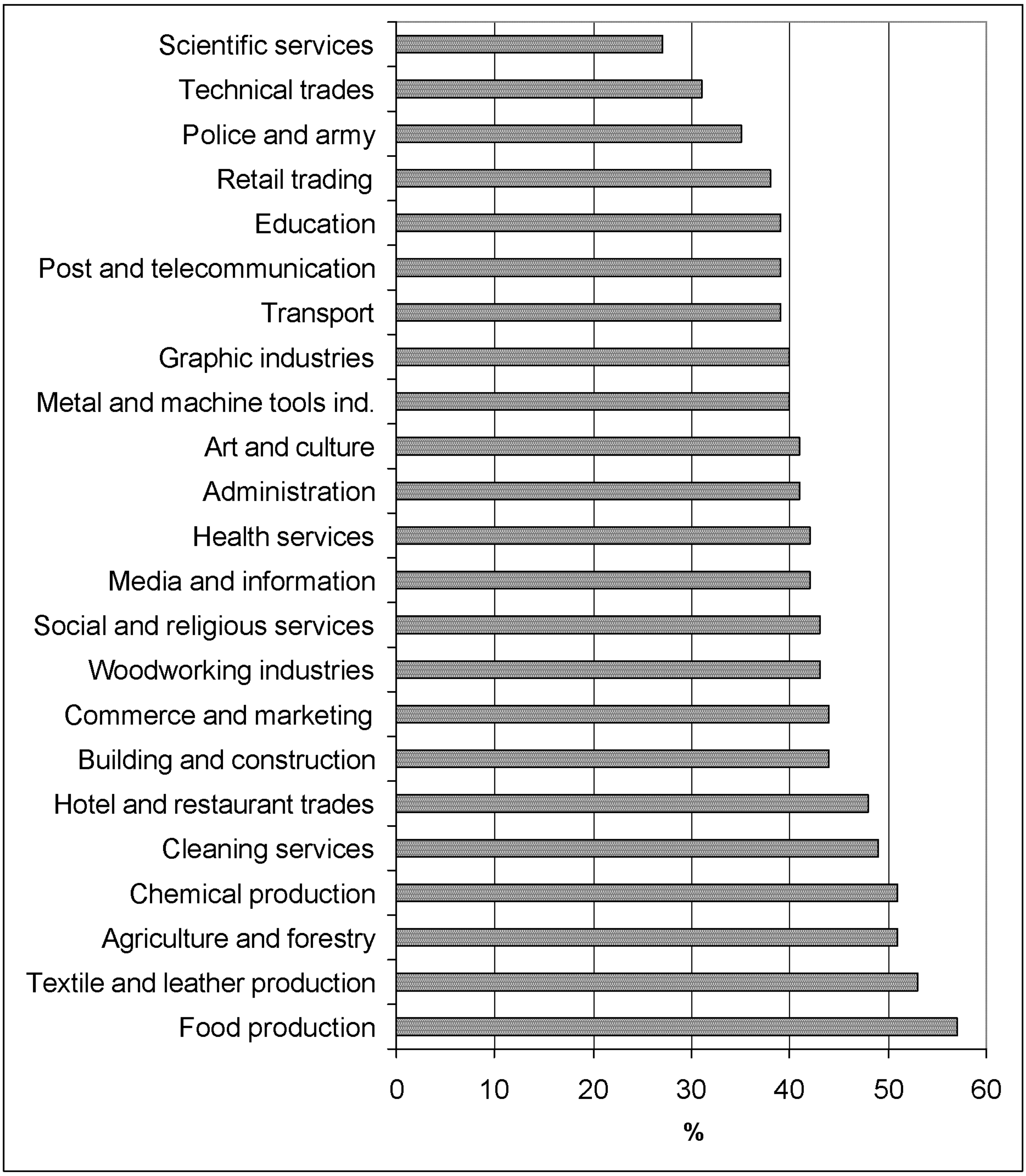



**Figure 42** The frequency of lumbar disorders according to branch of employment in Switzerland. (Source: Swiss National Health Survey, 1997).

An occupational disease is one which is contained within a list of specified disorders compiled by the state insurer (SUVA). This list is reviewed from time to time and is compiled with the criterion that the diseases it contains must be due "mainly to harmful substances or prescribed activities". Other diseases may be compensated if it can be shown that they are caused "exclusively or very predominantly by occupational activities". The definition reflects more a legal perspective than any medical criteria, as the attribution of causality cannot from a medical viewpoint generally be attributed with such certainty. A back disorder therefore entitles the sufferer to compensation if it results indisputably from an occupational accident. Degenerative types of back disorders are not included within the list of recognised occupational illnesses, with the justification that they are not due exclusively to work but can arise from many other causes. The result of this legislative distinction is that back disorders which result from slower degenerative processes are not generally accepted for compensation and are therefore not represented within the compensation statistics.

Due to the legally prescribed format of the Swiss accident statistics, it is also not possible even to identify the frequency of back-related accidents. The statistics are not collated according to the type of injury, but rather to the cause of the accident and the type of workplace. The data are subdivided for sex and nationality, overall cost and time off work (SUVA, 1995). This reflects a strong orientation towards industrial accidents and their prevention in the Compensation Act. The frequency of work-related back disorders in Switzerland cannot therefore be accurately determined, or even inferred, from the available compensation statistics but an indication can be obtained from other sources of information such as health statistics from other sources. Health insurance is compulsory in Switzerland, and persons who are unable to work because of degenerative back disorders are eligible for health insurance payments. However, due to the privacy laws, the Health Insurance companies are not generally able to obtain specific information about the nature of the disorders that they are covering. On the other hand, disability insurance is also compulsory for all employed persons and is levied from salaries. In the statistics of the disability insurance, back disorders might be placed into either of two categories, namely, “paraplegia/tetraplegia” and “other musculoskeletal disorders (excluding legs and feet)”. These two categories account for approximately 15% of the persons receiving disability benefits, of which the second category is by far the most numerous (Bundesamt für Statistik, 1994). This figure can be compared with statistics collected from the general medical practitioners relating to the frequency of disorders resulting in medical consultations. Lower back disorders are the 8th most frequent reason for patients to seek out a general medical practitioner in Switzerland (Landolt-Theus, 1992).

How many of these cases are primarily attributable to workplace activities cannot be accurately stated. It is necessary to compare these figures with statistics from other comparable lands and the results of workplace epidemiological studies.

Statistics from the United States have the advantage that they are less likely to be biased by the legal issues relating to the definitions of disease and accident than those of Switzerland. Most employees in the USA are insured through their employment for both accidents and illnesses. The distinction between accident and disease is therefore less of an issue, although disputes about the involvement of workplace factors in the aetiology of diseases are still common especially within the Common Law domain of negligence suits. The US Bureau of Labor Statistics estimated in 1994 that back disorders accounted for over 15% of cases involving days away from work.

The most comprehensive study of the links between workplace factors and musculoskeletal disorders which has been attempted to date is the meta-study which was conducted by the National Institute for Occupational Safety and Health (NIOSH, 1997). In this meta-study, over 600 epidemiological studies conducted in multiple countries on musculoskeletal disorders were reviewed. It excluded publications in languages other than English. The study found that there was strong evidence linking workplace lifting and forceful movements and whole body vibration to the development of back disorders. Evidence of work-relatedness was also found for back pain due to awkward postures and heavy physical work. Furthermore, there was strong evidence that work posture was a risk factor in the development of neck disorders. On the other hand, NIOSH found insufficient evidence to support a connection between static work posture and the development of back pain (presumably lower back pain). This finding is not a finding of no effect. Rather the study concluded that the reviewed studies were either too few in number, consistency, quality or statistical power for a conclusion to be made. The question of whether static work postures, without other mediating factors, can result in back disorders therefore remains open according to the study.

There has been a lot of attention focused over the last two decades on the incidence of back pain in office workers so the results of the NIOSH study are somewhat surprising. Magora (1972) first reported a high incidence of low back pain in persons sitting for prolonged periods or unable to stand at all during the working day. He found almost a complete absence of low back pain in those sitting at work for brief, repeated periods. In 1986, Grieco reviewed the literature from various countries on this theme and concluded that ‘postural fixity’ can increase the frequency of spinal disorders but he also pointed out the deficiencies in the studies which were available. He was particularly concerned about the changes in office work brought about by the introduction of VDT workstations. At the time of his study, little distinction was made between lower back pain and cervical disorders.

One of the principle problems for the NIOSH (1997) reviewers was that workplace physical activities were often not sufficiently well described in the studies for a conclusion to be drawn. They felt that the observed high incidence of lower back disorders amongst office workers in several studies might have been due to other confounding factors. For example, this type of work may attract workers from other occupations who have been forced to reduce their physical load because of previously incurred back disorders. Additionally psychosocial factors such as monotonous work content, low work-satisfaction and non-occupational stress factors have been found to be risk factors for spinal disorders amongst office workers (see Michaelis et al, 1997). The broad classifications “office work” or “VDU work” does not necessarily mean that the work involves static postures. Seated work may be interspersed with frequent periods of static postures. Seated work may be interspersed with frequent periods of standing and other postural adaptations depending on the tasks and situation at hand. This topic will be covered in more detail later in this work.

In summary, it can be concluded that the incidence of back disorders is high across the industrialised world but it is not generally known exactly how high or to what extent the problem is related to workplace factors. The community costs, both financial and human, are high enough to warrant further investigation of the causes, particularly of those problems where slow degenerative processes are suspected to be involved.

# Annex B. Stadiometric measurements

## The relationship between workload and spinal load

Because of the high prevalence of back pain in the population, the evaluation of the effect of seating on the incidence of back pain has been of major interest to ergonomists, physiologists and medical scientists. Ideally the evaluation of the effects of working situations is made directly by examining their relationship to health consequences, however, this requires longitudinal epidemiological research, and in this case, because of the complexity and multi-causality of back pain, this type of research is extremely difficult. Health consequences have, therefore, generally been inferred by an examination of the effects of different loads on measurable changes in the spinal tissues. However, as has been stated in the body of this work, the link between spinal load and health consequences is not as linear as was originally believed. This section, nevertheless, reviews the work that has been done on spinal loads, particularly in relation to the validity of the various methods used. The stadiometric method is discussed in most detail as it was used in this work.

## Measurements of intradiscal pressure

The first experiments into intradiscal pressure (IDP) were done by Andersson and Nachemson (1974). They inserted a pressure-sensitive needle into the nucleus of the disc between the 3rd and 4th lumbar vertebrae of live subjects and then calibrated their findings against cadaver studies. They found that sitting in an upright posture increase IDP by 40% compared to standing. Sitting in a backwards position (recumbent) on the other hand reduced IDP by 75% and sitting with a kyphotic posture increased it by 85-150%. The cadaver experiments were most likely done when the discs were superhydrated, as they had not been under any load for some time. This introduces a potential source of error, as the relationship between the applied load and the pressure in the nucleus is altered. It constitutes a systematic bias in the results. Experiments on cadavers have several other drawbacks. Supporting structures around the discs often have to be altered to allow access. For example, the longitudinal and supraspinatus ligaments are often removed because they contain fibres which span several vertebrae. The influence of the supporting structures may therefore be overlooked. Post-mortem changes may also affect the mechanical properties of the tissues. For example, body temperature makes ligaments more extensible and alters the rate of disc creep (Adams and Nolan, 1995).

More recent *in vivo* studies have attempted a replication of Nachemson et al's experiments. LeLong et al (1992) used a piezo-resistant pressure sensor to compare the effect of various seat types. They found that a seat angle of 10° forwards slope decreases IDP by 30% compared to a horizontal seat. The effect does not increase at an angle of 15° and variability is greater. They attributed this to the increased muscular load, as earlier studies in the same laboratory (Drevet et al, 1990) had found that contraction in the paravertebral muscles increases IDP by 100-400%. Their studies agreed with Nachemson et al's findings in that kyphotic postures substantially increased IDP. The use of a lumbar support reduced it by up to 15% and arm support by 5%.

In a further series of studies Wilke et al (1999) concluded that the intradiscal pressure during sitting (sitting unsupported, 0.46 Mpa) may in fact be less than that in erect standing (0.5 Mpa). Their findings agree with the previous studies in that kyphotic postures and muscle activity increase pressure. They found that during the night, pressure increased from 0.1 to 0.24 Mpa, indicating that constantly changing position is important to promote flow of fluid (nutrition) to the disc. They used only one subject for these experiments but Rohlmannt et al (2001) using a different technique (an internal spinal fixation device for stabilising unstable spines) with 10 patients also found slightly lower loads for sitting than for standing.

The advantage of IDP measurements is that the effects of various combinations of loads can be investigated, for example, posture and vibration. They permit a quantification of the effects of the load but have disadvantages in terms of personnel required and equipment. They are generally not practical for field studies and have the limitation that the movements of the subjects are unlikely to be very natural. Additionally, the size and shape of discs is crucial to their function, as well as age and posture, so the validity of studies on small numbers of subjects is questionable.

To overcome these problems researchers have tried to estimate compressive load by the use of biomechanical models. These models use body weight, the extensor moment of the back muscles and gravitational force to calculate the spinal compression. The models rely on the accuracy of the estimates of the lever arm (extensor moment) of the back muscles. The modellers are also obliged to make simplifications about the behaviour of complex materials and structures.

The precise measurement of body-height shrinkage answers the need for a non-invasive method which can be applied in field studies. It measures spinal load directly from workload and individual capacities can be compared. Nevertheless, as with IDP and biomechanical model methods, the relationship between the loads and their health consequences has not yet been determined. Health consequences do not depend only on spinal load, but are influenced by age, health, sex and other factors.

# Stadiometric investigations of spinal load

## Circadian rhythm and external loading

It has been known since last century that people shrink in height over the course of a day and regain height during the night (Bencke, 1897). De Pukys (1935) compared the morning and evening height of 1200 people and found that the amount of shrinkage depends on age. The average for his subjects was 1% height loss over a day. Children decreased in height by approximately 2% during the course of a day whereas 70-80 year olds shrank approximately 0.5% of their height. This circadian variation was studied on young men using a more modern and accurate method by Tyrrell et al. (1985). They found a mean variation of 1.1% of stature with 54% of this taking place within the first hour after rising. Wilby et al (1987) monitored 10 young females over the course of a day and found a mean variation of 0.92% of stature.

Loading on the shoulders has been shown to result in increased spinal shrinkage (Fitzgerald, 1972; Kraemer, 1973) and spinal traction, a common medical treatment, has been shown to result in an increase in body height (Worden and Humphrey, 1964). An increase in body height of up to 5 cm has also been reported for astronauts after spending days or weeks in weightlessness (Jayson, 1981). De Pukys held the opinion that the height loss took place in the spinal discs as a result of loading. This opinion was supported by Kraemer (1980) who concluded that it resulted from pressure dependant fluid shifts.

Eklund and Corlett (1984) first proposed using the measurement of height loss as a non-invasive indicator of spinal loading. They based their reasoning on the work of Markolf (1972, 1974) and Kazarian (1975). Kazarian had found that the rate of reduction of disc height decreases over time until the disc is in equilibrium with its load. As disc height increases, the stiffness of the elastic modulus increases.

In real life the spine is loaded by forces and torques in a plane perpendicular to the disc as well as by forces and torques parallel to the disc but the height loss seems to be caused principally by the compression forces (van Dieen and Toussaint,1993). It is not known whether forces parallel to the disc and torques can lead to any height loss, or whether they mediate the height loss due to compression forces.

### A mathematical model and the characteristics of disc height change

Burns and Kaleps (1980) calculated a model to describe mathematically the visco-elastic response of the discs. To do this they used a three parameter Kelvin solid model. The model describes disc height (H) as a function of time (t) in Equation (4) where $A_1$, $A_2$ and K are constants.

$$H(t) = A_1 + A_2 e^{-Kt} \quad \text{(Equation 4)}$$

The model is illustrated in Figure 43. Eklund and Corlett (1984) found that the model gave a very accurate description of height loss under constant axial compression. They applied it to data obtained from subjects over the course of 8 hours after rising from bed and were able to find a fit for the constants A = 1876.5, B = 14.1 and K = 0.186.

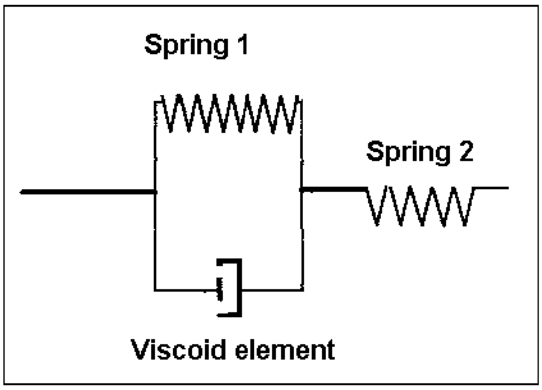



**Figure 43** The three-parameter Kelvin solid model of the disc under load proposed by Burns and Kaleps (1980).

Since these initial studies various authors have used height loss to examine the effects of axial compression (vertical loads) on the spine. Althoff et al (1992) found a linear relationship between proportional load, scaling for the cross-sectional area of the discs, and height loss when subjects wore a 30 kg vest. They did not include upper body mass in the calculation so the exact relationship between load and height loss was not determined. Tyrrell et al (1985) found that with increasing weights between 2.5 and 40 kg on the shoulders the height loss was not linear. They also found that repetitive lifting resulted in greater shrinkage than the equivalent static loading. Köller et al (1984) also found that when the load is varied the shrinkage response is not linear. The rate of deformation is greater in intermittent loading as compared to, on average, equally large continuous loading. Van Dieen and Toussaint (1993) have suggested that this effect may be due to the cumulative effect of subsequent peak loads with insufficient recovery time. They noted that the initial deformation at loading seems to be larger than the initial recovery at unloading so that if a further load was applied before recovery was complete an increased effect may be found.

## Applied work studies using stadiometry

De Looze et al (1996) studied the effects of weight and frequency on spinal shrinkage in a bricklaying task and found no effect on shrinkage for the different regimes in the study. Wilby et al (1987) found that height losses from a given spinal load depend on the circadian variation as well as the isometric strength of the back muscles.

In another experiment, Van Dieen et al (1993) compared the effects of the leg-lifting (lifting from floor with bent knees) and back-lifting (lifting from floor with legs expended) techniques but also found no shrinkage difference between the two techniques. The older subjects shrank more with the back lift and tended also to do so with the leg lift. Schultz et al (1995) used stadiometry to investigate the effectiveness of various rest activities following lifting exercises. They found that regains in stature were most effective when the subjects lay on their sides with knees and hips flexed on a vibration table. Regain of stature did not occur if the subject sat on a chair. Gravity inversion, that is, lying on a table tilted at 50° to the horizontal with the head lower than the feet, produced an intermediate recovery.

Other studies have examined the effect of vibration on height loss with varying degrees of success. Brisland and McGill (1989), for example, studied the effectiveness of a suspension seat in vehicles, and concluded that the seats were no better than wooden chairs in reducing spinal shrinkage, however they used only one level of vibration. In reviewing the studies on vibration and height loss, van Dieen and Toussaint (1993) concluded that the relationship depended on the frequency of the vibration. They further concluded that, because of the tensile forces at work, the application of spinal shrinkage techniques is inappropriate for studies of the effects of vibration.

The method has, however, captured the attention of sports physiologists and ergonomists interested in the effects of different types of physical training. Boocock et al (1988) used the method to investigate the effects of the bounding and jumping regimes used in 'plyometric' training and pre-training periods of gravity-facilitated traction (inversion). This type of training has also been the subject of studies by Fowler et al (1994, 1997) with drop-jumping and pendulum swings as experimental variables. Garbutt et al (1990) examined the effects of spinal mobility exercises prior to training compared to Old warm-up exercises. Reilly and Chana (1994) used stadiometry to assess the effects of fast bowling in cricketers on back load. In these studies significant differences were found between regimes.

In a different application of the method, Hutchinson et al (1995) successfully used stadiometry to investigate the effects of gravity-facilitated inversion (head-down tilt) to develop a procedure for simulating microgravity in order to investigate the effects of spinal expansion and back pain in astronauts.

There have been stadiometric studies done in real work situations, including seated work. Foreman and Troup (1987), for example, studied stature loss during nursing duties. Ericson and Goldie (1989) studied the effects of different types of chairs used during 8 hours of real workplace VDU work. In these cases, it was not possible to strictly control the amount of loading. The relative measurement difference between groups is therefore more important than the absolute measurements. The studies done on seating and office work will be covered in more detail in the section on The Theory of Active Seating. Suffice it here to say that the method has proved sensitive enough to detect differences between different sitting conditions.

Following a review of the literature on spinal shrinkage as a parameter of spinal load van Dieen and Toussaint (1993) concluded that the method showed promise as a means for providing more insight into the relationship between work bads and their physiological consequences. They concluded that the method appears to be sufficiently sensitive and accurate for comparing different workload situations and that it has some advantages over other methods. It nevertheless has some limitations in terms of reliability and several questions remain open concerning its validity.

## The reliability of the spinal shrinkage measurement method

A number of factors have been found to influence the reliability of stadiometric measures. It has generally been necessary to control for recent loading history and the time of day as both of these factors significantly influence the results. Althoff et al (1992) have developed a method to control for time of day, making the second factor less of a problem.

A large degree of unexplained inter-individual variation has nevertheless been found in most studies. The age and sex of the subject play a significant role in this variation. It is therefore necessary to control for these factors. Althoff et al (1992) found a relationship between disc area and height loss, which may account for the sex difference as females have a smaller disc area. It has been suggested that the inter-individual variation may reflect the discs state of degeneration and would therefore be a useful diagnostic tool (Eklund, 1988). Further investigations of the inter-individual differences may therefore shed light on the differences between the capacities of different workers.

Errors from changes in posture are the most serious potential deficiency of the stadiometric technique and various methods have been devised to reduce this source of error. Most of the methods used in the last decade are based on the method developed by Eklund and Corlett (1984). In their original experiments the subjects were measured standing on a 5-15° backward inclining surface. The subjects leaned against a number of plates which were individually adjusted to fit the subjects' body contours. The distribution of the weight over the feet was controlled as much as possible and reproduced for each subsequent measurement. The knees were kept extended by positioning of the feet slightly forward of the pelvis. Micro-switches were used to control for contact with adjustable supports at key points on the body. The head position was controlled by the use of spectacles with extensions on the arms which had to be lined up with marks on a mirror in front of the subject. The measurements were taken on the top of the head by lowering a contact probe attached to a linear transducer. Subjects are asked to relax as much as possible to control for the effects of muscular effort. This is also partially controlled by the backwards lilt of the apparatus, which forces subjects to "lie" into it.

Various modifications of this method have aimed to further reduce measurement errors due to posture. Helander and Quance (1990) modified Eklund's stadiometer by adding a horizontal arm with a mouthpiece attached onto which the subject had to bite. With this modification, the large variability introduced by head movement was substantially reduced. Althoff et al (1992) removed head posture as a source of measurement error by measuring height at a point marked on the neck. This resulted in a marked improvement in measurement reliability but has the disadvantage that cervical shrinkage is no longer included. They were further concerned about the effect of heel compression so performed corrections on the data to take account of this. Foreman and Linge (1989) proposed waiting 2 minutes after standing up before taking the measurements, as heel compression occurs quickly. This factor also concerned Hol et al (1992) who measured the height of the anterior superior iliac spine and concluded that inclusion of the lower limbs in the height change resulted in an overestimation of the length changes. They decided to use a seated method for future studies.

The question arises of where within the regions of the spine the most shrinkage takes place. Van Dieen et al (1993) used markers on the S1 and T12 vertebrae along with height measurements on top of the head. They found that the reading at T12 gave a good estimate of the total shrinkage.

A further source of measurement error arises from the subjects' inexperience in reproducing their posture. Various criteria have been used to train the subjects until they were able to reproduce measurements with sufficient reliability. Klingenstierna and Pope (1987) repeated measurements until the standard deviation of 10 successive measurements was less than 1 mm. Foreman and Troup (1987) trained the subjects until the standard variation was less than 0.5 mm. Van Dieen and Toussaint (1993) report that all authors achieved a reproducibility of error below 1 mm. The reproducibility depends on the subject's co-operation, co-ordination and propriocepsis. For some subjects the training period can last as much as an hour but most subjects require much less time.

There is also a methodological difficulty when the effects of different postures on spinal loading are investigated. This is particularly relevant in seating studies. The subject has to change posture to be measured, and this postural change results in changes to the pressures on the spine which may affect the measurements. In order to minimise this source of error the time between the experimental condition and the measurement is kept as small as possible. Because of the non-linear nature of the shrinkage and recovery, the greatest effect is evident within the initial time period. This has been termed the 'instantaneous creep' (Ericson and Goldie,1989) and means that the magnitude of the change which is measured may be systematically underestimated. The measurement is always of the residual effect after the period in which the subject stands up, walks to the stadiometer and positions themselves in it.

In order to investigate the effects of vibration while seated, Jafry and Haslegrave (1992) developed a stadiometer for measuring height while seated then compared the results with those obtained from a standing stadiometer. They found a significant difference between the two sets of data and concluded that the transfer from a sitting position to a standing position could have a considerable affect on the results. Their findings indicate that the standing stadiometer systematically underestimates the amount of shrinkage that takes place and results in more variability of the measures. A substantial disadvantage of their method, however, is that it cannot be used to compare different types of chairs or real workplace seated tasks as the measuring apparatus is the chair in which the subject sits.

## The validity of the spinal shrinkage measurement method

The validity of a method depends on its congruity with other methods and related knowledge. According to van Dieen and Toussaint (1993), the stadiometric method correlates well with comparisons of subjective ratings of load. As has been mentioned it also fits well with the previously described model of loading factors, capacity and health consequences. This gives it construct validity, but a quantitative precise relationship between load and stature loss has not yet been conclusively established. Most of the studies have been done in practical situations where a precise measurement is not possible.

It should not be assumed that height loss only occurs in the spinal tissues. To quantify the possible contribution of heel-pad changes Althoff et al (1992) evaluated height difference by measuring between points marked on the lateral maleolus and the vertebra prominens. They assumed a negligible contribution from length changes in the femur, tibia, knee joint and hip joint. They found that compression changes in the tissues of the heel contributed between 0.1 and 0.7 mm to the measurements after 30 minutes of sitting. The difference depended on how much weight was on the feet while sitting. It has also been suggested that pelvis height should be measured in addition to body height such that corrections can be made if necessary (van Dieen and Toussaint, 1993). A limitation of the methods used to date is that they give little indication of the distribution of the shrinkage across the spinal column. Refinements of the technique with further markers will prove valuable in this regard.

Another limitation of the use of stadiometric measurement techniques is that they concentrate on the effects of compression forces. The effects of other forces have been largely ignored. Investigators using the method also tend to ignore loading on the apophyseal joints. Most importantly further studies need to be done on the chemical changes within the disc which result from the loading, such that the validity of the technique for predicting disc degeneration can be evaluated.

In spite of the drawbacks outlined above the technique of stadiometry has been shown to be a valuable indicator of the risk from one aspect of workplace loads, that is, the compression forces, which act on the spine. The method is relatively cheap and non-invasive, which makes it very attractive for workplace studies. Disadvantages in this regard are that training of the subjects may be time-consuming and the work needs to be interrupted for the measurements. A number of studies on sitting and chairs have been done using stadiometry.

# Previous stadiometric studies on sitting

Ericson and Goldie (1989) used spinal shrinkage as an indicator of the effects of sitting on three different types of chair, a chair with a horizontal seat, a 'Balans' chair with a forward sloping seat, and a chair with a horizontal back section but forward sloping front section. The study was conducted in real workplaces with eight VDU workers. Shrinkage was significantly greater on the Balans chair after three hours of sitting with no significant difference between the other two chairs. They concluded that the difference was most likely due to the absence of the backrest. Newer studies on intradiscal pressure (Drevet et al,1990, Lelong et al, 1992 and Wilke et at, 1999) indicate that the muscular effort required with the 15° forward slope of the Balans chair would have produced the increased shrinkage.

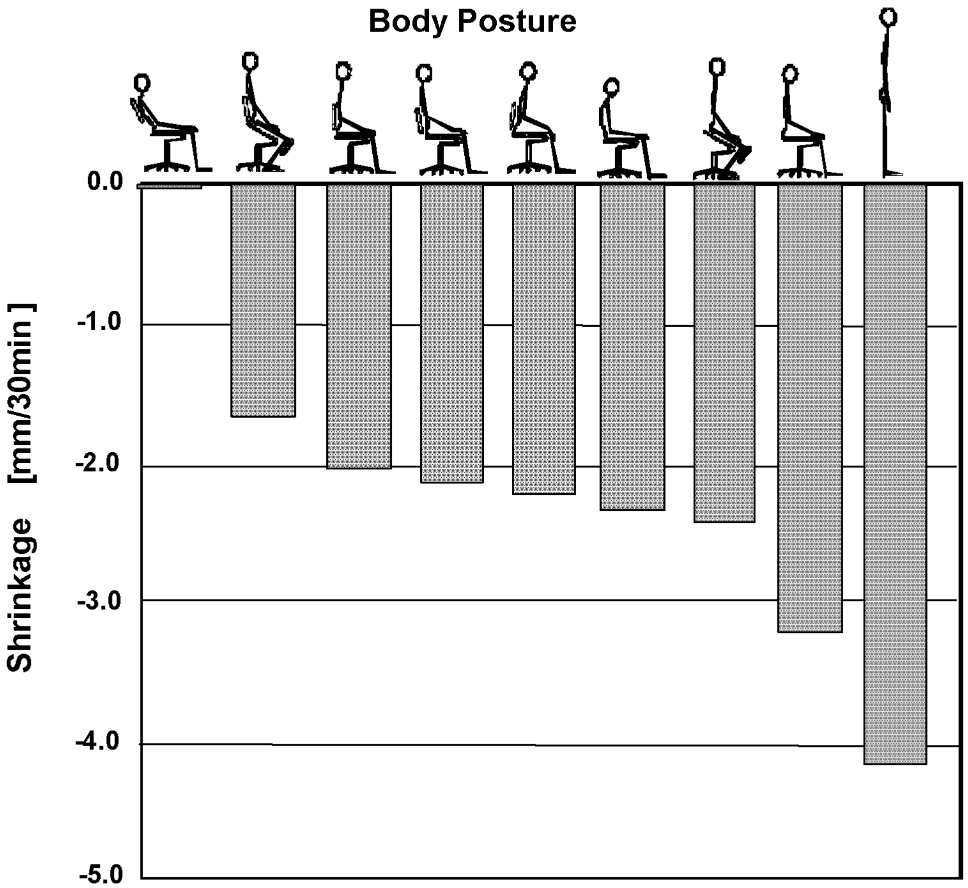
Althoff et al (1992) found that compared to sitting on a horizontal chair with a backrest, sitting on a Balans chair increased shrinkage if no backrest was available and decreased it when the chair had a backrest, confirming Ericson and Goldie's supposition. They compared sitting under the following conditions;

- erect sitting on a stool,
- relaxed sitting on a stool,
- sitting on an office chair with a lumbar support,
- sitting on a forward inclining seat with a vertical backrest,
- sitting on a chair with a forward inclined seat and a forward inclined backrest
- sitting on a Balans chair (forward inclined seat and knee support)
- sitting on a Balans chair with a lumbar backrest and
- sitting on an office chair with a 30° backward inclined back-rest (120° from the horizontal) and arm support (the easy chair).

They used a repeated measure design and 10 subjects and corrected for the change in heel-pad thickness. Measurements were made after 30 minutes of walking followed by 30 minutes of sitting. Stature increase was greatest for the easy chair and least for the unsupported erect sitting. The results are displayed in Figure 44. Women had a larger height increase than men which, they found, reflected their smaller cross-sectional disc areas. The amount of shrinkage across all subjects correlated significantly with disc area. A significant difference was found between sitting in the easy chair and all of the others. Leaning backwards onto the backrest during sitting resulted, in the least shrinkage.

Althoff et al concluded that spinal stress while sitting was less than during standing regardless of chair type, although the difference was not always statistically significant.

This conclusion is in contrast to the conclusions drawn by Andersson et al (1974) using intradiscal pressure measurements in that they found that sitting loads the spine more than standing. Althoff et al argued that the difference in results was unlikely to be due to measurement error. They proposed that because Andersson et al's intradiscal meas-




urements were calibrated to in vitro cadaver measurements they may have been misled. They further commented that in the older experiments there was no consideration made of the relative angle between the vertebrae, which has subsequently been found to play a substantial role in intradiscal pressure. The more recent *in vivo* studies of intradiscal pressure by Lelong et al (1992), Wilke et al (1999) and Rohlmannt et al (2001), have also found that intradiscal pressure while sitting may be slightly less than in standing but they also indicate that the most important factor is body posture and muscular effort. This accounts for the effect of the backrest and body posture. It should also be noted that the IDP measurements only considered pressure in one disc, not over the whole spine.

**Figure 44** Increase in stature after 30 minutes of sitting on various types of chairs (Althoff et al. 1992)

Anderson and Helander (1990) also investigated the effects of a forwardly-inclined seat pan (0°, 15° and 30°), with and without a backrest, on the pressure in the lumbar spine using spinal shrinkage, ratings of comfort and EMGs. The subjects did VDU work for 2 hours. They found the least shrinkage for the seat angle of 15° forwards. The presence of the backrest significantly reduced the calculated intradiscal pressure and the EMGs of the erector spinae and improved comfort. Mid and upper back comfort were improved by the forward seat inclination but leg comfort decreased. Additionally they found that shrinkage, calculated disc pressure and EMGs were highly correlated. Comfort and performance were also highly correlated. These studies and the newer IDP studies, indicate that increasing forward slope up to an absolute maximum of 15° decreases spinal load, whereas greater seat slopes result in increased loading, but the results depend on the presence of a backrest.

Michel and Helander (1994) also compared the effects of two different types of chair; a chair with 5° of backward seat slope and a fixed backrest angle of 100° and a sit-stand seat. The sit-stand seat had no backrest and the seat sloped 20° forwards. It was adjusted in height such that the trunk-thigh angle was approximately 140°. For the study they used three groups of six subjects; a young (23-26 years), healthy, mixed sex group, an old (sic), healthy, male group (30-47 years) and an old male group with herniated discs (30 to 44 years). They found that height loss was greatest after sitting on the 5° backward sloping seat compared to the sit-stand seat and greatest for the subjects with herniated discs. The interaction between these two factors was also significant. Additionally they found a significant positive correlation between age and stature loss on the sit-stand chair.

The results of Michel and Helander's study do not seem to agree with the results of the study by Ericson and Goldie described above, or the IDP studies, as the backward sloping seat produced more shrinkage than the sit-stand seat. The sit-stand seat more approximates a standing posture, which may, in fact, reduce spinal load compared to sitting on any chair. The effect of the muscular load needs to be further investigated.

An obvious difference between the studies is that the Ericson and Goldie study was performed using real workplaces whereas the other involved a simulated laboratory task. In the simulated task, posture was controlled and static on both chairs, whereas in the real work-place experiment there was little control of posture. It may therefore be that the effects of greater movement and postural change have substantially altered the results. Additionally Michel and Helander proposed that the difference may be due to the presence of armrests on the horizontal chair used in the other study or to the subjects adopting kyphotic postures on the Balans chairs. Kyphotic postures are not uncommon on forward sloping seats (see Chapter 3) so the in vivo situation would more accurately reflect the real consequences of these chairs in terms of shrinkage.

But what is the best backrest angle? Magnusson and Pope (1994), in an investigation of vibration while seated, found that a back-rest angle of 110° seemed to cause less shrinkage than 120°, however the difference was not statistically significant. In a later study, Magnusson and Pope (1996) proposed that hyperextension, a common postural adjustment which temporarily shifts loads from the disc to the facet joints, may provide a means by which disc hydration can temporarily increase with a concomitant improvement of disc nutrition, but increased hydration leads to increased IDP, which may not be beneficial. Lelong et al also found that a hyperlordosis increases IDP. This poses the question of whether an increase in pressure is advantageous or disadvantageous to disc health. The most reasonable position is that relatively small increases in IDP (less than the multi-fold increases found in lifting tasks) are beneficial to disc nutrition but are disadvantageous if maintained for extended periods. With this view, seated postural change is beneficial to disc health, as all seated postures produce relatively small changes in disc pressure compared to lifting of weights, jogging, jumping on a trampoline and skipping (Rohlmann et al. 1994). The alternation of relatively small changes in disc pressure would serve to increase fluid exchange between the disc and surrounding tissues.

The effect of posture change and movement has also been studied using stadiometry.

Amin et al (1988) used a stadiometric method to investigate whether the wearing of a seat belt reduced spinal load whilst driving. They generated sinusoidal vibration at 4 Hz to an experimental car seat and found that shrinkage increased with the use of a seat belt. They concluded that the difference was due to a reduction in the influence of the vibration. In this instance, the subjects were effectively tied to their seats but it is difficult to distinguish the effects of the static posture from the effects of the vibration.

Bendix et al. (1988) used spinal shrinkage, among other measures, to compare the effects of sitting on the forward sloping Balans chairs with sitting on chairs with tiltable seats. The tiltable seats had a backrest but the Balans chairs did not. After one hour of office work and simulated assembly work there was no difference found between the shrinkage of the twelve subjects on the two chair types. It seems that the subjects did not use the tilt possibilities that the chair offered during the experimental period. There was no difference found in the amount of movement, however the posture was notably different depending on chair type. It could be that the positive effect of the forward slope on one chair was roughly equal to the positive effect of the backrest on the other. This would be in line with the findings of Althoff et al (1992).

Helander and Quance (1990), designed a study to investigate the ameliorating effects of different work and rest schedules but, following the findings of Nachemson et al, they assumed that the compressive forces on the discs are greater during sitting than standing and therefore they expected that standing would result in increased height. They used seven subjects (for two of the conditions only six subjects) who performed simulated VDU work for 4 hours in the morning. The subjects were tested over four days under four regimes of sitting and standing. The regimes were, in order, for all subjects;

1. 3 hours 20 minutes of sitting then 40 minutes of walking about,
2. 1 hour 40 minutes of sitting then 20 minutes of walking about repeated once,
3. 50 minutes of sitting then 10 minutes of walking about repeated four times,

4. 25 minutes of sitting then 5 minutes of walking about repeated eight times.

The chairs had a relatively small backrest (only pelvic support and no lumbar support) so as to minimise the support offered and maximise the amount of shrinkage that, it was hypothesised, would occur. Shrinkage was found to be affected by height and weight. Five of the six subjects tested in condition 1 decreased in height while seated then increased in height while walking about. A similar pattern was found in the second condition but height gain was less during walking about. In conditions 3 and 4 there was a general tendency to shrink during the experimental period but during the walking periods some subjects shrank while others regained height. This was also true during the shorter sitting periods. Significant differences were found between the conditions for the total amount of shrinkage during sitting but not expansion during walking about. Comparing the final amount of shrinkage at the end of the experimental period, shrinkage was greatest for condition 4 and least for condition 1, with the results of conditions 3 and 2 falling in between. It was reported that the subjects preferred the conditions with more frequent position changes.

The authors suggested that walking about might facilitate disc expansion. They noted, that the subjects in the last condition did not, because of the interference of the measurements, have much time to walk about and speculated that 10 minutes might not be long enough for shrinkage to start to reverse. From the studies described in the previous chapter, shrinkage due to pressure occurs more quickly than expansion, which relies on diffusion. The most likely explanation for the results is, however, that standing does not load the spine substantially more than sitting. The amount of time that the posture is fixed may be more important to disc pressure than the effect of the posture.

# Annex C Sample subject information and questionnaires

## Annex C 1 Sample information leaflet from spinal length study

(translation follows)

**Ergonomie-Forschung bei Firma X**

Datum

**Hintergrund**

Es wird immer wieder festgestellt, dass Leute, die Bürotätigkeiten besonders an Bildschirmarbeitsplätze ausüben, unter Rückenbeschwerden leiden. Der Grund ist sehr umstritten, da die Entwicklung solcher „schleichender" Krankheiten sehr unterschiedlich verlaufen kann. Es können zu wenige oder zu viele (falsche) Bewegungen zu Beschwerden führen. Es wird behauptet, dass die Bandscheiben beim Sitzen zu hoch belastet sind, vor allem weil ihr Stoffwechsel von Bewegung abhängt. Um sitzende Bewegungen zu fördern, sind Stühle entwickelt worden, die mehr Bewegung beim Sitzen erlauben, und die den Körper gut unterstützen. Genau wieviel Bewegung (Stärke und Dauer) die Bandscheiben brauchen, ist noch nicht bekannt.

Es ist aber bekannt, dass Leute einige Zentimeter im Tagesrhythmus schrumpfen und wachsen. Diese Änderungen können als Mass für die Wirbelsäulenbelastung verwendet werden. Dazu wurde das „Stadiometer-Messverfahren" entwickelt. Die Messgenauigkeit liegt bei 0,5 mm. Wichtig bei diesem Messverfahren ist die Körperhaltung der Versuchsperson und die Festlegung der Tageszeit der Messungen.

**Zweck der Studie**

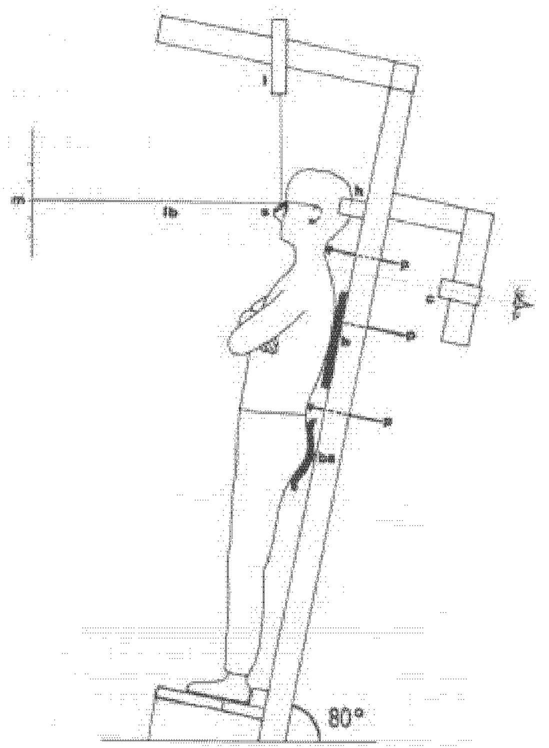
Ziel dieser Untersuchungen ist die Wirkung der neueren Synchro-Mechanik-Stuhlmodelle zu erfassen und die allfällige Wirkung im Bezug auf häufiges Aufstehen zu qualifizieren.

**Art und Ablauf der Untersuchung**

Die Versuchspersonen wurden gebeten, an drei aneinanderfolgenden Tagen vor Arbeitsbeginn zur gleichen Zeit zur Messstation zu erscheinen. Es ist erwünscht, dass Ihre Tätigkeiten vor Arbeitsbeginn an jedem Tag der Versuchsreihe mehr oder weniger gleich sind. Am ersten Tag gibt es eine Orientierung und Trainingsphase vor dem Versuch. Aktivitätsprogramme werden Ihnen persönlich gegeben und erklärt. Diese beinhalten, wie Sie an jedem Tag während des Versuchs sitzen sollen, z.B. ob Sie ihren Stuhl frei bewegen können, ob er fixiert werden soll oder ob Sie ab und zu aufstehen müssen.

Während der drei Tage des Versuchs sollten sie immer den gleichen Stuhl benützen. Ich werde sicherstellen, dass er für Sie richtig eingestellt ist. Es ist wichtig, dass Sie sich strikt ans Versuchsprotokoll, bzw. an die täglichen Aktivitätsprogramme halten. Insbesondere sollten Sie nicht während der sitzenden Aktivitätsprogramme aufstehen und herumlaufen. Wenn dies nicht eingehalten werden kann, sollten Sie mich informieren.

Vor der ersten Messung werde ich Ihnen ein allergiefreies Klebeband hinten auf Ihren Nacken kleben. Wenn möglich sollten Sie dieses Klebeband währen der drei Tage des Versuchs unberührt lassen. Sie dürfen Ihren Hals waschen, aber nicht zu intensiv! Es ist wichtig, dass diese Markierung während der Messung sichtbar bleibt, dabei ist erwünscht, dass Sie ein **Hemd ohne Kragen** tragen. Es ist auch wichtig, dass die Messtaster in guten Kontakt mit ihrem Rücken kommen können. Dafür sind **Pullis ungünstig.** Ihre Bekleidung sollte soweit wie möglich jeden Tag ähnlich sein. Am geeignetsten ist ein T-shirt oder ein Body.




**Der Stadiometer**

Während der Messung steht man in entspannter Haltung mit auf der Brust verschränkten Armen und durchgedrückten Knien. Um die Reproduzierbarkeit der Aufstellung zu gewährleisten, werden Füsse, Beine, Becken, Rücken und der Kopf durch hintere Auflageflächen abgestützt. Zusätzlich wird das Becken und der Kopf durch seitliche Positionierhilfen fixiert.

Um den noch verbleibenden Bewegungsspielraum weiter zu reduzieren, werden für den Rücken drei Messtaster benutzt (am tiefsten Punkt des Kreuzes, am höchsten Punkt der Brustwölbung und am tiefsten Punkt der Halswölbung). Eine Messung ist nur dann möglich, wenn die drei Messtaster in leichter Berührung mit dem Rücken stehen, wobei alle Kontrollichter rot erscheinen. Die Stellung des Kopfes wird aktiv von Ihnen kontrolliert: ein mit einem Spiegel auf einer Spezialbrille abgelenkter Laserstrahl muss an einem festgelegten Ort erscheinen. Die Einstellung der Positionierhilfen erfolgt für jeden Probanden individuell. Sie wird dokumentiert und für alle Untersuchungstermine wieder reproduziert. Am Anfang braucht es ein wenig Übung, um die Körperhaltung zu reproduzieren. Nach Absolvierung der Übungsphase braucht man üblicherweise nicht mehr als ca. 30 Sekunden, um die Messposition einzunehmen. Meistens werden dann drei Messungen gemacht, die nachher gemittelt werden.

Die Grössenmessung selbst erfolgt durch optisches Abtasten der Messmarke am Hals. Zeitpunkt und Höhenlage der Messmarke wird durch einen PC registriert.

Sie werden jeden Tag der Versuche einen kurzen Fragebogen erhalten. Er beinhaltet einige Fragen über Ihre Befindlichkeit während der Sitzphasen.

Es ist wichtig, dass Sie die folgenden Prinzipien verstehen:

**Ihre Teilnahme ist ganz freiwillig**

Wenn Sie sich entschliessen, an dieser Studie teilzunehmen, können Sie sich auch jederzeit davon zurückziehen.

**Unerwünschte Wirkungen und Gefahren**

Es ist anzunehmen, dass Sie gar keine Beschwerden haben werden. Es ist aber möglich, dass die ungewöhnliche Haltung zu Versteiffungung führen könnte. Diese sollten innerhalb ein paar Stunden wieder verschwinden.

**Datenschutz**

Die gesammelten Daten werden voraussichtlich wissenschaftlich publiziert. Die Namen der Probanden werden aber nie veröffentlicht und Ihre persönlichen Daten werden an niemanden weitergeleitet.

Es steht Ihnen frei, noch weitere Fragen zum besseren Verständnis der Untersuchung zu stellen. Sollten Sie im Laufe der Untersuchung Zweifel haben, stehe ich für weitere Informationen gerne zur Verfügung. Auch dürfen Sie sich jederzeit von der Studie zurückziehen.

Ihr Interesse und Ihre Hilfsbereitschaft bedeutet mir sehr viel.

Vielen Dank im Voraus

Maggie Graf

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Vp Nr.

Name:.................................................... Vorname:..............................................................

Datum: Unterschrift:

English translation of the preceding text

**Egonomics Research at Company X**

Date

## Background

It has frequently been found that people who perform office duties, particularly at VDU workplaces, suffer from back problems. The reason is very contentious, because the development of such „insidious“ diseases can run very differently. Both too little and too much (false) movement can lead to disorders. It is believed that the intervertebral discs are overloaded during sitting, particularly because their metabolism is influenced by movement. In order to encourage seated movements chairs have been developed which permit more movement during sitting but still provide good support. Exactly how much movement (strength and duration) the discs need is not known.

It is however known that people shrink and grow several centimetres in a daily rhythm. These changes can be used as a measurement for disc load. For this reason the „Stadiometer measurement technique“ was developed. The method is accurate to approximately 0.5 mm. Most important for the accuracy of the method is the body posture of the subject and a strict adherence to the starting time of the measurement.

## Purpose of the study

The aim of the investigation is to establish the effectiveness of the new synchron-mechanism chairs and their effects in relation to frequent periods of standing.

## What will be done during the investigation?

The subjects will be asked to come to the measuring station at the same time before starting work on three consecutive days. It is necessary that their activities before coming to work are more or less the same every day of the experiment. On the first day, there will be an orientation and training period before the experiment. The activity programs will be given to each subject personally and explained. These include how you should sit on each day of the experiment, e.g., whether you should let your chair swing freely, whether it should be fixed in position or whether you must stand up from time to time.

During the three days of the experiment, you should always use the same chair. I will ensure that the chair is correctly adjusted for you. It is important that you follow the instructions of the experiment strictly, especially adhering to the activity program. In particular, you should not stand up and walk about at all during the sitting programs. If you are not able to adhere to the program you should inform me.

Before the first measurement, I will stick a non-allergenic plaster on the back of your neck. If possible, this plaster should be left in place for the whole three days. You may wash your neck, but not too industriously! It is important that this plaster remains visible during the measurement, therefore it is desired that you wear a shirt without a collar. It is also important that the measuring probes can come in close contact with your back. Pullovers are not convenient. As much as possible your clothing should be the same on each day of the experiment. The most convenient is a T-shirt or a tank-top.

During the measurement, you stand in a relaxed posture with your arms crossed across your chest and your knees locked. In order to reproduce your posture your feet, legs, hips, back and head will be held in place with rear supports. Additionally your hips and head will be positioned with side supports.

In order to reduce the remaining freedom in your movements three measurement probes are used (on the deepest point of your waist, the farthest curve at your shoulders and the deepest curve of your neck). A measurement is only possible when these three probes are in light contact with your back, whereby all of the control lamps will light up. You will need to position your head yourself: A laser beam which is reflected by special glasses must be positioned to match a marked point on the wall. The positioning of all of these supports will be done individually. Their position will be documented and reproduced for each measurement. At the beginning, it takes a bit of practice to reproduce your posture this accurately. After the training period, most people don't need much more than 30 seconds to get into position. Generally, three measurements will be made which are later averaged.

The actual height measurement is taken by recording the height of the marker attached to your neck. The time of the measurement and the position of the marker are recorded by a computer.

On each day of the experiment, you will be given a short questionnaire. It includes questions about your impressions during the sitting periods.

It is important that you understand the following principles.

**Your participation is voluntary.**

If you decide to partake in the study, you can withdraw at any time.

**Undesired effects and dangers**

It is assumed that you will not suffer any damage. It is however possible that, due to unaccustomed postures you may become stiff. This should disappear within a couple of hours.

**Data protection**

It is expected that the collected data will be published in scientific works. The names of the subjects will however never be published and the personal data will not be passed on to anyone else.

You are free to ask any other questions relating to your understanding of the investigation. If you have any doubts during the investigation, I am very willing to give further information. Additionally you may withdraw at any time from the study.

Your interest and generous help mean a lot to me.

Thank you in advance.

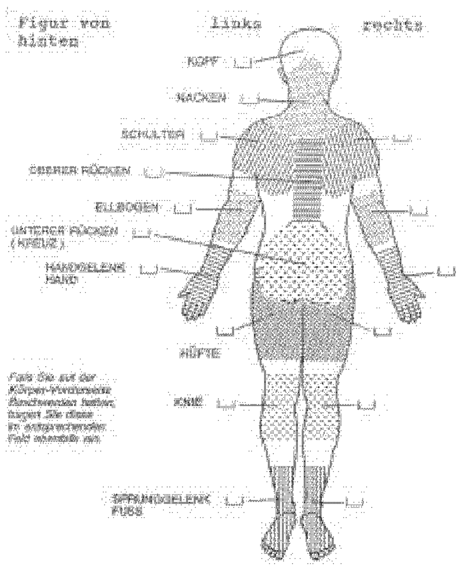
# Annex C 2 Sample questionnaire from spinal length study

VP Nr............... A B C

Bitte beurteilen Sie den Komfort oder das Unbehagen des Sitzprogrammes, das Sie gerade abgeschlossen haben. Machen Sie einen Kreis um die Ziffer, die am besten Ihr Befinden oder Ihren Eindruck wiedergibt. 1= gar nicht und 9 = äusserst.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ich hatte Muskelschmerzen. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich hatte schwere Beine. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich fühlte mich verkrampft. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich fühlte mich unruhig. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich fühlte Müdigkeit. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich war entspannt. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich fühlte mich erfrischt. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich fühlte mich wohl. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ich war bequem. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

In diesem Bild sehen Sie verschiedene Körperteile. Wenn Sie während dem Versuch heute Beschwerden hatten, kreuzen Sie das Feld neben dem Körperteilnamen an.



# Annex D Raw data and results

## Annex D 1 Questionnaire results from the seat shape and slope experiment

| | Standard profile | | Modified profile | |
|---|---|---|---|---|
| | **Mean rating** | **Standard error** | **Mean rating** | **Standard error** |
| **Q1. How comfortable did you find the chair?** | | | | |
| **Slope** | | | | |
| 4° Backwards | 3.8 | 0.6 | 4.8 | 0.7 |
| 0° | 3.8 | 0.6 | 4.1 | 0.5 |
| 8° Forwards | 2.8 | 0.7 | 4.3 | 0.6 |
| **Task** | | | | |
| Assembly | 3.8 | 0.5 | 4.5 | 0.4 |
| VDU | 3.2 | 0.5 | 4.3 | 0.6 |
| **Q2. How well did the chair support you?** | | | | |
| **Slope** | | | | |
| 4° Backwards | 4.3 | 0.4 | 4.5 | 0.4 |
| 0° | 3.0 | 0.6 | 5.7 | 0.6 |
| 8° Forwards | 2.1 | 0.8 | 4.3 | 0.6 |
| **Task** | | | | |
| Assembly | 3.1 | 0.6 | 4.7 | 0.4 |
| VDU | 3.3 | 0.5 | 5.0 | 0.5 |
| **Q3. How relaxed did you feel on the chair?** | | | | |
| **Slope** | | | | |
| 4° Backwards | 4.3 | 0.4 | 4.3 | 0.6 |
| 0° | 3.7 | 0.5 | 4.5 | 0.8 |
| 8° Forwards | 2.6 | 0.7 | 4.7 | 0.6 |
| **Task** | | | | |
| Assembly | 3.7 | 0.6 | 4.7 | 0.5 |
| VDU | 3.4 | 0.4 | 4.3 | 0.6 |
| **Q4. How easy did you find it to change your position?** | | | | |
| **Slope** | | | | |
| 4° Backwards | 4.8 | 0.8 | 5.2 | 0.8 |
| 0° | 4.7 | 0.6 | 6.7 | 0.2 |
| 8° Forwards | 4.5 | 1.0 | 4.5 | 0.8 |
| **Task** | | | | |
| Assembly | 5.3 | 0.4 | 5.8 | 0.5 |
| VDU | 4.0 | 0.7 | 5.1 | 0.7 |

# Annex D 2 Structured interviews results from the school study

(percentages of positive answers)

| Questions (Opinions of the pupils) | Traditional furniture | | Proposed new furniture | |
|---|---|---|---|---|
| | Primary school | Secondary school | Primary school | Secondary school |
| Hat schon jemand/Hast Du Deinen Stuhl für Dich angepasst? | 100 | 83 | 100 | 83 |
| Wurde der Tisch für Dich angepasst? | 92 | 83 | 98 | 83 |
| Weisst Du, dass man die Höhe Deines Sitzes verstellen kann? | 96 | 100 | 100 | 100 |
| Weisst Du, wie man die Sitzhöhe verstellt? | 62 | 100 | 67 | 100 |
| Weisst Du, dass man die Sitztiefe verstellen kann? | - | - | 60 | 90 |
| Weisst Du, wie man die Sitztiefe verstellt? | - | - | 58 | 90 |
| Weisst Du, wie hoch der Sitz für Dich sein sollte? | 9 | 8 | 8 | 47 |
| Weisst Du, wie tief der Sitz für Dich sein sollte? | 4 | 0 | 8 | 31 |
| Weisst Du, dass man die Höhe Deines Tisches verstellen kann? | 96 | 100 | 94 | 100 |
| Weisst Du, wie man die Tischhöhe verstellt? | 46 | 100 | 77 | 90 |
| Weisst Du, dass man die Neigung des Tisches verstellen kann? | 92 | 92 | 100 | 100 |
| Weisst Du, wie man die Tischneigung verstellt? | 88 | 92 | 100 | 100 |
| Rutschst Du vom Stuhl? | 0 | 20 | 21 | 30 |
| Wie ist es mit der Rückenlehne? Ist es Dir wohl, wenn Du dich zurücklehnst? | 63 | 33 | 73 | 77 |
| Tut Dir der Stuhl irgendwo weh oder stört er Dich? | 12 | 36 | 23 | 13 |
| Findest Du den Stuhl zu schwer für Dich? | 8 | 8 | 13 | 43 |
| Haben Deine Füsse genügend Platz? | 71 | 50 | 85 | 70 |
| Fallen Deine Sachen auf den Boden? | 29 | 55 | 50 | 70 |

| | Proposed new furniture only (both schools and both series) | | |
|---|---|---|---|
| Soll die Sitzfläche höher oder tiefer sein? | höher 32 | ist gut so 67 | tiefer 1 |
| Soll die Sitzfläche noch tiefer oder weniger tief sein? | tiefer 19 | 81 | weniger tief 0 |
| Wie findest Du die Neigung des Stuhls? Soll sie anders sein? | nach hinten 17 | 82 | flach 1 |
| Findest Du die Sitze zu hart oder weich? | zu hart 18 | 81 | zu weich 1 |
| Glaubst Du, dass man die Höhe der Rückenlehne verstellen müsste? | höher 23 | 71 | tiefer 6 |
| Soll der Tisch höher oder tiefer sein? | höher 35 | 64 | tiefer 1 |
| Soll der Neigung der Tisch anders sein? | nach vorn 3 | 84 | nach hinten 13 |

| | Primary school | Secondary school |
|---|---|---|
| *Welchen Stuhl findest Du besser? Den, den Du vorher gehabt hast oder diesen?* (% of answers positive for proposed new chairs) | 87 | 90 |

# Annex D 3 Spinal shrinkage experiment data

## Subject details

| Subject Details | | | |
|---|---|---|---|
| Sex | Age | Height (cm) | Weight (Kg) |
| Male | 40 | 171 | 74 |
| Female | 27 | 169 | 54 |
| Male | 29 | 183 | 77 |
| Male | 34 | 176 | 65 |
| Male | 47 | 173 | 92 |
| Male | 34 | 178 | 78 |
| Male | 60 | 174 | 71 |
| Male | 62 | 179 | 70 |
| Male | 37 | 174 | 62 |
| Male | 41 | 173 | 95 |
| Male | 42 | 168 | 68 |
| Male | 35 | 186 | 79 |
| Male | 46 | 170 | 60 |
| Male | 58 | 170 | 69 |
| Female | 32 | 162 | 52 |
| Male | 32 | 174 | 80 |
| Female | 17 | 167 | 63 |
| Mean | 40 | 173 | 71 |
| Median | 37 | 173 | 70 |
| Min | 17 | 162 | 52 |
| Max | 62 | 186 | 95 |

## Raw data of height change measurements

| | | Begin | | | | End | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sub. | Cond. | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Changes |
| 1 | fixed (A) | 151.06 | 151.07 | 151.06 | | 151.19 | 151.16 | 151.13 | | |
| | free (B) | 151.30 | 151.36 | 151.48 | | 151.26 | 151.11 | 151.32 | | |
| | mixed (C) | 141.89 | 141.86 | 141.76 | | 141.62 | 141.80 | 141.68 | | camera |
| 2 | fixed (A) | 136.94 | 137.02 | 137.00 | | 137.15 | 137.29 | 137.18 | | camera |
| | free (B) | 154.63 | 155.04 | 155.08 | | 154.69 | 154.69 | 154.46 | | |
| | mixed (C) | 157.12 | 156.98 | 157.01 | | 156.77 | 156.83 | 156.90 | | |
| 3 | fixed (A) | 155.27 | 155.14 | 155.18 | | 154.96 | 154.95 | 154.75 | | |
| | free (B) | 157.28 | 157.27 | 157.31 | 157.34 | 157.10 | 157.06 | 157.11 | 157.10 | plaster |
| | mixed (C) | 154.26 | 154.42 | 154.62 | | 153.90 | 153.92 | 153.84 | | |
| 4 | fixed (A) | 152.07 | 152.25 | 152.19 | | 152.35 | 152.38 | 152.13 | | |
| | free (B) | 151.94 | 151.96 | 151.96 | | 151.68 | 151.90 | 151.78 | | |
| | mixed (C) | 152.26 | 152.26 | 152.24 | | 152.11 | 151.93 | 152.06 | | |
| 5 | fixed (A) | 140.12 | 140.08 | 140.07 | | 140.07 | 140.07 | 140.07 | | |
| | free (B) | 138.36 | 138.26 | 138.38 | | 138.08 | 137.99 | 138.01 | | |
| | mixed (C) | 139.89 | 139.92 | 139.88 | | 140.04 | 140.01 | 139.94 | | |
| 6 | fixed (A) | 152.96 | 153.05 | 153.16 | | 153.06 | 152.96 | 152.91 | | |
| | free (B) | 153.06 | 153.04 | 152.98 | | 152.96 | 152.85 | 152.96 | | |
| | mixed (C) | 152.63 | 152.63 | 152.62 | | 152.60 | 152.54 | 152.54 | | |
| 7 | fixed (A) | 144.67 | 144.63 | 144.77 | 144.74 | 144.57 | 144.50 | 144.56 | 144.48 | |
| | free (B) | 144.79 | 144.63 | 144.77 | 144.62 | 144.88 | 144.80 | 144.81 | 144.83 | |
| | mixed (C) | 144.84 | 144.82 | 144.86 | 144.76 | 144.46 | 144.51 | 144.54 | 144.49 | |
| 8 | fixed (A) | 144.47 | 144.37 | 144.36 | 144.42 | 144.04 | 144.07 | 144.07 | 144.01 | |
| | free (B) | 144.29 | 144.34 | 144.28 | | 144.42 | 144.32 | 144.32 | 144.43 | |
| | mixed (C) | 144.15 | 144.05 | 143.97 | 144.08 | 144.35 | 144.33 | 144.23 | 144.17 | |
| 9 | fixed (A) | 143.13 | 143.04 | 143.04 | 143.04 | 143.08 | 143.18 | 143.14 | 143.13 | |
| | free (B) | 143.00 | 143.19 | 143.33 | 143.20 | 143.15 | 143.19 | 143.19 | 143.14 | |
| | mixed (C) | 143.26 | 143.26 | 143.23 | | 143.05 | 143.04 | 142.93 | 142.82 | |
| 10 | fixed (A) | 139.38 | 139.32 | 139.32 | 139.35 | 139.49 | 139.39 | 139.37 | 139.32 | |
| | free (B) | 139.60 | 139.66 | 139.68 | 139.67 | 139.74 | 139.79 | 139.76 | 139.76 | |
| | mixed (C) | 139.77 | 139.74 | 139.71 | 139.73 | 139.65 | 139.54 | 139.58 | 139.5 | |
| 11 | fixed (A) | 136.79 | 136.84 | 136.82 | 136.82 | 136.63 | 136.60 | 136.68 | 136.58 | |
| | free (B) | 136.96 | 136.99 | 136.88 | 136.82 | 136.65 | 136.69 | 136.57 | 136.54 | |
| | mixed (C) | 136.90 | 136.93 | 136.93 | 136.99 | 136.67 | 136.61 | 136.64 | 136.69 | |
| 12 | fixed (A) | 159.59 | 159.54 | 159.54 | 159.54 | 159.78 | 159.76 | 159.75 | 159.74 | |
| | free (B) | 159.64 | 159.55 | 159.55 | 159.54 | 159.44 | 159.49 | 159.46 | 159.45 | |
| | mixed (C) | 159.54 | 159.46 | 159.46 | 159.46 | 159.62 | 159.62 | 159.62 | 159.64 | |
| 13 | fixed (A) | 137.09 | 136.99 | 136.89 | 136.89 | 137.10 | 137.10 | 137.13 | 137.14 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | free (B) | 137.34 | 137.32 | 137.34 | 137.33 | 137.24 | 137.22 | 137.18 | 137.18 | |
| | mixed (C) | 137.38 | 137.31 | 137.33 | 137.35 | 137.12 | 137.08 | 137.08 | 137.07 | |
| 14 | fixed (A) | 154.48 | 154.49 | 154.49 | 154.37 | 154.46 | 154.46 | 154.46 | 154.48 | |
| | free (B)* | 137.23 | 137.18 | 137.13 | 137.12 | 136.96 | 136.88 | 136.90 | 137.05 | camera |
| | mixed (C) | 154.45 | 154.43 | 154.43 | 154.43 | 154.37 | 154.29 | 154.22 | 154.32 | |
| 15 | fixed (A) | 137.27 | 137.18 | 137.18 | 137.17 | 137.07 | 136.96 | 136.90 | 136.9 | |
| | free (B) | 137.51 | 137.51 | 137.42 | 137.43 | 137.23 | 137.23 | 137.21 | 137.21 | |
| | mixed (C)* | 132.31 | 132.46 | 132.46 | 132.33 | 131.94 | 131.94 | 131.91 | 131.85 | plaster |
| 16 | fixed (A) | 150.29 | 150.28 | 150.27 | 150.26 | 150.12 | 150.15 | 150.14 | 150.13 | |
| | free (B)* | 148.81 | 148.82 | 148.83 | 148.83 | 148.63 | 148.60 | 148.60 | 148.6 | plaster |
| | mixed (C) | 150.68 | 150.68 | 150.60 | 150.61 | 150.79 | 150.79 | 150.78 | 150.77 | |
| 17 | fixed (A) | 134.21 | 134.32 | 134.31 | 134.26 | 133.90 | 133.90 | 133.90 | 133.89 | |
| | free (B) | 133.71 | 133.71 | 133.71 | 133.63 | 133.43 | 133.43 | 133.39 | 133.38 | |
| | mixed (C) | 133.77 | 133.77 | 133.78 | 133.72 | 133.45 | 133.44 | 133.35 | 133.35 | |

## Calculated bony structure weight (SW), estimated disc areas and adjusted height change per square centimetre for each activity regime

| Subject | SW(g) | Disc Area at L3-L4 ($cm^2$) | Height change per $cm^2$ of disc area | | |
|---|---|---|---|---|---|
| | | | Fixed | Free | Mixed |
| 1 | 10370 | 21.69 | 0.04 | -0.07 | -0.06 |
| 2 | 8851 | 18.65 | 0.12 | -0.18 | -0.11 |
| 3 | 10801 | 22.55 | -0.14 | -0.09 | -0.24 |
| 4 | 10890 | 22.73 | 0.04 | -0.05 | -0.10 |
| 5 | 12486 | 25.92 | -0.01 | -0.13 | 0.04 |
| 6 | 11459 | 23.87 | -0.03 | -0.05 | -0.03 |
| 7 | 10410 | 21.77 | -0.08 | 0.06 | -0.15 |
| 8 | 10928 | 22.81 | -0.16 | 0.03 | 0.09 |
| 9 | 9446 | 19.84 | 0.04 | -0.01 | -0.15 |
| 10 | 11727 | 24.40 | 0.02 | 0.05 | -0.07 |
| 11 | 10051 | 21.05 | -0.09 | -0.14 | -0.14 |
| 12 | 11128 | 23.21 | 0.09 | -0.05 | 0.06 |
| 13 | 9098 | 19.15 | 0.08 | -0.07 | -0.13 |
| 14 | 9560 | 20.07 | 0.00 | -0.11 | -0.07 |
| 15 | 7471 | 15.89 | -0.15 | -0.16 | -0.31 |
| 16 | 10983 | 22.92 | -0.06 | -0.09 | 0.06 |
| 17 | 8432 | 17.81 | -0.21 | -0.16 | -0.20 |

## Standard deviations within each measurement period

| Subject | Fixed | | Free | | Mixed | |
|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After |
| 1 | 0.06 | 0.30 | 0.92 | 1.08 | 0.68 | 0.92 |
| 2 | 0.42 | 0.74 | 2.49 | 1.63 | 0.74 | 0.65 |
| 3 | 0.67 | 1.18 | 0.21 | 0.22 | 1.80 | 0.42 |
| 4 | 0.92 | 1.77 | 0.12 | 0.85 | 0.12 | 0.93 |
| 5 | 0.26 | 0.00 | 0.64 | 0.14 | 0.21 | 0.51 |
| 6 | 1.00 | 0.76 | 0.42 | 0.78 | 0.06 | 0.35 |
| 7 | 0.64 | 0.44 | 0.90 | 0.36 | 0.43 | 0.34 |
| 8 | 0.51 | 0.29 | 0.32 | 0.61 | 0.75 | 0.85 |
| 9 | 0.45 | 0.41 | 1.36 | 0.26 | 0.17 | 1.08 |
| 10 | 0.29 | 0.71 | 0.36 | 0.21 | 0.25 | 0.64 |
| 11 | 0.21 | 0.43 | 0.77 | 0.69 | 0.38 | 0.35 |
| 12 | 0.25 | 0.17 | 0.47 | 0.22 | 0.40 | 0.10 |
| 13 | 0.96 | 0.21 | 0.10 | 0.30 | 0.30 | 0.22 |
| 14 | 0.59 | 0.10 | 0.51 | 0.76 | 0.10 | 0.63 |
| 15 | 0.47 | 0.80 | 0.49 | 0.12 | 0.81 | 0.46 |
| 16 | 0.13 | 0.13 | 0.10 | 0.15 | 0.43 | 0.10 |
| 17 | 0.51 | 0.05 | 0.40 | 0.26 | 0.27 | 0.55 |

## Raw data of subjective responses from spinal length study

| | Mean Discomfort Score | | | Mean Comfort Score | | |
|---|---|---|---|---|---|---|
| Subject | Fixed | Free | Mixed | Fixed | Free | Mixed |
| 1 | 1.2 | 2.8 | 1.0 | 6.3 | 2.3 | 6.8 |
| 2 | 1.4 | 4.2 | 1.6 | 5.3 | 2.5 | 8.0 |
| 3 | 3.6 | 2.8 | 2.0 | 4.3 | 6.5 | 5.0 |
| 4 | 5.4 | 5.0 | 3.4 | 3.8 | 4.3 | 6.3 |
| 5 | 1.4 | 1.0 | 1.0 | 7.5 | 7.8 | 8.3 |
| 6 | 1.4 | 1.0 | 1.0 | 5.0 | 8.5 | 5.0 |
| 7 | 2.4 | 1.4 | 2.0 | 4.3 | 6.5 | 5.0 |
| 8 | 1.6 | 1.8 | 2.0 | 7.5 | 7.5 | 7.0 |
| 9 | 2.4 | 3.8 | 3.8 | 7.3 | 6.0 | 4.0 |
| 10 | 3.4 | 1.0 | 1.4 | 1.3 | 4.0 | 3.3 |
| 11 | 1.8 | 2.0 | 2.0 | 7.8 | 7.3 | 8.0 |
| 12 | 2.6 | 3.0 | 1.0 | 3.5 | 2.8 | 5.5 |
| 13 | 3.0 | 2.0 | 3.0 | 4.0 | 3.5 | 4.0 |
| 14 | 2.2 | 2.0 | 2.6 | 7.3 | 7.3 | 7.3 |
| 15 | 2.2 | 1.0 | 1.0 | 7.0 | 8.8 | 7.8 |
| 16 | 3.8 | 1.2 | 2.0 | 1.0 | 8.0 | 8.0 |
| 17 | 5.0 | 4.0 | 1.6 | 4.0 | 2.5 | 6.8 |

## Means of the responses for the questions on comfort and discomfort obtained from the questionnaire answered after each experimental period.

| Subject | Discomfort | | | Comfort | | |
|---|---|---|---|---|---|---|
| | Fixed | Free | Mixed | Fixed | Free | Mixed |
| 1 | 1.2 | 2.8 | 1.0 | 6.3 | 2.3 | 6.8 |
| 2 | 1.4 | 4.2 | 1.6 | 5.3 | 2.5 | 8.0 |
| 3 | 3.6 | 2.8 | 2.0 | 4.3 | 6.5 | 5.0 |
| 4 | 5.4 | 5.0 | 3.4 | 3.8 | 4.3 | 6.3 |
| 5 | 1.4 | 1.0 | 1.0 | 7.5 | 7.8 | 8.3 |
| 6 | 1.4 | 1.0 | 1.0 | 5.0 | 8.5 | 5.0 |
| 7 | 2.4 | 1.4 | 2.0 | 4.3 | 6.5 | 5.0 |
| 8 | 1.6 | 1.8 | 2.0 | 7.5 | 7.5 | 7.0 |
| 9 | 2.4 | 3.8 | 3.8 | 7.3 | 6.0 | 4.0 |
| 10 | 3.4 | 1.0 | 1.4 | 1.3 | 4.0 | 3.3 |
| 11 | 1.8 | 2.0 | 2.0 | 7.8 | 7.3 | 8.0 |
| 12 | 2.6 | 3.0 | 1.0 | 3.5 | 2.8 | 5.5 |
| 13 | 3.0 | 2.0 | 3.0 | 4.0 | 3.5 | 4.0 |
| 14 | 2.2 | 2.0 | 2.6 | 7.3 | 7.3 | 7.3 |
| 15 | 2.2 | 1.0 | 1.0 | 7.0 | 8.8 | 7.8 |
| 16 | 3.8 | 1.2 | 2.0 | 1.0 | 8.0 | 8.0 |
| 17 | 5.0 | 4.0 | 1.6 | 4.0 | 2.5 | 6.8 |
| Mean | 2.64 | 2.35 | 1.91 | 5.10 | 5.63 | 6.22 |
| Std Dev | 1.25 | 1.28 | 0.87 | 2.13 | 2.33 | 1.62 |

**The body areas which were indicated on the body diagram in the questionnaire as being uncomfortable.**

| Subject | Fixed | Free | Mixed | Area of Discomfort |
|---|---|---|---|---|
| 4 | n t | | | n = neck |
| 7 | n s ub | n ub | n s | s = shoulder |
| 13 | n s | n ub | n s ub | ub = upper back |
| 16 | | | lb | lb = lower back |
| | | | | t = thigh |

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# Glossary

| | |
|---|---|
| active seating | This refers to behaviour at seated workplaces and varies from dynamic seating in that the person stands from time to time and walks about during the working periods. During seated periods, the posture is also alternated as in dynamic seating. |
| backward position | The centre of gravity of the upper body is situated posterior to the ischial tuberosities while seated. |
| body position | The position of the upper body in relation to the hips while seated. In this work three body positions are distinguished: forward position, middle position and backward position) |
| body posture | The shape of the spinal curve while seated. During sitting the natural S-curve of the spine flattens in the lumber region. In this work, a distinction is made between a lordotic seated body posture (curve anterior as during standing) and a kyphotic seated posture (curve posterior). |
| dynamic seating | This refers to seated behaviour and indicates that the seated body posture is frequently changed. Generally, it means that the upper body position, relative to the hips, is frequently changed between leaning forwards, positioned above the hips and leaning backwards. |
| EMG | Electromyelogram. This is a measure of muscle activity whereby the electric impulses within the muscles are measured, mostly using surface electrodes. |
| forward posture | The centre of gravity of the upper body is situated anterior to the ischial tuberosities. |
| kyphosis | A posterior curve of the lumbar spine. Kyphotic curves occur while seated, if the pelvis tips backwards. |
| lordosis | In an upright standing posture the lumbar spine curves anteriorly. This is referred to as the lumbar lordosis. A seated lordotic posture is one where, due to forward tilting of the pelvis, the spine curves anteriorly, although the curve is not as pronounced as during standing. |
| middle position | The centre of gravity of the upper body is directly over the ischial tuberosities |

| | |
|---|---|
| | tuberosities. |
| motion segment | This term includes a vertebra and attached disc including the spinous processes and with the ligaments attached to it. |
| seat shape | The form of the surface on which the buttocks rest while seated. |
| seat slope | The angle relative to the floor of the surface on which the buttocks rest while seated. For the purposes of this study it is measured at the area under the ischial tuberosities. |
| seated movement | Body posture and/or position changes while seated. |
| stadiometer | An apparatus to measure body height. See Chapter 5 for a detailed description of the apparatus used in the study. |
| synchronized mechanism | A design feature of chairs where the backrest angle is coupled to the seat-pan angle such that independent adjustment of the two surfaces is not possible. Tilting the seat-pan will result in a proportional backrest angle change. |
| tiltable chairs | This term describes chairs which have a facility for varying the seat angle. On some chair models, the seat may be either fixed at any point of the tilt range or left to swing freely. |
| VDU | Video display unit. This is the output device for a computer and consists of a screen where information is displayed. It is generally placed on the work table in front of the person using the computer such that they can receive feedback about their interactions with the computer. |

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