Background to sitting at work: research-based requirements for the design of work seats

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The body's responses to sitting are complex and involve the anatomy and physiology of the sitter as well as the structure of the seat, the desk and the environment. In the light of recent research, the major reactions of the spine, the muscles and the spinal discs are discussed. Their interactions when adopting sitting postures are described. Reasons are given why certain sitting postures are to be preferred. The mechanisms that may give rise to muscle and disc damage, as well as back pain, as a result of adverse sitting postures are outlined. The design consequences of the research are then presented, showing how the seat shape arises from the previously described data. The influence of backrest design on sitting comfort and in the reduction of loading on the body is shown. Finally, a brief discussion of the influences from the work surface illustrates how the combination of seat and workplace can reduce the risks of injury by mitigating body loadings over the working day.

Keywords: Chair design; Back pain; Sitting at work; Spinal loading

1. Introduction

The ergonomics of sitting has been a subject for discussion since well before the term ergonomics was coined. A brief review of 19th century writing demonstrates the belief in the need to sit up with a straight back. This was reinforced in schools and elsewhere by the use of backboards to maintain this posture. Sitters used chairs with vertical backs and horizontal seats, usually 46 cm off the floor. The belief in a straight back when sitting on a horizontal seat is still implicit in descriptions of 'correct' sitting.

In the 20th century, the understanding of the consequences of sitting increased, probably driven by the increase in seated workplaces and a recognition of the prevalence of back pain in the population. But there was still a background, often unrecognized, that decided on chair features, using criteria that were secondary factors rather than primary ones. For example, key design claims could be that the chairs were designed to stack, that they looked 'executive' in form, were 'ergonomic' (not explained) and seat and backrest movements were stated to decrease fatigue. The emphasis on such criteria, whilst they

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may be good in themselves, can miss the main point, that the chair should be designed for the user to do the work, in the workplace, healthily, safely, comfortably and efficiently. All the previous often-quoted requirements may help, but are contributory to this main point.

So, how should this main point be addressed? Of course some of the criteria mentioned above do assist in a successful design, including adjustment, lumbar support and clearance at the back of the knee. What are not usually addressed in a holistic way are the human consequences of the interaction between the seat and the workplace; the musculoskeletal effects of the working activities and postures that occur as a result of doing the work.

Since any postures that exert undue stresses, particularly if held for long periods such as may arise during work, can lead to damage, then the postures called into play at the seated workplace should minimize the loads on the spine and on the working musculature. When examining how these loads arise, some design requirements become clearer.

2. The spine

2.1. Spinal loading

Spinal discomfort and back pain arise from several sources. Aching back and shoulder muscles come from too-long maintained postures (Van Wely 1970). The intensity of the ache is an indicator of the amount of overuse (Corlett 1981) and requires appropriate recovery time. When a muscle is loaded without relaxation for long periods, its recovery time is more than proportionally related to the holding time (Milner et al. 1986).

If it is the muscles of the back that are active, they are applying pressure to the spinal discs. Variations in this pressure are beneficial since the discs gain their nutrients from such pressure changes. But if the pressure is held for a long period the discs, which creep under load, experience a gradually increasing convexity around the rim, which over time may cause them to rupture or produce pressure on the nerves in the spinal column. Hence, the workplace design must permit postural changes to allow recovery of disc height without inhibiting the work activities.

Spinal loading arises not only from the muscles, but also from gravity and from the shape of the spine. The centre of gravity of the upper body lies just in front of the middle vertebrae of the thoracic spine and in a standing posture the vertical thrust runs through the lumbar spine. When the trunk is upright, particularly when standing, the weight of the upper body produces very little moment to displace the trunk, allowing the muscles supporting the trunk to relax and act only to counterbalance sway. This gives the lowest loading to the discs of any upright posture.

A forward bend causes an increase in the forces generated by the erector spinae and other contributing trunk muscles in order to support the trunk. The resisting moment from these forces increases as the sine of the angle of inclination of the trunk (Van Dieën and Nussbaum 2004). Thus, to the gravity load imposed on the discs is the additional pressure from the muscular forces providing the restraining moment, increasing disproportionately as the body bends further forward.

The effect of the spinal curvature is also significant for disc load. As the intervertebral discs are a fibrous annulus surrounding an incompressible fluid centre, they allow the vertebrae to rock relative to each other. In the upright posture, the faces of adjacent vertebrae are approximately parallel and the pressure is relatively evenly distributed across the surfaces of the discs.
In a forward bend, some resistance is provided by the discs being compressed at their front edges by the inclination of the vertebral end plates. Due to the fluid centre of the discs, this loading is still distributed more or less evenly over the vertebral end plates, but there is an increased load at the discs' forward edges. As described earlier, this angulation may also lead to undue loading on the fibrous rim of the discs. This counteracting resistance of the spine to bending is a part of the loading that is experienced by the discs and is additional to that from gravity and the forces from the back muscles described above. Note that, when bending, the load transmitted to the floor or the seat pan does not change, although the loading on the discs can increase dramatically.

The ‘neutral’ position of the spine is the posture in which the muscles are least loaded and the muscle forces generated when moving away from this position are in the direction of returning the spine to its least loaded posture. It is desirable, if it can be arranged, that chair design and work movements allow the neutral position to occur, so that both muscles and discs may experience alternations in loading and relaxation.

### 2.2. Muscle and disc loading

There are four major procedures for examining muscle loading. One is by the use of biomechanical models, which infer internal loads using externally recorded forces of the body on the environment. Another is by measuring the bioelectric activity of the back muscles, either by surface electrodes or needle electrodes in the muscle itself. A third method is by recording subjective reports of discomfort, whilst the fourth is to measure the shrinking in height of the spinal discs by measuring changes in stature. Of these four this section will consider the last three, electromyographic (EMG) measures, subjective reports and shrinkage.

EMG studies have a long history and, as Hagberg (1981) amongst others has shown, are capable of revealing the development of fatigue by the frequency analysis of the recordings of activity during exercise. As muscle loads are an important source of disc loadings and can involve cooperative or antagonistic activities, which will also add to the loads, EMG studies can show these effects (Van Dieën and Visser 1999), demonstrating the variations in muscular activities with changes in postures.

Postural limits to activity at work are defined by levels of acceptable pain in the muscles, identified by the use of a body part discomfort assessment (Corlett and Bishop 1976). The holding time for different loadings of skeletal muscle has a negative logarithmic relation with the increase of the imposed load, (measured as a proportion of the maximum capacity of the muscle in terms of its % maximum holding time in the posture concerned). The maximum force that a muscle can exert is defined by the maximum voluntary contraction (MVC). For a muscle force to be held for long periods without fatigue it is considered that only 5% or less of MVC should be exerted (Sjøgaard 1986). Thus, any posture that is held for a period and gives rise to discomfort requires a recovery period.

Recovery from such exposures is also a logarithmic relationship. The more severe the muscle force exerted, the quicker the discomfort limit is reached and the longer it takes for the muscle to recover. This recovery is not proportional to the holding time (Milner et al. 1986), but for severe exposure it has been shown that recovery is in excess of 12 times the initial holding time (Barbonis 1979) and, indeed, may take several days (Kilbom et al. 1983). A seated workstation that requires the user to maintain postures that produce noticeable discomfort is likely to introduce serious risks of physical damage as well as reduced performance (Tomlinson and Corlett 1975). Thus, the recovery from static
loading can be a long process and recovery from long exposure will not occur over a lunch break (Corlett and Manenica 1980).

For the back, the discomfort in the back muscles is only one part of the consequences of postural load. The intervertebral discs are also loaded and prolonged pressure on them (and on the vertebral end plates), due to a lack of postural change, is a recognized contributor to spinal damage. The mechanical behaviour of the discs under load can be measured by changes in stature (Eklund and Corlett 1984). This measure gives a direct indication of the spinal loading arising from different seat designs and work activities (Eklund and Corlett 1986). The stature change measures give results that support those of Andersson et al. (1974), whose direct measures of disc pressures show that a seat with 110° backrest angle provides the least disc pressure for a seated person.

In a study examining several features of a chair for its use in sewing tasks, Yu et al. (1988) used four measures in a fractional factorial experiment. These measures were a general discomfort questionnaire, a body part discomfort evaluation, stature change and EMG records. Their analysis showed that the body part discomfort evaluation and the stature change measures gave most information and the other two did not contribute anything further to the selection decision.

3. The sitting posture

3.1. Spinal shape when sitting

As mentioned above, the conventional sitting posture is with an erect back and a horizontal thigh. To achieve this requires that the thighs rotate through 90° but only some 70% of their rotation to the horizontal occurs at the hip joint. As the hip joint flexes to adopt a sitting position, initially the flexors relax whilst the extensors, the hamstring muscles and others, experience an increase in tension. The hamstring muscles run up the back of the thigh from just below the back of the knee to the pelvis. When they stretch they exert a pull on the pelvis, which causes it to rotate backwards, a rotation that contributes the remaining angular rotation of the thighs. But the sacrum, central to the pelvis and to which the spine is connected, also rotates backwards, which causes the lumbar curve to flatten (Keegan 1953, Bridger 1988).

The position adopted by the pelvis is an equilibrium primarily between the hamstring muscles and the hip flexors, which is influenced by their lengths. If the hamstrings are relaxed somewhat by, for example, tucking the legs under the seat, (which reduces their length), the equilibrium is modified as there is a reduction in the pull on the pelvis, reducing the kyphosis in the lumbar spine (Link et al. 1990, Bridger et al. 1992). However, this effect is small compared to the effect of hip flexion, which is by far the major influence on the lumbar curve (Brunswic 1984).

Reducing the amount of hip flexion by using a seat that slopes forward reduces the amount of kyphosis (Mandal 1985). Brunswic (1984) showed that, for a seat that had forward slopes of 15, 20 or 25° and a knee angle of between 70 and 110°, the lumbar curve approximated to its standing curvature. As the seat pan passed through the horizontal to slope backwards (i.e. the hip joint became more flexed), for a given angle at the knee the lumbar curve became increasingly kyphotic, losing up to 85% of its curvature. Using a ‘balance chair’, Chlebicka (2004) demonstrated that, comparing subjects, aged 20–21 years, both male and female, a seat slope of 15, 30 or 45° reduced chest kyphosis and increased lumbar lordosis when compared to the effect of a horizontal seat pan. There was little difference between the three angles in their effects. Both Brunswic (1984) and Eklund
and Liew (1991) are reported by Bridger and Bendix (2004) to find that the effect of hip flexion on spinal posture was up to eight times more influential than that of knee flexion.

3.2. Seat pressure distribution

When sitting, the gravity load from the trunk, head, etc is transmitted to the seat via the protuberances on the base of the pelvis, the ischial tuberosities. The tissue between the ischia and the seat pan is capable of transmitting pressure without damage, much as the feet do. This does not apply to the underside of the thighs, so the weight of the seated body should not be distributed equally over the whole contact surface of the seat. It should be transferred predominantly under the ischia, between the buttocks and the seat pan. Indeed, Bush (1969), in experiments using seats of different depths, found that extending the depth of the seat made no significant change to the pressure under the ischia, but deeper seats increased the pressure under the thighs. This suggests that the thighs were carrying some of the weight of the legs, which otherwise would have been transmitted to the ground via the feet.

4. Consequences for design

4.1. The seat shape

A working seat has to give the least possible restrictive access to the workplace and work activities. The users should be able to see, reach, move, get up and down or use the back rest, maintaining the lowest working loads on their bodies. The influences causing the body loads experienced whilst sitting, given earlier, define the specification that the seat must fulfil.

A basic requirement is that the seat shape must support the body whilst allowing the thigh–trunk angle to be about $115^\circ$. Unless the trunk slopes backward, which is shown later to be a poor posture for most work activities, the seat pan itself must provide a forward and downward slope of some $15^\circ$ or more. If the seat pan is sloping but flat, the reaction forces of the body have a downward component along the surface of the seat, which must be resisted for the sitter to be stable. This has been attempted by providing shin rests, by shaping the seat to support the ischia, by upholstery and by relying on the increased load on the feet.

There are many limitations to such provision. Shin rests limit changes in posture and put a load on the shins. No seat shaping suits the wide anthropometric variation found in all potential sitters; upholstery on a sloping seat provides a drag on clothing, whilst loads on the feet are seen as uncomfortable if they exceed about a quarter of bodyweight, approximately the weight of the legs (Eklund et al. 1982).

A seat shape that overcomes some of these problems, and has been used in several designs, has the rear part of the seat horizontal and the front section sloped downwards. This allows the upper body weight to be supported on a horizontal surface with clearance available for the sloping thighs. The consequences of this design will be discussed later.

Further advances and the availability of seat-tilting mechanisms produced a seat with a curved surface from front to back and a longer forward sloping section (Corlett and Gregg 1994). This provided horizontal support for the ischia, clearance for the thighs and tilting adjustment for various working heights, body sizes and working conditions. Such a design would appear to be a logical consequence of the research outlined above. It provides stable support and the possibility to sit at varying heights, but with feet firmly
on the floor. It is able to fulfil Mandal’s (1985) proposal that both the seat and the workplace are most satisfactory when they are well above the conventional height so that retention of the lumbar curve is possible, thoracic and cervical flexion are reduced and rising from the seat is easier.

A seat that has a horizontal rear portion and a sloping front part can give a similar effect to that experienced with a curved seat. It can be adjusted in height for people of different stature but requires that the work surface is also adjustable. For a fixed height work surface, the use of the design for those of different statures would not be so effective. Raising the chair to use the work surface would lift the feet of short people off the ground, whilst tall people would either have to lower the seat, thus closing the angles at hip and knee, or crouch because they were too high for the work. Although, with the curved seat and a fixed height work surface, the same effect would arise for tall people, for short people the forward tilt would let them put their feet on the ground and still sit at a suitable height for the work.

It should be noted that the literature on seat angle and thigh/trunk angle sometimes equates seat angle with the angle at the hip. Given the variability of individual anthropometric data this conflation, although convenient and, in many cases of little importance, is inaccurate and this must be borne in mind.

4.2. The back rest

When sitting upright on a horizontal seat, the lumbar curve is considerably reduced from the standing position, as described earlier. Pushing a pad into the lumbar region cannot, on its own, recreate the lumbar curve but will push the upper trunk forward. To regain stability and reduce back muscle activity, the sitter must lean back so that the upper trunk rotates backwards over the backrest pad, which will then increase the lumbar curve. However, this posture increases the reach distance to the work point and increases the gravity load moment on the cervical and thoracic spine. Hence, it is not a suitable arrangement for working.

As described elsewhere (Corlett and Eklund 1984), a backrest allowing the user to lean back beyond the vertical position, even with a horizontal seat, can reduce the load on the back and discs by transmitting more of the upper body load to the floor via the backrest. By opening the angle at the hip it also retains some of the lumbar curve, with its benefit to the load distribution on the discs. It has been shown (Grandjean et al. 1983) that many computer users prefer to lean on a seat back that is substantially past the vertical. This position requires the flexion of the cervical spine to adjust the line of sight to the screen. The centre of gravity of the head is over this part of the spine, requiring low muscular activity to maintain the posture. However, the cervical vertebrae are displaced from their ‘neutral’ position, stretching the muscles at the back of the neck and also applying load to the discs at their front edges.

The backrest position in relation to the seat should be adjustable in height and also horizontally, forward and backward. This latter movement allows clearance for the anthropometric variations in buttock size. Insufficient clearance here will require a person with large buttocks to sit forward of the crest of the seat curve, causing discomfort from the adverse distribution of pressure. In some seat mechanisms this adjustment can be done by moving the seat pan horizontally.

The dimensions of the backrest as well as the seat are dependent on the work activities. A laboratory study investigated three seated work postures. One was typical of assembly, requiring the exertion of a horizontal force. A second involved looking sideways as when
using a side-operated fork-lift truck and the third posture involved a restricted knee space whilst doing small assembly, such as assembling nuts and bolts (Eklund and Corlett 1986).

The first two tasks used a flat seat whilst the third was tested using both a flat and a sloping seat, whilst two sizes of backrest were used. A small, lumbar pad backrest was most suitable for the sideways-looking task because it allowed the rotation of the shoulders. A high backrest was best for the pushing task, giving support for the shoulders and reducing muscular activity otherwise needed to stabilize the spine. Very little use of the backrest was seen for the restricted knee space assembly task. Evaluation of the effects was undertaken using spinal shrinkage (see below), backrest and foot forces. All three measures supported the results, with the shrinkage giving convincing evidence of reduced back loadings for the preferred backrests as well as showing major reduction in back load for the sloping seat in the restricted knee space arrangement.

Colombini et al. (1986) examined six seated postures, three using a backrest and three without. Of the three without, a seat sloping forward by 20° gave the lowest lumbar loading but the three seats with a backrest had lumbar loads approximately half of all those where a backrest was not used. These authors also note (using work by other workers) that the backrest seats provided disc loads that were at, or below, the critical pressure for disc-nourishing fluid changes, whereas the three seats with no backrest had discal pressures that were above this critical level.

4.3. The work surface

Sitting at work is to help the person to do the work and is not an end in itself. Thus, any consideration of sitting posture must take into account what the sitter is doing. A major activity for seated workers is desk work. Reading, writing and keyboarding are major parts of such activity. Some consideration of the placement of the paper, work or keyboard in relation to the seated subject reveals the major contribution that this activity makes on the sitter’s posture.

Mandal (1985) has demonstrated the interaction between seat height and seat slope, work height and desk slope on both back and neck postures. He points out that sitting on a higher than conventional seat with a forward slope, whilst using a high desk with a slope of about 10°, can not only reduce the bend in the spine by 20°, but reduce the bend in the neck by 10–15°. A study for sewing machine design (Li et al. 1995) illustrated the effect of a 15° upward slope of the machine bed combined with a 20° backward tilt of the machine body, (the subjects sat on seats with a conventional horizontal seat pan). The former reduced the trunk flexion by 10°, whilst the latter reduced the neck flexion by another 10°.

A review of studies of neck flexion and head inclination (Delleman 2004) quotes a study by Kilbom et al. (1986) of the incidence of neck disorders with neck flexion angle. The difference in symptoms between those with neck inclination of $<20°$ and those with angles $>20°$ was significant. After a 2-year follow-up, these authors found that the time and frequency of maintaining head angle and the percentage of the cycle time that it was maintained were found to be strong predictors of severe neck disorders.

The extent of neck flexion/extension is an important measure independently of the angle of the trunk. In a study by Bonney (1990, see also Bonney and Corlett 2002), a change in neck flexion from zero (upright head) to 20° and then 40° produced significantly increased disc loadings, identified by changes in stature. This experimental evidence supported the work of Colombini et al. (1986), who calculated a significant increase in load on the C6/C7 disc when the neck was flexed 20 to 30° from the upright position.
After reviewing a series of studies of neck flexion and head inclination, Delleman (2004) concluded that: ‘neck flexion/extension is a determinant of neck loading and should be used as an evaluation criterion for working postures in addition to the traditionally used inclination of the head’.

5. Conclusions

The concern with seated workspaces has been consistent over several decades. There must be millions of office workers using seats that may match national or international standards but are nevertheless damaging to their health.

Mandal (1985) was not the first, but probably the most direct, in asserting that the experts, particularly the doctors, have little understanding of the sitting position and have got it wrong. He commented that the commonly accepted recommendations to improve the sitting position have ‘one thing in common, they make a bad working position even worse!’ (p. 56). Perhaps it is now time to accept what the very considerable body of research is saying and use this information to create better seated work.

Although the adult workplace is important, the position in schools is perhaps more serious. As a result of decisions bearing little relationship to the work of pupils, school furniture is devastatingly inadequate. Again Mandal (op. cit.) has demonstrated the serious problems and how they may be alleviated. Lueder and Noro (1994) devoted a complete section of their book (part VIII) to seating in schools, with studies from Denmark, Korea and Japan. Reports by research groups in many countries, including New Zealand, Australia and the US, have raised awareness about the large numbers of pupils with back problems. A committee working with a major charity in Britain has put forward to the government proposals for a change in school furniture to link with the developments in school design and changes in teaching methods (Gardner and Kelly 2005). The report is a direct response to repeated findings (quoted in the report) of an annual incidence of 20% or more of pupils aged 15/16 years reporting recurrent back pain.

References


