Humanics Ergonomics, Inc.

Specialists in Ergonomics

ERGONOMICS REVIEW

Anatomical, physiological and health

Considerations relevant to the SwingChair™

For SmartMotion Technology, Inc.

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Certificant, Board of Certification of Professional Ergonomists

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Pierre-Auguste Renoir - The Swing (1876)

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Dynamic Motion Range	Feature Specification
Forward Tilt Up to 13°	Chair Capacity 250 lb.
Recline Angle Up to 13°	Back Angle Up to 15°

Specifications from www.SwingChair.com

Overview

The following is a review of the ergonomics literature relevant to seat designs that promote dynamic motions by the user[1]. Rani Lueder, CPE of Humanics Ergonomics Inc. wrote it at the request of Ronald Kleist of SmartMotion Technology Inc., a company headquartered in Santa Rosa, California.

Inventor Hector Serber developed the SwingChair. This chair has unique design features that provide more dynamic support than is commonly available in today's office chairs.

The chair is designed to provide continued support while facilitating movements such as fore-aft rocking, forward and reclined sitting and small axial (sideways) movements. The research indicates that such capabilities may provide important benefits.

Ergonomic considerations associated with the SwingChair:

The following pages review the scientific literature along several research dimensions relevant to the evaluation of the SmartMotion Technology Inc. SwingChair.

These research dimensions include:

A) Why movement is so important;

B) The negative consequences associated with common sitting postures;

C) Seat design features (forward sloping seats, counter-balanced motion and axial rotation).

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[1] **Some background may be in order on terms used for advanced seating.**

About two decades ago, the phrase "dynamic seating" came to refer to seat design features that enable users to maintain support as they change postures - with a minimum of required adjustments. Later, the term passive ergonomic seating" supplanted the previous usage of "dynamic seating".

Although these phrases were interchangeably, they emphasize different things. One can suppose that the concept behind "passive ergonomic seats" is to passively support movements.

In contrast, "dynamic seating" suggests that as a consequence of the design, the chair not only helps maintain support - but it also dynamically interacts with the user to encourage and facilitate their movements, while re-aligning, centering and stabilizing postures.

Of course, these terms are just abstractions… Aristotle once wrote that the real idea of a chair is an abstraction that is at all times beyond our grasp. In the purest sense, no chair is truly "dynamic" or "passive" because such chairs would need to function in a range of situations without adjustment.

Even so, some chair designs clearly approach this ideal more closely than do others.

In that spirit, we review the SwingChair, which provides noteworthy capabilities enabling users to move freely while supported and assume beneficial postures without continually "fighting the chair"

What is wrong with sitting?

Most people prefer sitting, because it requires less overall effort by the large muscles than when they stand. Sitting also stabilizes posture and often helps us work.

Many of us spend most of our day (at work, at home, driving, and out) sitting.

However, continuous sitting has disadvantages and potential long-term consequences.

We need to move

Movement is essential for our well-being. Researchers have long known the negative consequences of constrained sitting (*s.f.*, Adams and Hutton, 1983; Duncan and Ferguson, 1974; Eklund, 1967; Graf et al, 1995; Hunting, et al, 1980 and1981; Hult, 1954; Langdon, 1965).

People have difficulty tolerating unsupported, seated postures in static positions for more than a short while (Reinecke et. al., 1985). Reinecke et al (1992, 1994) describe a pneumatic device they developed to induce continuous passive motion in the lumbar region in order to negate some of the detrimental aspects of constrained sitting.

When allowed to move freely, people are usually in constant motion (Branton, 1967, 1969, Jurgens 1980). They often alternate through postural cycles continuously over the day[2] (Branton and Grayson, 1967).

Unfortunately, today's computer workers' are becoming increasingly constrained as the work process systematically automates activities that previously required changes in posture (Grieco, 1986; Waersted and Westgaard, 1997).

Such research demonstrates that constrained postures increase discomfort and health risks (e.g., Aaras et al, 1997)

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[2] Even so, research by Ortiz et al (1997) on postures among computer users at one office, suggests that individuals tend to develop characteristic postures that are more consistent over the day than they are with nearby office workers.

Lack of movement has health consequences

It is commonly recognized that constrained postures contribute to a broad range of chronic disorders. These include joint impairments (arthritis); inflamed tendons and tendon sheaths, chronic joint degeneration (arthroses), and muscle pain (Grandjean, 1987).

Sitting in one position increases local build-ups of pressures on the body and postural disorders (orthostatic intolerance) (Kilbom, 1986).

Graf et al. (1993 and 1995) reported higher incidences of discomfort and chronic disorders among workers assuming fixated or constrained sitting postures. Static and constrained postures interrupt blood flow in direct proportion to the loads acting on the muscles (Grandjean, 1987). Muscle oxygenation is reduced with fairly low loads[3] (McGill and Hughson, 2000).

Faiks and Reinecke (In press) write, “the scientific literature on musculo-skeletal disorders makes it clear that prolonged static postures are uncomfortable and can lead to serious problems. In the area of sitting and seating, researchers demonstrated that workers who are required to maintain static seated postures report more discomfort than those who are not.”

Hunting et al. (1981) found it “reasonable to assume a causal relationship between constrained postures at terminals and other office machines and impairments and symptoms."

These effects can magnify over time, following a dose-response relationship. Kumar (2001) notes, “an accumulation of residual strain over years may set the stage for injury even if stress does not rise extraordinarily. The latter is due to a progressive reduction in stress tolerance capacity”. Movement reduces these risks (*s.f.* Aaras et al, 1997).

Some researchers maintain that such detrimental effects may be attributed to a "lack of physical variation", rather than simple inactivity (Bendix 1994; Winkel and Oxenburgh, 1990). That is, the lack of movement is more important than the fact that the work is sedentary.

[3] These researchers found a reduction in tissue oxygenation of the lumbar extensor muscles with as little as 2% of MVC (Maximum Voluntary Contraction).

Movement and leg swelling (Edema)

Leg swelling (edema) occurs when circulation is impaired[4]. Edema is also common. Widmer (1986) interviewed 4,529 workers, finding that 70% of the women and 44% of the men reported this form of discomfort.

Leg edema causes more than cold feet. Local pooling of the blood increases venous pressures to the heart, blood pressure, and heart rate. It pre-disposes users to peripheral venous disorders such as varicose veins (Kilbom 1986; van Deursen 2000c).

Lack of movement is strongly associated with leg swelling (Winkel 1981; Winkel and Jorgensen, 1986). During movement, the "expansion and contraction" of the muscles help promote circulation and prevent edema.

When seated subjects move about in their seat, they experience much less edema than inactive sitters (van Deursen et al, 2000c; Winkel and Jorgenson, 1986).

Van Deursen (2000c) reported that incorporating small but continuous movements into the day increased the time of onset of leg swelling. Not surprisingly, intermittent exercise is also effective (Winkel, 1981).

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[4] In techno-speak, this means there is "an increase in net transcapillary filtration, which exceeds the removal of fluids by the lymphatics" (Van Deursen et al, 2000).

Constrained postures and back pain

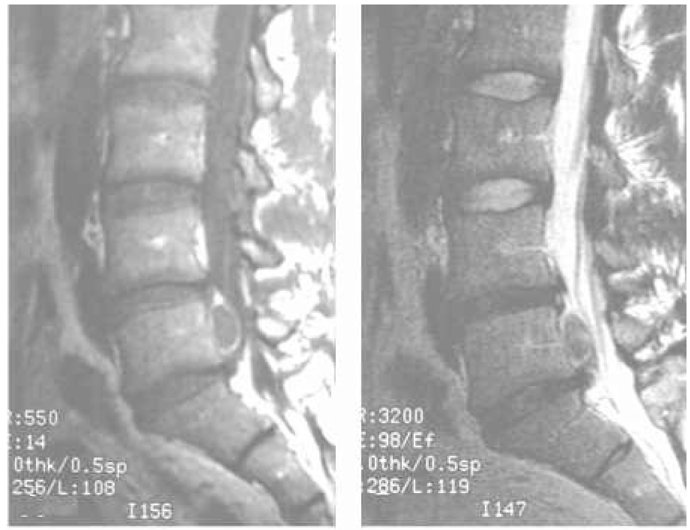
Over seventy percent of those past the age of 40 experiences back pain some of the time. Our sitting habits affect our risk of back pain (e.g., Bendix 1994).

Many assume that short-term (acute) impact forces cause back pain. Although (for example) slips, trips and falls have caused many back injuries, research suggests long-term (low-level) chronic stressors are as important.

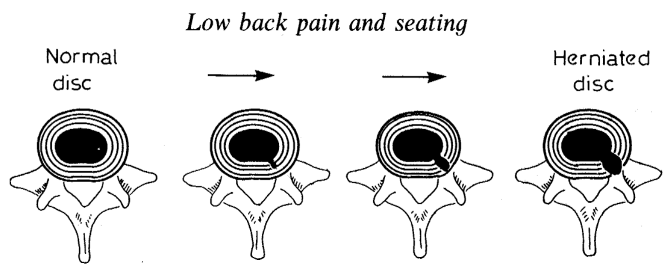
That is, sedentary employees performing constraining work that allows few movements are as likely to have disabling back pain as those performing heavy manual work.

Constrained postures cause chronic degenerative alterations of the cervical, thoracic, and lumbo-sacral spine (Graf et. al. 1995; Hunting et. al., 1980; Occipinti et. al., 1987; Polus et. al., 1985).

Insurance and bank employees, who commonly sit in static positions for long periods, are prone to very high levels of intervertebral disk immobility (Wood and McLeich, 1974).



MRI of the herniated lumbar spine, from two directions (Slavin & Raja, 2001)



Progression of disc herniation (Bendix, 1994)

One reason that it is so important to move is that after the age of ten, our spine loses its ability to actively feed itself (or, rather, feed the inter-vertebral discs) and eliminate waste products (Adams and Hutton, 1983; Grandjean, 1987; Maroudas, et al, 1975; Schoberth, 1978). After this age, the spine receives nutrients and eliminates wastes through passive changes in osmosis that are induced by movement.

Faiks and Reinecke (in press) write "moreover, there is scientific evidence that prolonged static sitting may compromise spinal structures by reducing disk nutrition, restricting capillary blood flow, and increasing muscle fatigue."

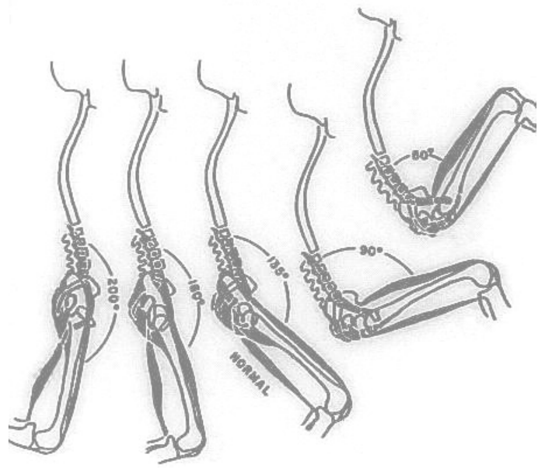
Adams (1996) reported that people with severely degenerated discs had more extensive disc innervation than "normal" people.

Sitting flattens our lumbar curve

When we sit down, our hamstrings flex, causing the pelvis to rotate back. This excessively[5] flattens the lumbar curve[6]. It also tilts the angle of the individual vertebra so that pressures at the front of the discs increase (Adams et al, 1996; Bendix et al, 1996; Corlett, 1999).

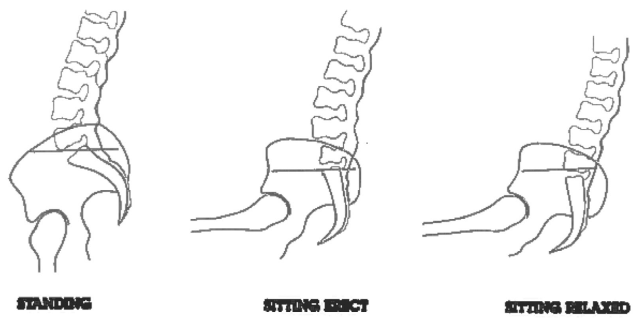
Keegan (1953) demonstrated that changes in the angle between the torso and the legs tilts the pelvis forward and flattens the lumbar area (see his graphic on the right)[7].

He reported that the discs seem more evenly distributed when the legs are approximately 135° from the torso[8].



Nachemson (1981) concluded leg-torso angles needed to be at least 110° to reinstate the natural curve of the lumbar spine (lordosis).

He found that sitting caused the lumbar curvature (lordosis) to decrease by about 38°. About two-thirds of this flattening is from pelvic rotation (28°), and one-third from flattening the lumbar curve (10°)[9].



[5] On the other hand, standing causes the pelvis to rotate forward, and increasing the lumbar curve depth excessively.

[6] Leivseth and Drerup (1997) found less spinal shrinkage when sitting – which they attributed to the loss of the lumbar curve. That is, users are taller because their spine is longer – since it is flatter.

[7] Keegan's research seems rather unconventional today – it certainly would not pass committees and peer reviews. His research involved repeated X-rays of a man laying on a horizontal surface.

[8] Interestingly, this corresponds to the "Neutral Body Posture" in space, with a 128° thigh-torso angle (Webb Assoc., 1978). Santschi et al (1964) recorded angles of about 126° in space.

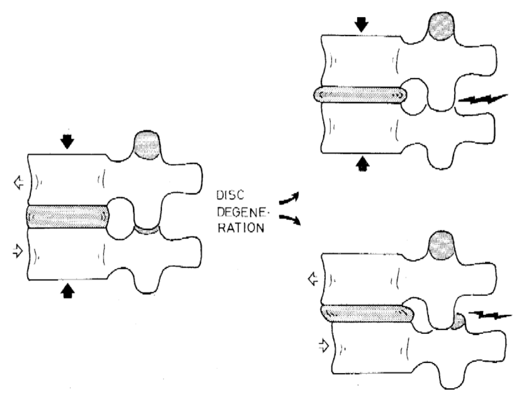
[9] The sacroiliac joint angle (between the lumbar vertebra and tailbone) changes 4° (Andersson, 1986).

Constrained postures and back pain

Sitting increases intra-discal pressures (Andersson et al). However, the key issue is not the overall forces acting on the spine. Rather, what matters is the concentration of forces and moments acting on specific spinal structures such as the discs, ligaments (Dolan and Adams, 2001)… and the susceptibility of those structures to damage.

These authors add “tissue stress probably plays a major role in determining if a given tissue is painful, it is tissue stress rather than overall loading which influences the metabolism of connective tissue cells” (Dolan and Adams, 2001).

These spinal structures are affected differently by different postures. During unsupported sitting, forward leaning (anterior) postures are associated with higher intradiscal pressures than with leaning back (Andersson et al. 1974, 1980, 1986).



Facet joints contribute to back injuries in particular. (Bendix, 1994)

Yet Bendix (1987) notes posterior characteristics of the lumbar vertebrae can be adversely affected by lordotic extension; prolonged compression of the facet joints may contribute to pain. Poor posture and obesity (which shifts the center of gravity and increases the weight borne by the spine) aggravate those problems.

There is no best position – the best solution is to keep moving!

Sitting and seat design

Each person has their own unique postural dynamics relating to their physiology, their habits, the products they use, and the actions required of them. Even so, there are characteristics associated with our postures that are common to us all.

Unsupported sitting (upright)

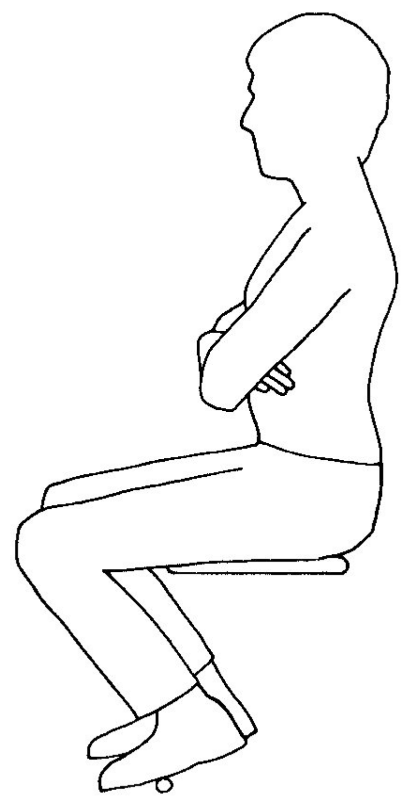
Unsupported upright sitting involves the worst of all worlds.

The angle between the torso and the legs is insufficiently large to enable the user to assume a lumbar curve (e.g., Nachemson, 1981).

Additionally, the force (moment arm) acting on the spine shifts forward (e.g., Corlett and Eklund, 1984; Reinecke and Hazard, 1994).

This destabilizes postures, increasing loads acting on the ligaments. This can cause the ligaments to deform, weakening the structure of the joints and increasing loads on the spine.

It is obvious to anyone sitting in this position takes more “muscle work” than sitting with the back supported (Andersson et al, 1974, 1980 and 1986; Corlett and Eklund, 1984).



Unsupported upright posture
(Corlett and Eklund, 1984)

Unsupported sitting (relaxed)

It is difficult to sit upright and unsupported for very long. Most users would rather slump than perform the muscle work required to do so (which is uncomfortable and fatiguing).

Several things happen in the process. Of particular note, users slump forward, reversing the lumbar curve (lumbar kyphosis) (Bridger and Eisenhart-Rothe, 1989)

If they are fit, (i.e., have strong abdominal muscles), the abdomens absorb some of the pressure, helping to stabilize posture a bit (Corlett and Eklund, 1984).

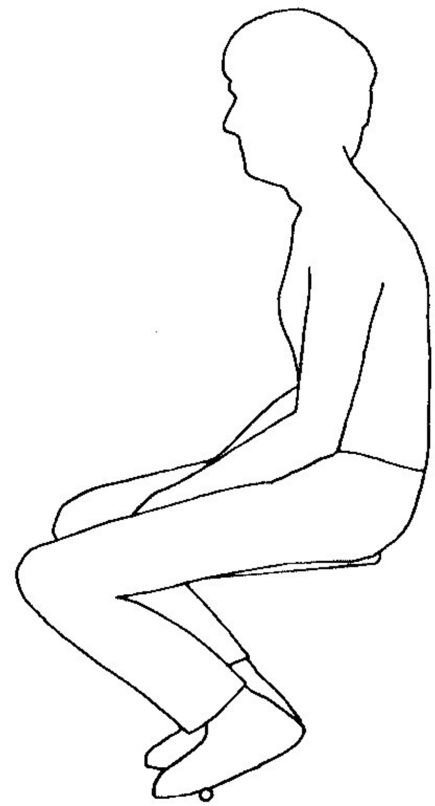
But fit or not, postural support shifts from the muscles to the ligaments that support the spine. The ligaments deform, and there is an increased risk of damage to the spine and joints.

You may be thinking now, "What does that have to do with office work? Just about everyone has a backrest these days".

It is absolutely the case that office employees have chairs with backrest, but are they using them?

If you work at a typical office, many or most of these employees work with their backs unsupported by their backrest[10]. (Please verify this for yourself.)

You should be proud if you find that most of your employees work with their back supported. Your furniture, lighting, work and your organization probably all contributed. But you're special.



Relaxed unsupported sitting
(Corlett and Eklund, 1984)

[10] For example, this writer once surveyed a large telecom center with over 1,000 intensive computer users. There was not a single person leaning back against their backrest in the entire center.

Reclined sitting (relaxed)

Reclined postures have advantages.

They simultaneously reduce loads on the spine (intra-discal pressure) and effort (Andersson et al, 1974).

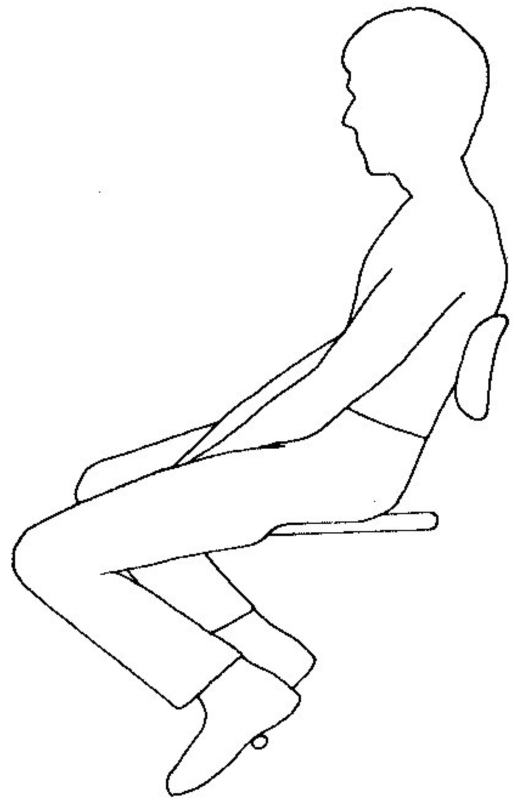
Backrests stabilize posture by relieving the amount of effort required as we fight gravity.

They should theoretically reinstate the lumbar curve 1) as the weight of the torso shifts back against the backrest and 2) as the angle between torso and the legs increases.

Umezawa (1970) showed that leaning back could promote neutral postures. This research also showed that both the seat angle and the backrest contributed to this effect.

But leaning back also has disadvantages.

Many (perhaps even most) intensive computer users slump against their backrest, locking in their pelvis and causing them to lose (or reverse) their lumbar curve (Dolan and Adams, 2001).



Supported reclined sitting
(Corlett and Eklund, 1984)

Corlett and Eklund (1984) note, "this will lead to increased pressure on and within the discs, both from forces arising from the stretched muscles and ligaments and the increased wedging at the anterior [forward] edges of the disks".

Bendix (1996) concluded, "the traditional conception that a backrest facilitates lordosis is apparently not true. It seems rather that backrests actually facilitate the opportunity for the user to stabilize their lumbar spines by providing their lower back with support, resulting in relative kyphotic increases".

There are also functional limitations associated with reclining. It can be difficult to lean back when while reading a document and trying to reach the mouse.

Reclined postures also increase loads on the neck as the reclined employees attempt to re-establish the task-related visual field (Grandjean et al, 1983; Corlett, 1999). Loads on the shoulders and arms increase if reclining takes the users away from their work items.

But the problem is not reclining itself so much as reclining in a static posture.

Intermittent reclining is important and beneficial - but as one of a range of working postures.

Lumbar curves

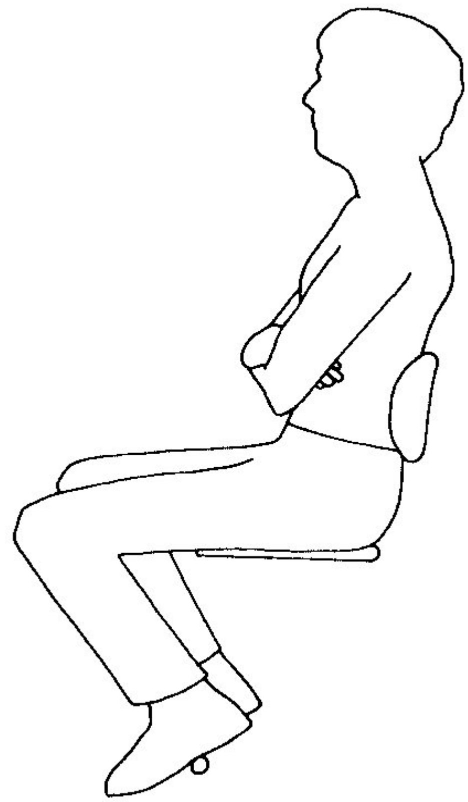
Although Anderson's research demonstrates that lumbar supports can reduce intradiscal loads on the lumbar spine, there is also evidence to suggest that lumbar supports on backrests sometimes provide limited benefits (Corlett, 1999).

Brodeur and Reynolds (1990) used cadavers to analyze the motion of the vertebra. They concluded that contour of the lumbar spine is little affected by the lumbar support. Rather, it results from the position of the thorax relative to the pelvis, and its' impact on pelvic angle.

Bendix et al (1996) reported that lumbar supports on backrests helped promote lordosis compared to straight backrests while performing tasks, but not during passive sitting and reading.

Lumbar supports only effective if they are properly designed and adjusted for the user.

The user must also learn to sit "properly" in the chair, so they avoid slumping, maintain backrest support and avoid postures characterized by forward-leaning or small angles between the thighs and torso.



Supported upright posture
(Corlett and Eklund, 1984)

That is not to say that lumbar supports are unimportant. They often stabilize postures, reduce muscle loads, and help promote comfort. In some users and situations, they may also promote a lumbar curve. But not necessarily, in every case.

Forward sloping seats

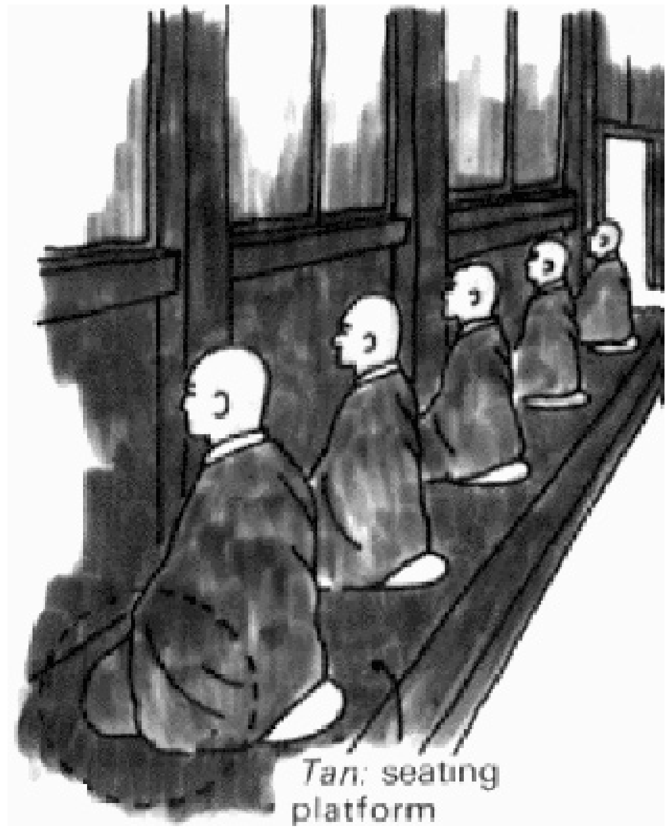
In the 1980's, considerable interest was generated in the ability of the forward sloping seat to counteract the potentially negative consequences of upright seating (Corlett, 1999; Mandal 1982, 1984, 1985).

Proponents of forward sloping seats maintained that tilted seats would reinstate lumbar lordosis by tilting the pelvis, with Mandal at the forefront.

Many variations for those designs developed over the years (e.g., Congleton et al. (1985); Brunswic 1984; Corlett, 1999).

Forward tilting seats certainly have functional advantages.

They extend reach and can facilitate rising from a chair[11]. They may enable short users to sit higher above the floor (and closer to the desk) while maintaining foot support. They may help users prevent leg edema by facilitating leg mobility.



Buddhist Monks historically sat with platforms in back that induce pelvic tilt.

From "An illustrated look at Japan" (published by JNTO, the Japan National Tourist Org.)

[11] This is a particularly important issue for the elderly, disabled, and pregnant women. Surveys suggest that the ability to get up from a chair is the single most important issue among the elderly.

Some research has indeed yielded positive results.

For example, Bridger and Eisenhart-Rothe (1989) found that subjects were the least kyphotic (in the lumbar area) when sitting at forward sloping seats with 115° thigh-torso postures. The opposite was observed with the upper torso; thoracic angles were the least kyphotic with forward inclined seats.

However, some research has been less dramatic than some proponents anticipated.

For example, Bendix's (1984) findings were more moderate than those by Mandal (1982, 1984). Brunswic (1984) found positive results in the laboratory setting, but not in the field[12].

It appears that forward sloping seats sometimes helps reinstate lumbar lordosis in the static position, but the research has not been consistent.

Interest in traditional chairs with forward seat capabilities has been waning. This writer presumes this is because it is difficult for people to sit for long periods in forward sloping seats in static positions. Long-term static sitting in a forward sloping seat may actually achieve the opposite of its' intent if it forces users to assume awkward postures in the process of trying to stabilize their position.

Users are unwilling (and often unable) to sit for very long at a pronounced forward sloping seat[13] . In fact, those who perform static work are the most likely to reject this position due to the greater muscle effort required.

Other difficulties associated with static forward seat positions are that they shift their weight to the thighs and ankles (Corlett, 1999, Eklund et al, 1982, Schoberth, 1978).

When the forward positions are static, users must struggle to keep from sliding off the chair (Corlett 1999).

Such research underscores the importance of incorporating "dynamic" motion in forward sloping seats. For example, Lengsfeld et al[14] (2000a) reported that a dynamic seat that tilted the seat pan forward while allowing some degree of recline increased lumbar lordosis, and this affect was superior to a dynamic "Synchro" chair that tilted the seat pan back as the backrest reclined.

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[12] Brunswic's study evaluated forward tilting seats with lower leg support (i.e., Balans-style).

[13] We are referring to strong forward inclinations. Many people are willing to sit with a few degrees of forward inclination (Bendix, 1984). Further, users that sit in constrained postures are more likely to avoid assuming this posture, due to the greater muscle work required.

[14] These researchers used mathematical equations / modeling to calculate distances between vertebral segments. The manufacturer provided the seat design geometry as CAD data.

Shifting center of gravity

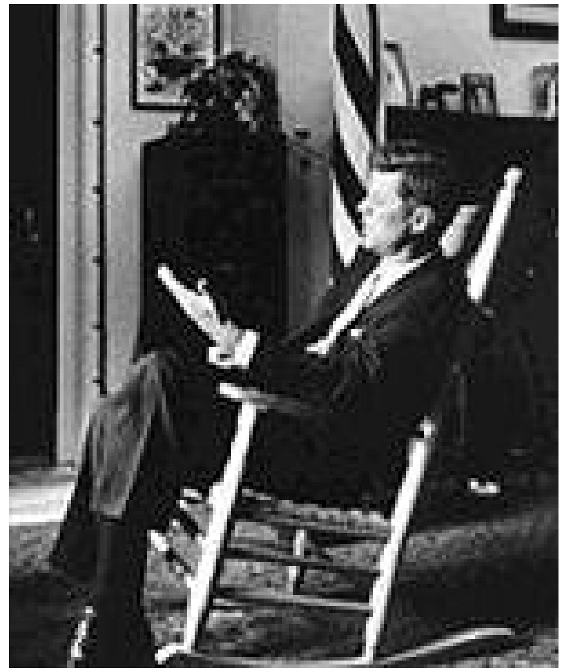
One of our cultural icons is President John F. Kennedy rocking on his chair in the Oval office.

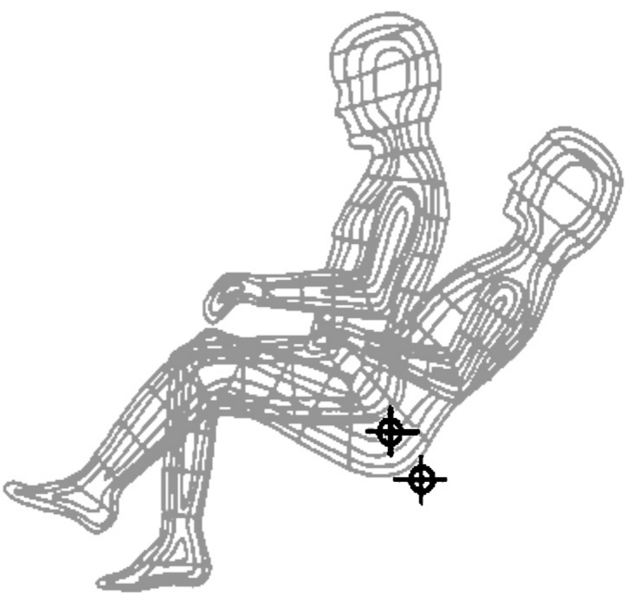
He sat in his rocking chair because it alleviated his back pain resulting from his war injuries.

This rocking motion allowed him to move while sitting in a stable posture.

He was able to maintain a stable posture through his long hours of intensive and stressful work by a characteristic of the chair.

That Is, as the chair rocked, it continually re-aligned his center of gravity.





You do not need to be an ergonomist to notice that different chairs have entirely different “feels”.

Some chairs fight you all the way, such as when the chair forces the user to sit in an awkward posture.

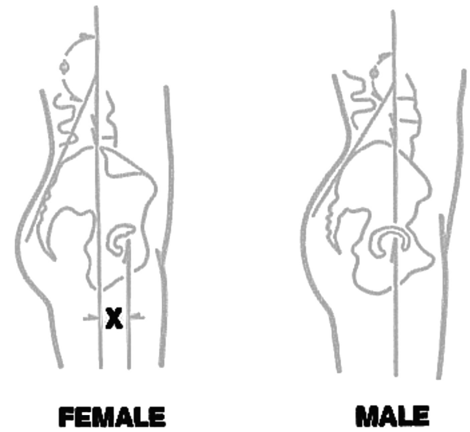
Another feature that affects the fit of the user and the chair is if the pivot point of the chair is markedly different from the pivot point of the user. If the chair’s pivot is close to that of the user, the chair responds in concert with the user.

A related aspect is the ability of the chair to shift the user’s center of gravity as they shift position. This important design consideration enables the user to maintain in a stable and centered position as they move.

Chairs that allow users to change their center of gravity as they change position have an added benefit.

Namely, most chairs have a standard pivot point – while people's centers of gravity can differ markedly. Pregnant women and heavy users, for example, have more forward center of gravities.

Tichauer (1978) notes that while men have centers of gravity above their hip socket, for women these are forward.



Perhaps this is why various researchers (*s.f.* Bridger & Eisenhart-Rothe, 1989) have reported that women have deeper lumbar contours than men do.

Finally, there appears to be a functional advantage to the shifting center of gravity while rocking with the SwingChair. As the user rocks forward and back, the design appears to facilitate maintaining a constant arm (and fingertip position) while typing. Additional research is required however to verify that the design facilitates maintaining a fingertip position (on the keyboard) while moving.

Rotary movements of the Seat

The flexibility of the SwingChair backrest allows the user to perform axial "micro-motions".

Extensive twisting (i.e., axial rotation of the spine) can increase risk of injury (Au et al, 2001; Kumar et al., 1998; Kumar, 2001).

Kumar (2001) explains how prolonged and extreme twisting can damage joints. First, the associated forces stress and deform connective tissues and thereby destabilize the joints. With time, as muscles fatigue and joints "weaken" the resulting imbalance can lead to unnatural and uncoordinated movements at the joint that result in injury.

That is not what we are dealing with here. While large degrees of twisting can be hazardous, there is also evidence to suggest that small amounts of lateral twisting can be beneficial.

In a laboratory study using a pig cadaver, Van Deursen et al (2001) found a consistent increase in disc height and decreased intradiscal pressure when regular but small (less than 2°) axial rotations were performed[15].

Another study of a chair with rotary movements[16] (Lengsfeld et al, 2000b) suggested that "rotatory" chairs could reduce forces acting on the lumbar spine. These researchers emphasized the greater importance of this type of chair on the discs' nutrition, and prevention of back pain.

More research is needed to understand the implications of this kind of movement. However, there is reason to believe that these small lateral motions can benefit.

Conclusion

Seated postures are problematic in that it tends to constrain postures and promote unnatural postures that deviate from the natural position of the spine. Each of these can negatively affect our health, comfort, and effectiveness at work.

Traditional seat design solutions have included backrest recline, forward seat pan slopes and lumbar curves. Although each feature has advantages, neither is provides an adequate solution.

The only truly effective way to maintain a seated posture for extended durations is to continuously cycle through the upright, reclined, and forward tilting positions.

This requires a chair that allows the user to dynamically change postures – while maintaining stable postures with shifting centers of gravity.

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[15] Of note, to perform this research they had to remove the facet joints (vertebral extensions) and spinal processes. However, the researchers maintained that this did not affect results because the range of rotation was within the free interspace range of movement of the joints.

[16] These researchers used one patient diagnosed with degenerative instability of the lumbar spine. The rotational movements of the chair were 1.2° to the right and left, at a frequency of .22 Hz.

References

Aaras, A, Horgen, G., and Ro, O. (2000) Work with Visual Display Unit: Health consequences. International J Human-Computer Interaction. 12(1) 107-134.

Adams, M.A. and Hutton, W.C. (1980) The effect of posture on the role of apophyseal joints in resisting intervertebral compressive force. J Bone Joint Surgery. 62-B, 358-362.

Adams, M.A. and Hutton, W.C. (1983) The effect of posture on the fluid content of lumbar intervertebral discs. Spine. 8(6), 665-671.

Adams, M.A., and Dolan, P. (1995) Recent advances in lumbar spinal mechanics and their clinical significance. Clinical Biomechanics, 10(1), 3-19.

Adams, M.A., McMillan, D.W., Green, T.P., and Dolan, P. (1996) Sustained loading generates stress concentrations in lumbar intervertebral discs. Spine. 21(4), 434-438.

Adams, M.A., McNally, D.S., and Dolan, P. (1996) 'Stress' distributions inside intervertebral discs. The effects of age and degeneration. J Bone Joint Surgery Br. 78(6), 965-972.

Andersson, B.J.G. and Ortengren, R. (1974) Lumbar disc pressure and myoelectric back muscle activity during sitting, Scandinavian Journal of Rehabilitation Medicine. 6, 115-121.

Andersson, G.B.J. (1980) The load on the lumbar spine in sitting postures. In: D.J. Oborne and J.A. Levis (eds.) Human Factors in Transport Research. New York: Academic Press, 1980, 231-239.

Andersson, G.B.J. (1986) Loads on the spine during sitting. In: Corlett, N., Wilson, J. and Manenica, I. (Eds.) The Ergonomics of Working Postures. Philadelphia: Taylor and Francis. 109-118.

Au, G., Cook, J., and McGill, S.M. (2001) Spinal shrinkage during repetitive controlled torsional, flexion and lateral bend motion exertions. Ergonomics. 44-4, 373-381.

Bendix, T. (1984) Seated trunk posture at various seat inclinations, seat heights, and table heights. Human Factors, 26(6), 695-703.

Bendix, T. (1987) Adjustment of the seated Workplace - With Special Reference to Heights and Inclinations of Seat and Table. Laegeforenigens Forlag. (Thesis published in the Danish Medical Bulletin.) Laboratory for Back Institute, Copenhagen.

Bendix, T. (1994) Low back pain and seating. In: Lueder, R., and Noro, K. (Eds.) Hard Facts about Soft Machines: The ergonomics of seating. Philadelphia: Taylor and Francis, 147-156.

Bendix, T. and Biering-Sorensen, F. (1983) Posture of the trunk when sitting on forward inclining seats. Scandinavian J Rehab. Medicine, 15, 197-203.

Bendix, T., Poulsen, V., Klausen, K. and Jensen, C.V. (1996) What does a backrest actually do to the lumbar spine? Ergonomics. 39(4), 533-542.

Branton, P. (1969) Behaviour, body mechanics, and discomfort. In: Grandjean, E. (Ed.) Sitting Posture: Proceedings of a symposium held in September 1968 at the Swiss Federal Institute of Technology. London: Taylor and Francis, 202-213.

Branton, P., and Grayson, G. (1967) An evaluation of train seats by observation of sitting behavior. Ergonomics. 10, 35-51.

Bridger, R.S., Von Eisenhart-Rothe, C., and Henneberg, M. (1989) Effects of seat slope and hip flexion on spinal angles in sitting. Human Factors. 31(6), 679-688.

Brodeur, R.R., and Reynolds, H.M. (1990) Passive mechanics of the lumbo-pelvic spine for erect and slumped seated postures. Proceedings of the May 1990 International Conference on Spinal Manipulation. FCER: Arlington, Virginia. 190-193.

Brunswic, M. (1984) Seat design in unsupported sitting. Proceedings of the International Conference on Occupational Ergonomics. Toronto, 294-298.

Callaghan, J.P., and McGill, S.M. (2001) Low back joint loading and kinematics during standing and unsupported sitting. Ergonomics, 44-3, 280-294.

Congleton, J.J., Ayoub, M.M., and Smith, J.L. (1985) The design and evaluation of the neutral posture chair for surgeons. Human Factors, 27(5), 589-600.

Coppes, M.H., and Marani, E. (1997) Innervation of "Painful" Lumbar Discs. Spine 22(20), 2342-2349.

Corlett, E.N. (1999) Are you sitting comfortably? International J Industrial Ergonomics, 24, 7-12.

Corlett, E.N., and Eklund, J.A.E. (1984) How does a backrest work? Applied Ergonomics. 15 (2), 111–114.

Dimberg, L., Ullman, J., Josefsson, L.G., Ericson, M., and Eriksson, B. (1994) A Comparison between the Effect on Low-Back Pain and Disorders of Sitting in Non-Traditional Chairs with Forward-Sloping Seats and Sitting in Traditional Chairs with Horizontal Seats, The Implementation of Change: NES '94 - Proceedings of the Nordic Ergonomics Society Annual Conference, Stenungsund, Sweden, 14-16 September 1994, Edited by G. Palmerud. Ergonomics Society of Sweden, Goteborg, Sweden, 144-147.

Dolan, P., and Adams, M.A. (2001) Recent advances in lumbar spinal mechanics and their significance for modeling. Clinical Biomechanics, 1, S8-S16.

Dowell, W.R. (1995) An estimation of lumbar height and depth for the design of seating. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting 1995. Santa Monica: Human Factors & Ergonomics Society. v. I, 409-411.

Duncan, J., and Ferguson, D. (1974) Keyboard Operating Posture and Symptoms in Operating. Ergonomics, 17(5), 651-662.

Dunlop, R.B., Adams, M.A., and Hutton W.C. (1984) Disk space narrowing and the lumbar facet joints. J Bone Joint Surgery. 66-B, 706-710.

Eklund, J.A.E., and Corlett, E.N. (1987) Clinical evaluation of spinal loads and chair design in seated work tasks, Biomechanics. 2(1), 27-33.

Eklund, J.A.E., Houghton, C.S., and Corlett, E.N. (1982) Industrial seating. Appendix 10. Thesis 1986 for the Dept. Industrial Ergonomics, University of Technology, S-581-83, Linkoping, Sweden.

Eklund, M. (1967) Prevalence of musculoskeletal disorders in office work. Socialmedicinsk, 6, 328-336.

Ericson, M.O. and Goldie, I. (1989) Spinal shrinkage with three different types of chair whilst performing video display unit work. International J Industrial Ergonomics, 3(3), 177-183.

Faiks and Reinecke. (Submitted for publication) Understanding the kinematics of the back and its' relation to back support.

Gordon, C.C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T., Tebbetts, I. and Walker, R.A. (1989). 1988 Anthropometric Survey of US Navy Personnel: Summary Statistics Interim Report. (Technical Report Natick/TR-89/027). Natick, MA: United States Army Natick Research, Development, and Engineering Center.

Graf, M., Guggenbuhl, U. and Krueger, H. (1993) Investigations on the effects of seat shape and slope on posture, comfort and back muscle activity. International J Industrial Ergonomics, 12(1-2), 91-103.

Graf, M., Guggenbuhl, U., and Krueger, H. (1995) An assessment of seated activity and postures at five workplaces. International J Industrial Ergonomics, 15(2), 81-90.

Grandjean, E. (1987). Ergonomics in computerized offices. London: Taylor and Francis. 96-156.

Grandjean, E., Hunting, W. and Pidermann, M. (1983) VDT workstation design: preferred settings and their effects. Human Factors. 25(2), 161–175.

Grieco, A. (1986) Sitting posture: an old problem and new one. Ergonomics. 29(3), 345-362.

Hult, L. (1954) Cervical, dorsal and lumbar spine syndromes. Acta Orthopaedic Scandinavia (Supplement 17).

Hunting, W., Grandjean, E., and Maeda, K. (1980) Constrained postures in accounting machine operators. Applied Ergonomics. 11(3), 145-149.

Hunting, W., Laubli, T. and Grandjean, E. (1981) Postural and visual loads at VDT workplaces: Constrained postures. Ergonomics. 24 (12), 917-931.

Jurgens, H.W. (1980) Body movements of the driver in relation to sitting conditions in the car: a methodological study. In: D.J. Oborne and J.A. Levis (Eds.) Human Factors in Transport Research. New York: Academic Press.

Keegan, J.J. (1953) Alterations of the lumbar curve related to posture and seating, J Bone and Joint Surgery. 35A (3), 589-603.

Kilbom, A. (1987). Short- and long-term effects of extreme physical inactivity: a brief review. In: Knave, B. and Wideback, P.G. (Eds.) Work with display units, Elsevier Science Publishers B V (North-Holland), Amsterdam, 219-228.

Kingma, I., van Dieen, J.H., Nicolay, K., Maat, J.J., and Weinans, H. (2000) Monitoring water content in deforming intervertebral disc tissue by finite element analysis MRI data. Magnetic Resonance in Medicine. 44, 650-654.

Kroemer, K.H.E. (1988) VDT Work station Design. In: Helander, M. (ed.). Handbook of Human-Computer Interaction. Elsevier Science Publishers B.V. (North-Holland), 521-539.

Kumar, S. (2001) Theories of musculoskeletal injury causation. Ergonomics, 44-1, 17-47.

Kumar, S., Narayan, Y. and Zedka, M. (1998) Strength in combined motions of rotation and flexion/ extension in normal young adults. Ergonomics 41(6), 835-852.

Langdon, F.J. (1965). The design of cardpunches and the seating of operators. Ergonomics, 8, 61-68.

Leivseth, G., and Drerup, B. (1997) Spinal shrinkage during work in a sitting posture compared to work in a standing posture. Clinical Biomechanics. 12(7/8), 409-418.

Lengsfeld, M., Frank, A., van Deursen, D. L., and Griss, P. (2000a) Lumbar spine curvature during office chair sitting. Medical Engineering and Physics. 22(9), 665-669.

Lengsfeld, M., van Deursen, D. L., Rohlmann, A., van Deursen, L.L., and Griss, P. (2000b) Spinal load changes during rotatory dynamic sitting. Clinical Biomechanics (Bristol, Avon). 15(4), 295-297.

Lueder, R., Corlett, E.N., Danielson, C. Greenstein, G.C., Hsieh, J., Phillips, R., and DesignWorks/USA. (1994) Does it matter that people are shaped differently yet backrests are built the same? In: Lueder, R., and Noro, K. (Ed.) Hard Facts about Soft Machines: The ergonomics of seating. London: Taylor and Francis. 205-220.

Magora, A. (1972) Investigation between low back pain and occupation. Physical requirements sitting, standing, and weight lifting. Industrial Medicine, 41, 5-9.

Mandal, A.C. (1982) The correct height of school furniture. Human Factors. 24(3), 257-269.

Mandal, A.C. (1984) What is the correct height of furniture? In: Grandjean, E. (ed.), Ergonomics and Health in Modern Offices, London: Taylor and Francis, 471-476.

Mandal, A.C. (1985) The Seated Man: Homo sedens. Denmark: Dafnia Publications.

Maroudas, A., Nachemson, A., Stockwell, R. and Urban, J. (1975) Some factors involved in the nutrition of the intervertebral disc. J Anatomy, 120, 113-130.

McGill, S.M., Hughson, R.L., and Parks, K. (2000) Lumbar erector oxygenation during prolonged contractions: Implications for prolonged work. Ergonomics. 43-4, 486-493.

Nachemson, A.L. (1981) Disc pressure measurements. Spine. 6, 93-97.

Occipinti, E., Colombini, D., Menoni, O., Molteni, G., and Grieco, A. (1987) Work postures and spinal alterations in telephone operators employed on Video Display Terminals. Posture di Lavoro ed Alterazioni del Rachide in Operatori Telefonici Addetti a Videoterminale, Italian, Medicina del Lavoro, 78(1), 59-67.

Ortiz, D.J., Marcus, M., Gerr, F., Jones, W., and Cohen, S. (1997) Measurement variability in upper extremity posture among VDT users. Applied Ergonomics. 28(2), 139-143.

O'Sullivan, P. B., Grahamslaw, K. M., Kendell, M., Lapenskie, S. C., Moller, N. E., and Richards, K. V. (2002) The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine, 27(11), 1238-1244.

Polus, B.I., and Webster, M.E.D. (1985) Adaptive changes in spinal structures and susceptibility to spinal injury. Ergonomics in the Tourist, Agricultural and Mining Industries, Proceedings of the 22nd Annual Conference of the Ergonomics Society of Australia and New Zealand. Toowoomba, Queensland, December 1985. ESANZ, Carlton South, Victoria, Australia, 222-227.

Reinecke, S., Bevins, T., Weisman, J., Krag, M. and Pope, M. (1985) The relationship between seating postures and low back pain. Rehabilitation Engineering Society of North America, 8th Annual Conference, Memphis, Tenn.

Reinecke, S.M., and Hazard, R.G. (1994) Continuous passive lumbar motion in seating. In: Lueder, R., and Noro, K. (Eds.) Hard Facts about Soft Machines: The ergonomics of seating. Philadelphia: Taylor and Francis, 157-164.

Reinecke, S.M., Hazard, R.G., Coleman, K., and Pope, M.H. (1992) A continuous passive lumbar motion device to relieve back pain in prolonged sitting. In: S. Kumar (Ed.) Advances in Industrial Ergonomics and Safety IV, London: Taylor and Francis. 20, 971-976.

Roberts, N., Hogg, D., Whitehouse, G.H., and Dangerfield, P. (1998) Quantitative analysis diurnal variation volume and water content lumbar intervertebral discs. Clinical Anatomy. 11, 1-8.

Rohlmann, A., Claes, L.E., Bergmannt, G., Graichen, F., Neef, P., and Wilke, H.J. (2001) Comparison of intradiscal pressures and spinal fixator loads for different body positions and exercises. Ergonomics. 44(8), 781-794.

Santschi, W.R., Du Bois J., and Omoto, C. (1964) Movements of inertia and centers of gravity of the living human body. Report AMRL-TDR-63-36. Wright Patterson Air Force Base, OH.

Sato, K., Kikuchi, S., and Yonezawa, T. (1999) In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. Spine, 24(23), 2468-2474.

Schoberth, H. (1978) Correct Sitting at the Workplace. Frankfurt, Germany: University of Frankfurt, Ostsee Clinic.

Sweere, J.J. (1988) Identifying individuals at risk to lower spinal instability - the Biomechanical Stress Index. Promoting Health and Productivity in the Computerized Office: models of successful ergonomic intervention. Sponsored by the National Institute for Occupational Safety and Health at Cincinnati, August 8-11. 20-21.

Tichauer, E.R. (1978) The Biochemical Basis of Ergonomics: Anatomy Applied to the Design of Work Situation. Wiley, John & Sons.

van der Fits, I.B., Klip, A.W., van Eykern, L.A., and Hadders-Algra, M. (1998) Postural adjustments accompanying fast pointing movements in standing, sitting and lying adults. Experimental Brain Research. 120(2), 202-216.

Van Deursen, D.L., Goossens, R.H.M., Evers, J.J.M., van der Helm, F.C.T., and van Deursen, L.L.J.M. (2000a) Length of the spine while sitting on a new concept for an office chair. Applied Ergonomics, 31, 95-98.

Van Deursen, D.L., Lengsfeld, M., Snijders, C.J., Evers, J.J.M., and Goossens, R.H.M. (2000b) Mechanical effects of continuous passive motion on the lumbar spine in seating. J Biomechanics. 33, 695-699.

Van Deursen, D.L., Snijders, C.J., van Dieen, J.H., Kingma, I., van Deursen, L.J.M. (2001) The effects of passive vertebral rotation on pressure in the nucleus pulposus. J Biomechanics. 34, 405-408.

Van Deursen, D.L., van Deursen, L.L.J.M., Snijders, C.J. and Goossens, R.H.M. (2000c) Effect of continuous rotary seat pan movements on physiological oedema of the lower extremities during prolonged seating. International J Industrial Ergonomics. 26, 521-526.

Van Dieen, J.H.l., de Looze, M.P., and Hermans, V. (2001) Effects of dynamic office chairs on trunk kinematics, trunk extensor EMG and spinal shrinkage. Ergonomics, 44(7), 739-750.

Waersted, M. and Westgaard, R.H. (1997) An experimental study of shoulder muscle activity and posture in a paper version versus a VDU version of a monotonous work task. International J Industrial Ergonomics, 19, 175-185.

Webb Associates (Eds.) (1978) Anthropometric Source Book, v. I, II, and III. NASA Reference Publication 1023, National Aeronautics and Space Administration, Scientific and Technical Information Service: Washington, D.C.

Widmer, L.K. (1978) Peripheral venous disorders. Prevalence and socio-medical importance. Observations in 4,529 apparently healthy persons. Basle Study III, H. Huber, Bern. (Cited in Winkel, 1981, op sit).

Wilke, H.J., Neef, P., Caimi, M., Hoogland, T. and Claes, L.E. (1999) New in vivo measurements of pressures in the intervertebral disc in daily life. Spine. 24(8), 755-762.

Winkel, J. (1981) Swelling of the lower leg in sedentary work: a pilot study. J Human Ergology, 10, 139-149.

Winkel, J., and Jorgensen, K. (1986) Evaluation of foot swelling and lower-limb temperatures in relation to leg activity during long-term seated office work. Ergonomics, 29(2), 313-323.

Winkel, J., and Oxenburgh, M. (1990) Towards optimizing physical activity in VDT/office work. In: Sauter, S.L., Dainoff, M., Smith, M.J. (Eds.). Promoting Health and Productivity in the Computerized Office: Models of successful ergonomic interventions. London: Taylor and Francis.

Wood, P.H.N., and McLeish, C.L. (1974) Statistical appendix: Digest of data on the rheumatic diseases: 5. Morbidity in industry and rheumatism in general practice. Annals of the Rheumatic Diseases. 33, 93-105.

Yamaguchi, Y. and Umezawa, F. (1973) Development of a chair to minimize disc distortion in the sitting position. Unpublished presentation at the 4th International Congress on Ergonomics.

Strasbourg, July 1970. Cited in: Grandjean, E. (1976) Ergonomics of the Home. London: Taylor and Francis.

Yu, C. and Keyserling, W.M. (1989) Evaluation of a new work seat for industrial seating operations: Results of three field studies. Applied Ergonomics, 20.1, 17-25.

Yu, C., Keyserling, W.M. and Chaffin, D.B (1988) Development of a work seat for industrial sewing operations: results of a laboratory study. Ergonomics, 31(12), 1765-1786.

Zander, T., Rohlmann, A., Calisse, J., and Bergmann, G. (2001) Estimation of muscle forces in the lumbar spine during upper-body inclination. Clinical Biomechanics. 16(1), S73-S80.

About Rani Lueder

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