Humanics ErgoSystems, Inc.

Specialists in Ergonomics

ERGONOMICS REVIEW

Ergonomics of seated movement

A review of the scientific literature

Considerations relevant to the Sum™ chair

written for Allsteel

by Rani Lueder, CPE

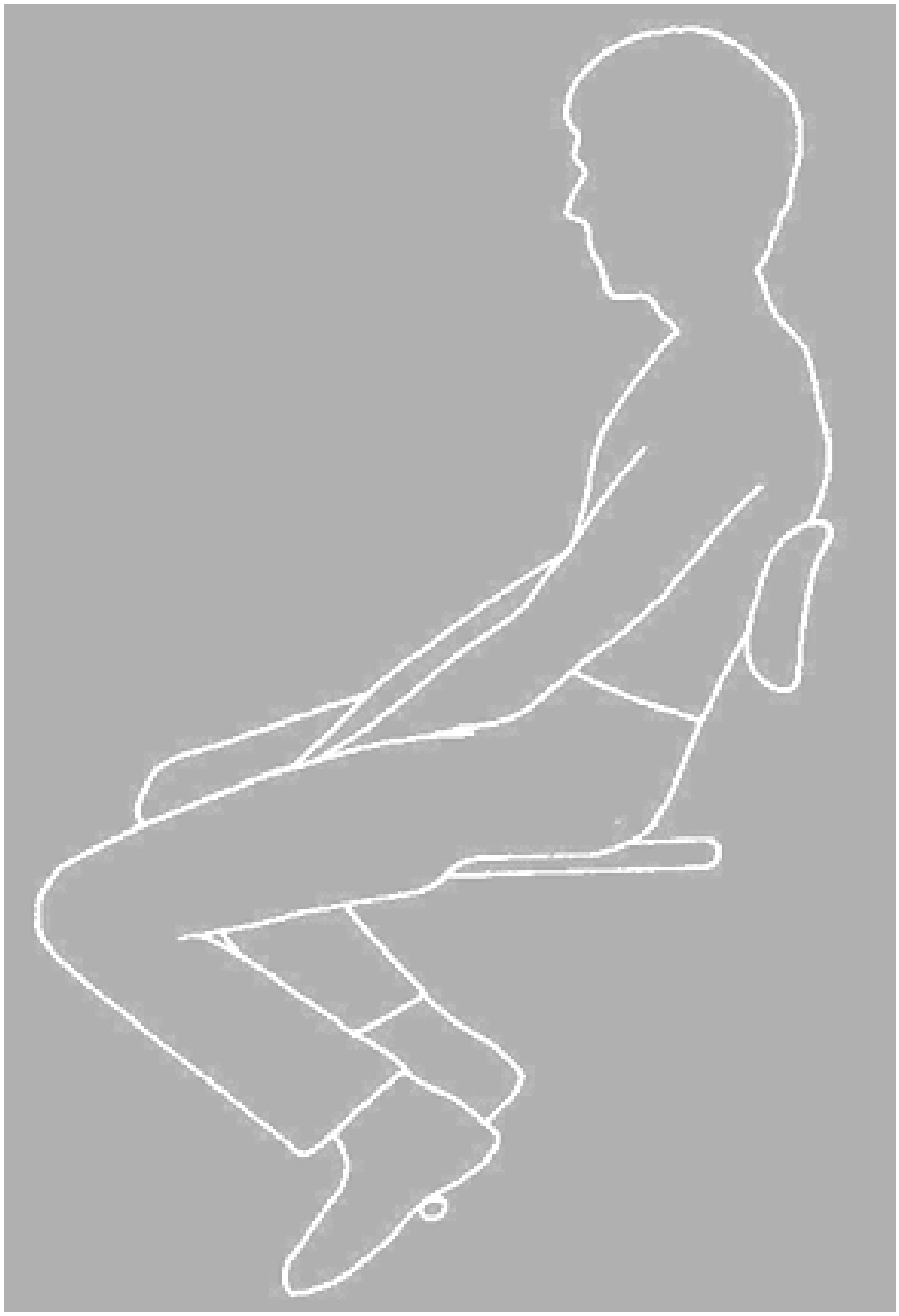
Humanics ErgoSystems, Inc.

June 1, 2004

Certificant, Board of Certification of Professional Ergonomists

Mail: P.O. Box 17388 Encino, CA 91416-7388

Ph: (818) 345-ERGO **Fax**: (818) 705-3903 rani@humanics-es.com www.humanics-es.com



From Corlett and Eklund (1984) How does a backrest work?
Graphic used with permission

Table of Contents

Ergonomics and the Sum

Summary

Over the last two decades, our focus has gradually shifted from identifying the best single sitting posture towards a more dynamic view of sitting and movement.

While this emphasis on movement has helped avoid ergonomic risk factors, it also confused the issues. Movement is critical, but it is not the only consideration. Taken to extremes, a strict emphasis on movement may even introduce new risk factors.

Movement is essential, but movements are not alike. Some should even be avoided.

Movements are not the same; we ought to avoid some movements. This paper describes research relevant to movement and its implications for sitting and seating.

These research dimensions include:

1. Why movement is so important.
2. Why different movements are not equal.
3. Selected seat design considerations.

Overview

As in all fields of science, our assumptions about sitting reflect changing paradigms in the research that shape the questions we ask and how we interpret its findings.

For most of the last century, ergonomists widely assumed that we should sit upright (Staffel, 1884; Hooton, 1945; Akerblom, 1954). This emphasis on what Dainoff (1994) described as the "cubist posture" (with 90° knee, torso and elbow positions) aimed to prevent ergonomic risk factors that lead to discomfort and health disorders.

The late 1980's saw a recognition that office work is more hazardous than had been believed – and that constrained sitting postures can cause health disorders, particularly when other risk factors are present (e.g., NIOSH, 1997).

While movement is critical, this emphasis on movement for its own sake sometimes takes extremes. The drumbeat that "we need to move" has heralded new products that may contribute to awkward, unstable and unsupported postures. At times, health professionals also worsen the situation by maintaining that awkward and unstable postures are fine if users change positions from anything, to anything.

This is not to downplay the importance of movement. Movement is essential.

Rather, the aim of this paper is to revisit these assumptions.

We need to move

We have long known that constrained sitting is bad for our health (*s.f.*, Adams and Hutton, 1983; Duncan and Ferguson, 1974; Eklund, 1967; Graf et. al, 1995; Hunting, et. al, 1980 and 1981; Hult, 1954; Langdon, 1965; NIOSH, 1997).

In 1777, Ramazzini described hazards of constrained sitting among writers:

> *"Now 'tis certain that constant sitting produces Obstructions of the Viscera, especially of the Liver and Spleen, Crudities of the Stomach, a Torper of the Leggs, a languid Motion of the refluent Blood and Cacbexies. In a word, Writers are depriv'd of all the Advantages arising from moderate and salutary Exercise."*

More recently, a report by the National Institute of Occupational Safety and Health (NIOSH, 1997) summarized research demonstrating a relationship between awkward and constrained postures and musculoskeletal disorders.

Constrained postures increase discomfort and health risks (*s.f.* the review by Aaras et al, 1997). Videman et al. (I990) found that both sedentary work and heavy physical work were associated with abnormalities of the spine[1], but the relationship was particularly strong for sedentary work such as in the office.

Static seating postures cause discomfort. Graf et al. (1993, 1995) reported more discomfort and chronic disorders among workers who sit in fixed postures. Movement reduces these risks (Aaras et al, 1997; Kilbom, 1987).

It is difficult for us to tolerate unsupported and static seated postures for more than a short while (Reinecke et. al., 1985). When allowed to move freely, people are usually in constant motion (Branton, 1967, 1969; Jurgens 1980). Sitters tend to cycle through postures over the day (Bhatnager et al, 1985; Branton and Grayson, 1967; Fleischer et al, 1987).

People tend to develop unique patterns of seated movements (Fleischer et al, 1987; Jurgens, 1980; Ortiz et al, 1997) - which Fleischer (1987) compared to individual handwriting styles[2].

Unfortunately, intensive computer work diminishes opportunities to change postures and move (Grieco, 1986; Waersted and Westgaard, 1997).

Not moving is harmful

---

[1] These researchers studied disc degeneration in 86 cadavers. They described abnormalities such as disc degeneration, end-plate defects and osteoarthrosis of the facet joints of the vertebra.

[2] That is, "as a sequence of actions thought to be produced by an internalized specification of commands that indicates which muscles shall act at what time and what intensity".

We have long known that constrained sitting is uncomfortable. Static postures contribute to a broad range of chronic disorders (e.g., Hunting et al., 1981) that include joint impairments such as arthritis, inflamed tendons and tendon sheaths, chronic joint degeneration (arthroses), muscle pain (Grandjean, 1987), impaired circulation and tissue damage (Kilbom, 1986).

> *The effect of static postures magnify over time.*
>
> *Kumar wrote, "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".*

Static and constrained postures interrupt blood flow in direct proportion to the muscle loads (Grandjean, 1987). Muscle oxygenation reduces with fairly low loads[3] (McGill and Hughson, 2000). At sixty percent of maximum force (e.g., working with elevated arms), blood flow is virtually occluded (Grandjean, 1987).

Static postures reduce our effectiveness[4], causing us to move more often[5], (Bhatnager et al[6], 1985; Fenety et al, 2000; Jurgens, 1980) and to move into postures (Bhatnager et al, 1985) that we know to be harmful (Andersson, 1980; Andersson et al, 1974a, 1975, 1986; Bhatnager et al, 1985).

Some researchers maintain that such damaging effects are more related to a "lack of physical variation" than inactivity (Bendix 1994; Winkel and Oxenburgh, 1990). That is, the actual lack of variety of postures is more hazardous than the sedentary nature of the work.

---

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

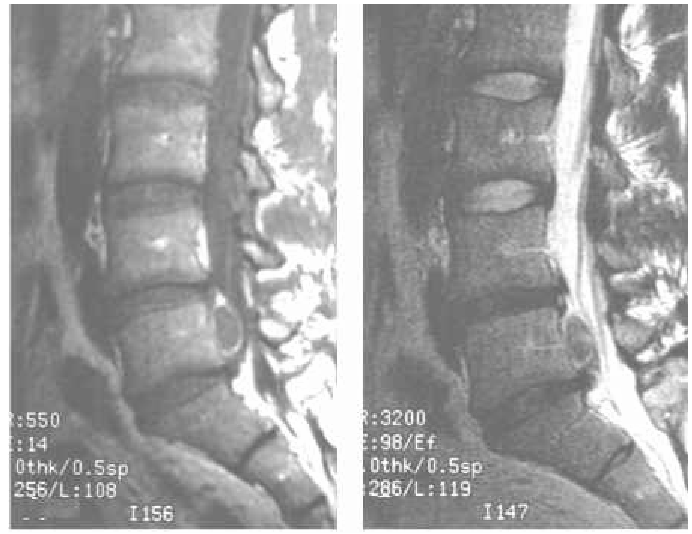
[4] Bhatnager et al (1985) reported that the percentage of errors increased from less than 2% to more than 8% over the three hours' of sitting, which they attributed to less effective scanning patterns. Between the best and worst workplace conditions, performance increased from about 4% to about 6% errors. They wrote, "subjects appeared to realize that their performance was getting worse and increased their stopping times in an (unsuccessful) effort to compensate."

[5] Such as by fidgeting.

[6] Bhatnager et al (1985) wrote, "The frequency and severity of body part discomfort increased with time on task, as did frequency of postural changes... Frequency of postural changed increased by more than 50% over the three hours and such appear to be a sensitive indicator of postural stress."

… and contributes to backpain and injury

More than seventy percent of people older than 40 experience intermittent back pain. Our sitting habits affect our risk of back pain (e.g., Bendix 1994; Kelsey 1975b).

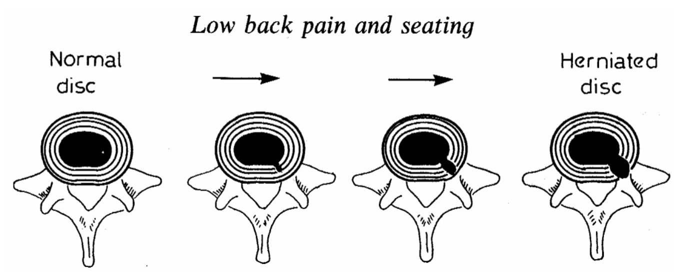


The herniated lumbar spine, from two directions (Slavin and Raja, 2001)

Kelsey (1975b) found that sitting more than half the time at work was associated with herniated discs in those older than 35.

People often assume that back pain is caused by short-term (acute) events such as accidents. Yet though slips and falls certainly injure, research suggests long-term (low-level) chronic stressors are at least as important.

That is, fixed postures are as likely to lead to disabling back pain as heavy manual work such as construction.



Progression of disc herniation (Bendix, 1994)

Constrained postures can cause chronic degenerative alterations of the cervical, thoracic, and lumbo-sacral areas of the 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 likely to develop very high levels of intervertebral disk immobility (Wood and McLeich, 1974).

> *Fixed postures are as likely to lead to disabling back pain as heavy manual work such as construction.*

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 of the spine) 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 resulting from movement.

Faiks and Reinecke wrote "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.

… as well as leg swelling (edema)

Leg swelling (edema) is caused by "an increase in net transcapillary filtration, which exceeds the removal of fluids by the lymphatics" (Van Deursen et al, 2000).

Leg swelling (edema) is common. Widmer (1986) interviewed 4,529 workers, finding that 70% of women and 44% of men reported this discomfort.

The American Public Health Association (APHA, 2003) indicates that between 200,000 and 600,000 Americans will suffer from deep-vein thrombosis (DVT) and pulmonary embolism each year.

> *Leg swelling causes more than cold feet.*
>
> *It increases blood pressure, heart rate and venous pressures to the heart. It predisposes users to varicose veins. It can also be fatal.*

They note:

> *Deep-vein thrombosis occurs when a thrombus forms … in one of the large veins, usually in the lower limbs, leading to either partially or completely blocked circulation. The condition may result in health complications…*
>
> *Pulmonary embolism can occur when a fragment of a blood clot breaks loose from the wall of the vein and migrates to the lungs, where it blocks a pulmonary artery or one of its branches. When that clot is large enough to completely block one or more vessels that supply the lungs with blood, it can result in sudden death.*

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

Lack of movement is strongly associated with leg swelling (Van Deursen et al, 2000)[7]; Winkel 1981; Winkel and Jorgensen, 1986). During movement, muscles expand and contract, thereby promoting circulation.

It can also be fatal (APHA, 2003; Beasley et al, 2003). The latter described a case in which a 32 year-old male developed life-threatening venous thromboembolism from sedentary work.

When users move about in their seat, their foot swelling improves (Sherman and Hedge, 2003; 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).

Ergonomists have traditionally emphasized the how seating affects intradiscal pressures. Yet this measure is only part of the equation.

High loads increase risk of injury – yet injury can be sustained despite relatively moderate intradiscal pressures.

Yet all movements are not the same

The overall forces acting on the spine are less important than the concentration of forces acting on the discs, ligaments and related spinal structures (Dolan and Adams, 2001) and the susceptibility of these structures to damage.

The associated risk also varies considerably between people. Compressive loads and displacement of force are affected by our age and the degeneration of the spine (e.g., Pollintine et al, 2004).

Dolan and Adams (2001) 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".

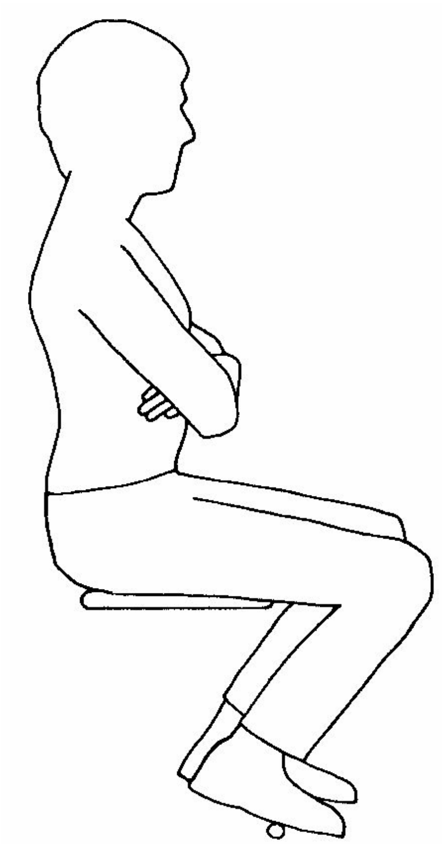
We know that repetitive movements can be hazardous (NIOSH, 1997). Repeated cycles of movements resemble the effects of static postures (e.g., Kumar, 2004).

Unsupported sitting

Most office employees spend most of their day working with their backs unsupported.

It is difficult to sit upright and unsupported for very long. Most people would rather slump than perform the muscle work needed to sit upright.

Leaning against a backrest reduces both intradiscal pressures in the spine and loads at the back portion of the spine[8] (Rohlmann et al, 2001).



Several things happen when we maintain unsupported postures – even when there is movement. Of particular importance, we tend to slump forward, reversing the lumbar curve (lumbar kyphosis) (Bridger and Eisenhart-Rothe, 1989)

If users are fit, their abdominal muscles may help stabilize postures (Corlett and Eklund, 1984) although this is not fully agreed on (Kumar, 2004). Even so, fit or not, postural support shifts from the muscles to the ligaments that support the spine. Ligaments deform, increasing risk of spine and joint injury.

This is particularly important in today's offices because most office employees work most of their day with their back unsupported by their backrest (e.g., Dowell et al, 2001).

[8] That is, at the fixator loads involving the facet joints, articular surfaces close to individual vertebral bodies (bones).

Forward-oriented movements

Sitting in static positions leads to small movements in our chair that we often refer to as "fidgeting" (Bhatnager et al, 1985; Fenety et al, 2000). That is, as we become uncomfortable we tend to move, perhaps to compensate for reduced effectiveness at work.

Further, this tendency to fidget with time is associated with a tendency towards forward oriented (anterior) movements and postures that increase loads on the spine and soft tissues[9] (Andersson, 1980; Andersson et al, 1974a, 1975, 1986; Bhatnager et al, 1985; Rohlmann et al, 2001; Wilke et al, 1999).

Forward-leaning postures increase risk of back injury.

This is in part because the posterior ligaments and fibrous tissues surrounding the discs are thinner and less able to withstand force and may rupture.

In fact, loads on the spine (intra-discal pressures) are almost twice as high when flexing forward relative to unsupported sitting – and almost three times higher than relaxed sitting (Wilke et al, 1999). Others reported that leaning forwards (flexion) dramatically increases intradiscal pressures as well (Andersson et al, 1974a, 1975; Rohlmann et al., 2001).

Research suggests that as the day progresses in static postures, we begin to assume more forward-oriented postures.

Forward-leaning postures also increase risk of disc rupture because the posterior segment of the disc lacks the strength to withstand these loads – even when intradiscal pressures are low[10] (Adams et al, 1994).

The posterior longitudinal ligaments are considerably thinner than the anterior (front) ligaments. Further, the

[9] This tendency to shift towards forward-leaning (anterior) postures during long-term static sitting should not surprise us. Long-term static sitting work is very demanding… muscle work and other physical loads become difficult to sustain, particularly given that static postures impair circulation.

It becomes increasingly difficult to perform the muscle work needed to "sit properly".

Forward leaning postures introduce risk factors, but users do not mind because they do not have to work their muscles as hard while their ligaments hold their spine in position.

Of course, other factors may also contribute to this tendency to lean forwards with time. For example, the visual demands of the task and the reach distances can also play a role.

[10] These researchers noted that serious disc failure is closely associated with what is called the "moment arm" of forces associated with forward bending – even when the compressive loads on the spine are not particularly high. They add, "Conversely, if the bending moment is small or absent, no amount of compression can damage the soft tissues before the vertebrae".

fibrous tissues that surrounds the intervertebral discs[11] are not equivalent – forward (anterior) postures are much more likely to cause tearing.

Fleischer (1987) emphasized the importance of designing chairs that promote movements that we recognize as beneficial - particularly between shifts between upright and reclined sitting (as opposed to shits toward forward-leaning postures).

Twisting / rotation / bending movements

Twisting is unique to human beings. We are fortunate to be able to do so; it would otherwise be difficult for us to function (Kumar, 2004).

Kumar (2001) described spinal rotation as "a destabilizating motion for an inherently unstable structure".

Much of this unpredictability relates to the fact that twisting typically involves a combination of rotation, forward / back and sideways (lateral) movements that are difficult for us to predict and control for any particular situation.

Hazards from twisting may increase because "If a single segment is restricted, the adjacent segments may assume part of its normal tasks in executing movement.

Thus, hypomobility and forced hypermobility may both exist in a relatively short section of the spine."

Further, combined movements along these three planes interact with each other when we twist. Combined movements are problematic in a variety of ways. Movement along one plane typically diminishes the available range of movement along other dimensions (Evjenth and Hamberg, 1984).

Twisting movements along the forward (anterior) plane is particularly compromising. Combined movements that lock the facet joints[12] at the back end of the spine introduce a different sort of risk.

Risk also increases when natural movements of individual segments are constrained. Evjenth and Hamberg (1984) wrote the following:

> *First, because the vertebral column consists of many articulating segments, movements are complex and usually involve several segments. This also means that restrictions may be complex. For instance, if a single segment is restricted, the adjacent segments may assume part of its normal tasks in executing movement. Thus, hypomobility and forced hypermobility may both exist in a relatively short section of the spine.*

---

[11] This fibro-cartilaginous tissue of the intervertebral discs is called the annulus fibrosus.

[12] Each facet joint represents two opposing bony surfaces separated by cartilage and surrounded by a capsule.

> *Second, because the spinal cord runs along the channel formed by the vertebral column, damage to or excessive movement of the column is potentially hazardous to the nervous system.*

Extremely small twisting movements (about 2° movement of individual vertebral segments) are beneficial and actually reduce the potential for injury.

These represent the natural range of movement of the individual segments of the spine.

That is not what we are referring to here.

Twisting is also complicated by the direction of twisting of its different components that sometimes work together and at other times are at odds with each other (Evjenth and Hamberg, 1984)

Twisting (axial rotation of the spine) increases risk of injury (Au et al, 2001; Kumar et al., 1998; Kumar, 2001), in part from the increased compressive loads on the spine (Au et al, 2001).

Yet compression is only part of the equation.

Kumar described how prolonged and extreme twisting damage joints. First, heightened loads increase the forces acting on the joints, deform connective tissues and ultimately destabilize the joints.

With time, as muscles fatigue and joints weaken, the resulting imbalance can lead to unnatural and uncoordinated movements at the joints that cause injury.

Research suggests that extremely small rotations (less than 2° per vertebral segment) are not harmful and may even benefit users[13] (Van Deursen et al, 2001).

Such micro-movements correspond to the natural / free range of motion of the individual motion segments that make up the spine[14].

Minute rotary movements[15] in one's chair may lessen back plain and reduce forces acting on the lumbar spine from improved disc nutrition (Lengsfeld et al, 2000b).

Yet our spine enables us to twist considerably farther than the 2° to 3° in natural range of motion lumbar segments– actually (when including motion of each of the segments). Kumar (1996, 2004) reported as much as 70° of twisting (axial rotation) for the entire spine.

Kumar (2004) described the massive body of research demonstrating a very strong relationship between twisting and back injury[16]. Some suggest that as little as 20° of

---

[13] This laboratory study by Van Deursen et al (2001) used pig cadavers. These findings appear to be confounded because they removed the facet joints (segments towards the back of vertebra) and related spinal components. Even so, these researchers maintained that this did not affect results as the range of rotation was within the joint's free inter-space range of movement.

[14] Punjabi and White (2001) suggest the natural range may be closer to 3°.

[15] 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.

twist involving across the mid-back may greatly increase the risk of disc herniation. Kumar described a number of possible mechanisms for this increased risk of injuries, including compression of spine.

Yet biomechanical forces on the spine (the "moment arm") alone cannot explain the increase in risk with twisting. Au et al (2001) found that even when biomechanical loads are equivalent in different postures, twisting resulted in considerably greater compression of the spine than when leaning forwards or in controlled sideways bending. The authors note, "it is interesting to consider that the torso is very limited in the production of dynamic twisting torque", even when relatively small levels of force are involved.

Kumar (2004) describes the effect of twisting as jamming the facet joints (bony protrusions of the vertebra), twisting intervertebral discs and tightening some ligaments while slackening others.

Even so, the associated risks vary across the spine and are greater at the lumbar spine. The different vertebrae that make up the spine are very flexible and rotate differently at each level of the spine. In part, these differences in flexibility relate to the facet joints at the back of the spine, which prevent rotation and lateral bending (flexion) displacement.

Seated twisting also reduces muscle strength. In his previous research, Kumar (2004) found that sitting forward in a neutral posture requires the least amount of strength, but the loads increase as the user moves to 20° of combined vertebral rotation[17]. He concluded, "thus, when it comes to forceful exertions involving axial rotations, human capability is considerably limited". He continues that "with increasing reach distances, the strengths significantly declined…"

Such studies point to twisting – even rotation while seated at the low (lumbar) and mid-back (thoracolumbar junction) may sometimes increase risk substantially.

We need more research to understand the full impact of these issues. Even so, caution is warranted; we expect people to rotate sideways to some extent during seated work, but then it should not be encouraged either.

Chairs that flex should limit specific combinations of movements that increase risk.

---

[16] Risk increased even when lifting was not involved. For example, Kumar (2004) describes research by Marras (1993) that found "twisting without lifting is associated with disc prolapse with an odds ratio of 3.0. A combination of twisting and lifting increased the odds ratio to 6.1.

[17] It is not surprising that twisting can lessen the amount of muscle work since twisting involves locking up the spine along the different dimensions (s.f. Evjenth and Hamberg, 1984). At the same time, these postures increase risk of injury to the spine in various ways, discussed earlier.

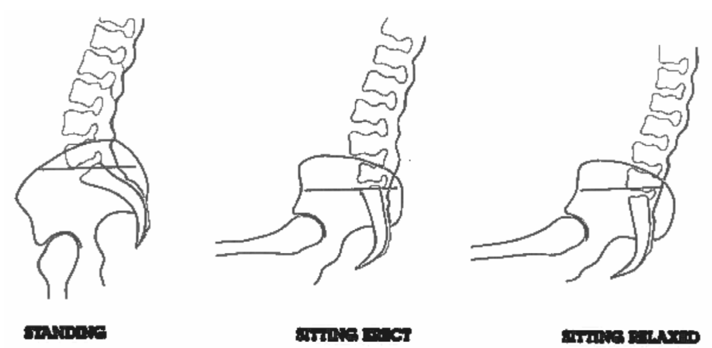
Sitting and seating

What happens when we sit?

Most of us would rather sit than stand. Sitting has been found to require less muscle work than standing (Andersson et al, 1974b). It is easier to work while sitting and it also stabilizes postures. Sitting may increase intradiscal pressure relative to standing (Andersson, 1980), but research is not consistent[18] (Althoff et al, 1992; Rohlmann et al, 2001; Wilke et al, 1999).

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.

Relaxed sitting flattens (flexes) our lumbar spine



Sitting flattens the lumbar spine. As we sit, our hamstring muscles stretch, rotating our pelvis back.

About 2/3 of this shift towards sitting is by flattening the lumbar spine – with the rest from tilting of the pelvis (e.g., Bendix and Biering-Sorensen, 1983). This[19] flattens the lumbar curve[20] excessively.

Research indicates that lumbar supports can reduce load on the spine (Andersson et al, 1974b; 1975). 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).

---

[18] Rohlmann et al (2001) suggests that research may sometimes seem contradictory because we still have so much to learn about the very complicated geometry of the spine. For example, high intradiscal pressures reflect greater loads on the forward portion of the spinal column, but tell us little about loads transferred to the rear portion of the spinal segments (facet joints)

Each facet joint represents two opposing bony surfaces separated by cartilage and surrounded by a capsule.

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

[20] However, Leivseth and Drerup (1997) found less spinal shrinkage when sitting (particularly relaxed sitting) than with standing work. They attributed this to several factors, but particularly to the greater bending and twisting while standing.

Although Andersson's research demonstrates that lumbar supports can reduce intradiscal loads on the lumbar spine, the benefits of backrest lumbar supports are not consistent (Corlett, 1999).

Bendix et al (1996) reported that lumbar supports on backrests helped to reinstate lumbar curves compared to straight backrests while performing tasks, but not during passive sitting and reading[21].

Characteristics of the lumbar support vary between users[22] and may vary over time for the same individual. Reinecke et al (1992, 1994) developed a pneumatic device that induces continuous passive motion in the lumbar spine in order to reverse the detrimental impact of constrained sitting.

Additionally, lumbar supports only benefit users if they are properly designed, correctly adjusted for the user, and the user sits in the chair in a manner that takes advantage of the feature.

That is not to say that lumbar supports cannot benefit users. They reduce intradiscal pressure, often stabilize postures, reduce muscle loads and help promote comfort.

Yet lumbar supports only benefit users if they are properly designed, adjusted for the user and the user sits in the chair in a way that enables them to benefit.

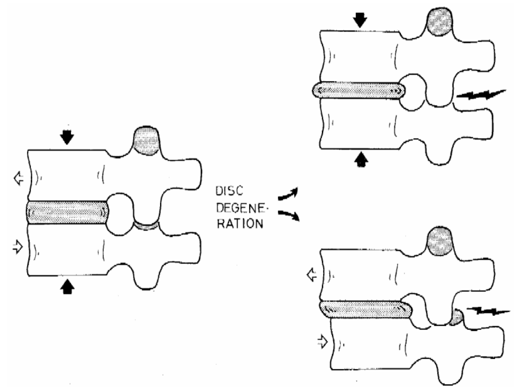
---

[21] Using pig cadavers, Brodeur and Reynolds (1990) concluded that lumbar supports have little effect on the contours of the lumbar spine. Rather, they reported that the pelvic angle had the greatest effect on the lumbar curvature. It's not clear, however whether this finding is relevant to humans.

[22] 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 and Eisenhart-Rothe, 1989) have reported that women have deeper lumbar contours than men.

Some suggest that excessive lumbar curvature also substantially increases risk. Bendix (1987) notes that excessive lumbar curvature can adversely affect posterior portions of the lumbar vertebrae. prolonged compression can contribute to pain.

Poor postures aggravate those problems. Most injuries involve combinations of flexion, side bending and rotation (Evjenth and Hamberg, 1984).



Facet joints forces are a significant source of injury (Bendix, 1994)

Neutral postures help reduce the impact of individual risk factors from combined movements[23].

Seat angles also affect the curve of the lumbar spine. Nachemson (1981) concluded that that we need a minimum of 110° thigh-torso angles to reinstate the natural curve of the lumbar spine[24]. The hip/pelvic angle affects the lumbar spine as well (Makhsous et al, 2003; Wu et al., 1998).

Although lumbar supports can clearly benefit users, they may also introduce new problems when the lumbar back support does not adjust high enough for the user.

Sitters may also position their lumbar support improperly (sometimes to lock in their hips to reduce the amount of muscle work) but in the process, they may reverse the natural curve of their lumbar spine.

Consequently, lumbar supports are important but they are affected by the specific conditions. The spine – and the lumbar spine functions best in a dynamic environment.

---

[23] As mentioned earlier, combined movements are problematic in that movement along one plane typically diminishes the available range of movement along other dimensions (Evjenth and Hamberg, 1984). Twisting movements along the forward (anterior) plane is particularly compromising. Combined movements that lock the facet joints at the back end of the spine introduce a different sort of risk.

[24] 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°).

”Dynamic” backrests promote continuous support

In recent years, there has been considerable interest in how chair designs can promote movements without user intervention. That is, how such features affect users' sitting behaviors and their sense of well-being.

Research indicates that back support reduces both loads on the spine and muscle work (e.g. Andersson et al, 1975). For this reason, many chair backrests enable users to set their backrest in “free-float” mode, and to adjust their backrest tension so that they can sit and move while maintaining continuous backrest support.

When used properly, these features provide important benefits… there is reason to believe that when set for the user, this free-float capability is the most important chair feature.

Research indicates that in the right circumstances, advanced “ergonomic seating”, in conjunction with high-quality training can lead to pronounced benefits in comfort and health, which exceeds benefits from training alone (Amick and Robertson, 2003). Yet training alone does not suffice.

Hedge and Ruder (2003) compared subjects typing intensively for 30-minute trials while sitting with their backrest either “locked” or “unlocked” in free-float. Short term sitting in these chairs in “free-float” mode did not cause them to move more often, but their back support improved.

> *Thus, the value of a dynamic chair back may not be in encouraging a greater frequency of movement [during the brief experimental periods], but in providing better support for such back recline movements.*

Van Dieen et al (2001) compared changes in stature between two types of dynamic seats and a traditional office chair[25]. They concluded:

> *“Results showed a potential advantage of the dynamic chairs. Spinal shrinkage measurements showed an increase in stature when working in dynamic chairs.*
>
> *This increase in stature is explained by recovery of disc height, which can be accounted for by compression being lower during the experimental trial than during preceding activities… In addition, movement [in normal postures] can contribute to recovery of disc height.*

[25] These researchers compared a traditional office seat with a synchro-tilt (which adjusted in a fixed ratio of seat and back recline) and a chair with freely movable seat and backrest.
Spinal shrinkage was measured with a Stadiometer (www.humanics-es.com/stadiometer.htm)

> *The stronger increase in stature observed after working on the dynamic chairs as compared with the fixed could be due to better trunk support or small effects on trunk kinematics. The increase in stature is to be interpreted as a positive effect, in view of the fact that it reflects an influx of fluids and consequently nutrients into the avascular disc."*

Yet movement does not always benefit the user. These beneficial changes in stature are greater during relaxed sitting than when performing task-related activities while sitting upright. Leivseth and Drerup (1997) attributed such increases in height while sitting relaxed to the unloading of the lumbar spine rather than the upper back (thoracic spine). Movement while in neutral postures also provides a greater potential for recovery of disc height.

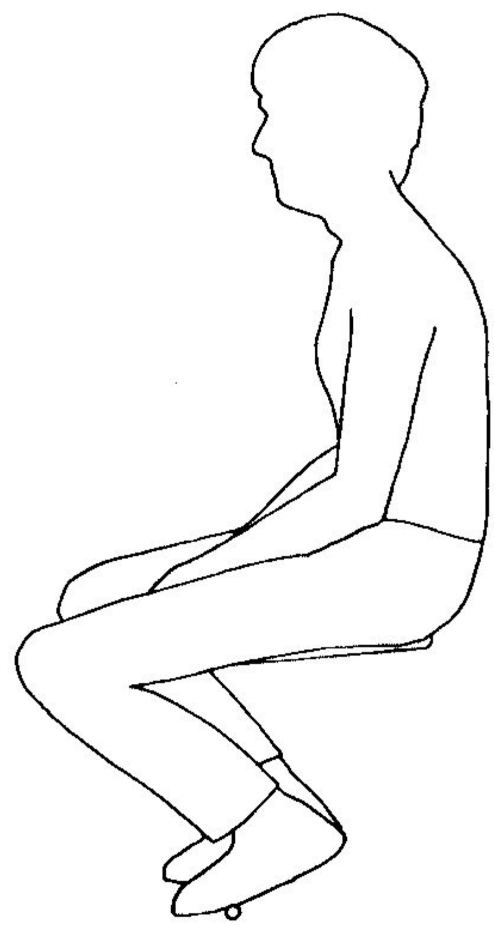
Unsupported sitting (upright)

Unsupported upright sitting involves the worst of all worlds (except forward leaning / anterior postures).

Sitting in this way does not allow for thigh-torso angles that are large enough to reinstate the natural curve of user's lumbar spine (s.f. Nachemson, 1981).

Additionally, the forces (called the "moment arm") exerted on the spine shifts forward (e.g., Corlett and Eklund, 1984; Reinecke and Hazard, 1994). This destabilizes postures, stresses and potentially deforms ligaments, weakens joint structures and increases loads on the spine.

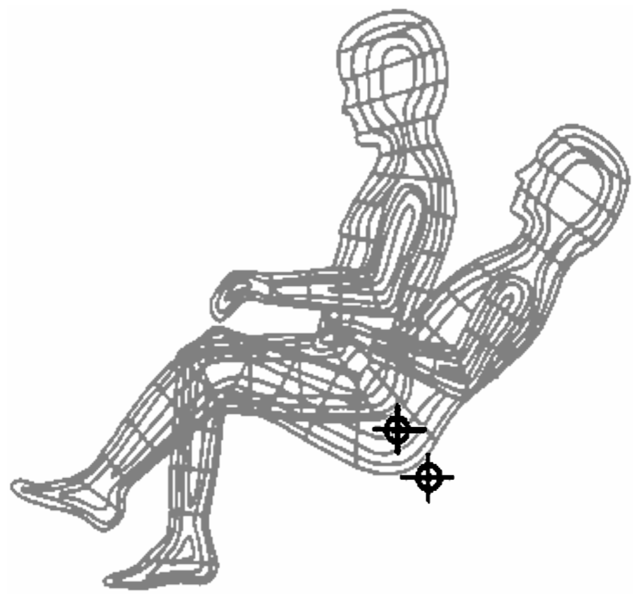
It is obvious to anyone that sits in a position that loads on the back muscles increase (Andersson et al, 1974, 1980 and 1986; Corlett and Eklund, 1984).



Unsupported upright posture
(Corlett and Eklund, 1984)

Support forward and back movements from centered positions

Hedge and Ruder (2003) found that sitting with backrests in the "free-float" mode improved users' back support as they worked on the computer.



Users benefit when the chair's center of gravity is close to that of the user, encouraging free movements of the user. Centered positions facilitate changes of posture (Andersson, 1986; Fleischer et al, 1987).

Andersson (1986) concluded that the relationship between the pivot point of the chair and its user is more important than the height of the backrest (which does not need to be exact[26]).

A close fit between users and their chairs' center of rotations also help prevent the "shirttail effect", where the backrest displaces upward, pulling up users' shirttails.

Finally, such chairs helps avoid the potential for ergonomic problems with some users in knee pivoting chairs[27]. Namely, knee-pivoting chairs take the user down and away from their worksurface. These chairs may increase risk by contributing to awkward postures from elevated arms and craned necks as they attempt to read.

Such issues suggest that a chair should enable the user to remain supported while moving through a range of postures characterized by a shifting center of gravity, where the chair and its user correspond.

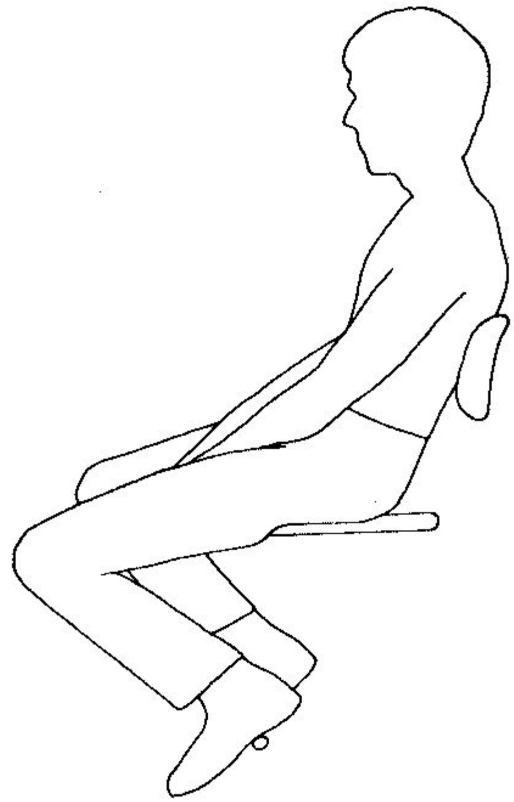
Reclined sitting (relaxed)

Reclined postures have advantages.

---

26 Boudrifa and Davies (1984) also found that the exact position of the lumbar curve does not need to be exact, as long as it is in the general lumbar area. Corlett (2002), Rebiffe (1980) and others suggested that the optimum lumbar height reflects the users' dynamic movements. For example, the driver of a car would benefit from a higher lumbar than the passenger where the driver's arms are higher (on the steering wheel), and they need to reach the controls.

27 Knee pivoting chairs enable the user to recline by tilting their seat away from their work surface while it pivots from the knees.



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

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

Leaning back 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.

Yet 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) the natural curves of their low back and neck (Dolan and Adams, 2001).

There also appears to be a relationship between flattening of the neck and the lower back[28] (Fitzsimmons, 2004).

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 is difficult to lean back when our visual target is a document and our hands need 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).

---

[28] Fitzsimmons (2004) reported that preloaded and flexed/flatter necks contribute to flattening of lumbar spines.

Loads on the shoulders and arms may increase if reclining causes the users to move back against their work items.

However, the problem is not reclining itself as much as reclining in a static posture. Intermittent reclining is important and beneficial if it is part of a range of postures users sit in over their workday.

Conclusion

Static sitting postures introduce ergonomic risk factors by constraining postures and promoting unnatural postures that deviate from the natural position of the spine. Each of these can negatively affect our health, comfort and effectiveness at work.

Both larger “macro-movements” and very small “micro-movements” are essential for our wellbeing. Yet while this emphasis on movement can avoid ergonomic risk factors, it has also confused the issues. Movement is critical, but it is not the only consideration. Taken to extremes, a strict emphasis on movement may even introduce new risk factors. Movements are not the same; we ought to avoid some movements

The only truly effective way to maintain a seated posture for extended durations is to continuously cycle through a range of natural, centered and healthful positions. This requires a chair that allows users to dynamically shift between a range of stable postures.

Acknowledgement

My thanks to John Fitzsimmons of John Fitzsimmons and Associates for his insightful comments.

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., Green, T. P., and Dolan, P. (1994) The strength in anterior bending of lumbar intervertebral discs. Spine. 19(19), 2197-2203.

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.

Akerblom, B. Chairs and sitting. (1954) In: Floyd, W. F. and Welford, A.T, (Eds.) In Symposium on Human Factors in Equipment Design. Proceedings of the Ergonomics Research Society, (pp. 29-35) V. 2.

Althoff, I., Brinckmann, P., Frobin, W., Sandover, J. and Burton, K. (1992) An improved method of stature measurement for quantitative determination of spinal loading. Application to sitting postures and whole body vibration. Spine. 17, 6, 682-693.

Andersson, B. J., Ortengren, R., Nachemson, A. L., Elfstrom, G., and Broman, H. (1975) The sitting posture: an electromyographic and discometric study, Orthop Clin North Am. 6(1), 105-120.

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

Andersson, B.J.G., Ortengren, R., Nachemson, A. and Elfstrom, G. (1974b) Lumbar disc pressure and myoelectric back muscle activity during sitting. Scandinavian J Rehabilitation Medicine. 6, 104-114.

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 (Chapter 27). In: Corlett, E.N., and Eklund, J.A.E. and Manenica, I. (Eds.) The Ergonomics of Working Postures. Taylor & Francis: London. 309-318.

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.

APHA (2003) Deep-vein thrombosis: Advancing awareness to protect patient lives. American Public Health Association. Available on their website at this URL: www.apha.org/news/press/2003/DVT_whitepaper.pdf

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.

Beasley, R., Raymond, N., Hill, S., Nowitz, M. and Hughes, R. (2003) eThrombosis: the 21st century variant of venous thromboembolism associated with immobility. European Respiratory Journal, 21(2), 374-376.

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.

Bhatnager, V, Drury, C. and Schiro, S.G. (1985) Posture, postural discomfort and performance. Human Factors. 27(2), 189-199.

Boudrifa, H. and Davies, B.T. (1984) The effect of backrest inclination, lumbar support and thoracic support on the intra-abdominal pressure while lifting, Ergonomics, 27(4), 379-387.

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.

Dowell, W.R., Yuan, F. and Green, B.H. (2001) Office seating behaviors: An investigation of posture, task and job type. Proceedings of the Human Factors and Ergonomics Society. 1245-1248.

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 VDU work. International J Industrial Ergonomics, 3(3), 177-183.

Evjenth, O. and Hamberg, J. (1985) Muscle Stretching in Manual Therapy. A Clinical Manual. Scand Book AB Sweden.

Faiks F. and Reinecke, S. (1998) Measuring the shape of the back while changing one's posture during sitting. Ergonomics Society. Taylor & Francis. UK, April 1998

Faiks F.S. and Reinecke S.M. (1998) Investigation of spinal curvature while changing one's posture during sitting. In: Hanson, M.A. (Ed.) Contemporary Ergonomics 1998, Taylor & Francis.

Fenety, P.A., Putnam, C. and Walker, J.M. (2000) In chair movement: Validity, reliability and implications for measuring sitting comfort. Applied Ergonomics. 31(4), 383-393.

Fitzsimmons, J. (2004) Critical observations of seated posture (In press). Ergonomics Expo, Las Vegas. December 2004.

Fleischer, A.G., Rademacher, U., and Windberg, H.J. (1987) Individual characteristics of sitting behavior. Ergonomics. 30(4), 703-7.

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 a new one. Ergonomics. 29(3), 345-362.

Hedge, A. and Bhambore, M. (2003) Effect of providing foot support on lower leg temperature for sedentary workers. Proceedings of the Human Factors and Ergonomics Society, \p937-941.

Hedge, A. and Ruder, M. (2003) Dynamic sitting: How much do we move when working at a computer? Proceedings of the 47th annual meeting of the Human Factors and Ergonomics Society, p947-951.

Hooton, E.A. (1945) A survey in seating, 101 p, Gardner, Mass. (op cit Akerblom 1985).

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.

Kelsey J.L. (1975). An epidemiological study of acute herniated lumbar intervertebral disc. Rheumatol. Rehab. 14, 144. *Cited in NIOSH (1997) op cit.*

Kelsey JL (1975b) An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral discs. Int J Epidemiology. 4(3): 197-205.

Kelsey, J.L. and White A.A. (1980) III: Epidemiology and impact on low back pain. Spine. 5(2):133-142

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.

Makhsous, M, Lin, F, Hendrix, R.W., Hepler, M. and Zhang, L. (2003) Sitting with adjustable ischial and back supports: Biomechanical changes. Spine. 28(11) p113-1122.

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.

NIOSH (1997) Low Back Musculoskeletal Disorders: Evidence for Work-Relatedness (Chapter 6). In: Bernard, B.P. (Ed.) Musculoskeletal Disorders (MSDs) and Workplace Factors. A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. National Dept. Health & Human Services. National Institute for Occupational Safety & Health. DHHS. (NIOSH) Publication No. 97-141 (1997). Second printing.

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.

Pollintine, P., Przybyla, A.S., Dolan, P. and Adams, M.A. (2004) Neural arch load-bearing in old and degenerated spines. Journal of Biomechanics. 37, 197-204.

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.

Punjabi, M. and White, A. (2001) Biomechanics in the Musculoskeletal System. Churchill Livingston.

Rebiffe, R. (1980). General reflections on the postural comfort of the driver and passengers: Consequences on seat design. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 240-248). New York: Academic Press.

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.

Staffel, F. Zur Hygiene des Sitzens, Zbl f. allg. Gesundheitspflege, 3, 403-421. (Cited in Akerblom, 1985 above).

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.I., 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.

Videman T., Nurminen M., and Troup J.D.G. (1990). Lumbar spine pathology in cadaveric material in relation to history of back pain, occupation, and physical loading. Spine. 15(8), 728-740.

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.

Wu, C., Miyamoto, H. and Noro, K. (1998) Research on pelvic angle when using a pelvic support. Ergonomics. 41(3), p317-327.

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

Rani Lueder, CPE is President of Humanics ErgoSystems, Inc., an occupational ergonomics-consulting firm in Encino, California established in 1982.

She has consulted for corporations, governments, and universities in five countries. Rani is a member of the ANSI committee revising the American National Standards for seating and computer workstation design and continues to serve on extended retainer to the *Japan Institute of Human Posture* (Tokyo) over the last decade.

Recent projects include establishing a nation-wide health and safety data base for the Social Security Administration as part of an five year involvement with them; consulting for NIOSH in the development of recommended guidelines for alternative keyboards; performing physiological and biomechanics research for evaluating products, working with a team to develop ErgoSaver expert system software for evaluating ergonomic risk factors and performing frequent worker's comp evaluations.

She is currently co-editing and co-writing a book on Ergonomics for Children for Taylor and Francis (London).

Her second edited book, "*Hard Facts about Soft Machines: The ergonomics of seating*" is available in seven countries from Taylor and Francis (December 1995).

Previously, she edited and was a joint author of the book *"The Ergonomics Payoff; Designing the electronic office*" (Holt Rinehart and Winston of Canada).

Rani has an MSIE in Ergonomics/Industrial Engineering from Virginia Tech, and is a member of the *Human Factors and Ergonomics Society* (U.S.) and The Ergonomics Society (Europe).

The Board of Certification certifies her in Professional Ergonomics (#258).