

Humanics ErgoSystems, Inc.

Specialists in Ergonomics

ERGONOMICS REVIEW

Anatomical, physiological and health
Considerations relevant to the SwingSeat™

For SmartMotion Technology, Inc.

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July 26, 2002

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Pierre-Auguste Renoir - The Swing (1876)



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Bodies in motion have energy in life.



Dynamic Motion Range

Forward Tilt Up to 13°

Recline Angle Up to 13°

Back Angle Up to 15°

Feature Specification

Chair Capacity 250 lb.

Shipping Weight 45 lb.

SwingSeat chair specifications from www.swingseat.com

Overview

The following is a review of the ergonomics literature relevant to seat designs that promote dynamic motions by the user¹. Rani Lueder, CPE of Humanics ErgoSystems, 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 SwingSeat. 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 SwingSeat:

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

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 SwingSeat, which provides noteworthy capabilities enabling users to move freely while supported and assume beneficial postures without continually "fighting the chair"

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).

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 and 1981; 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 day² (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)

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 loads³ (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 impaired⁴. 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).

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.

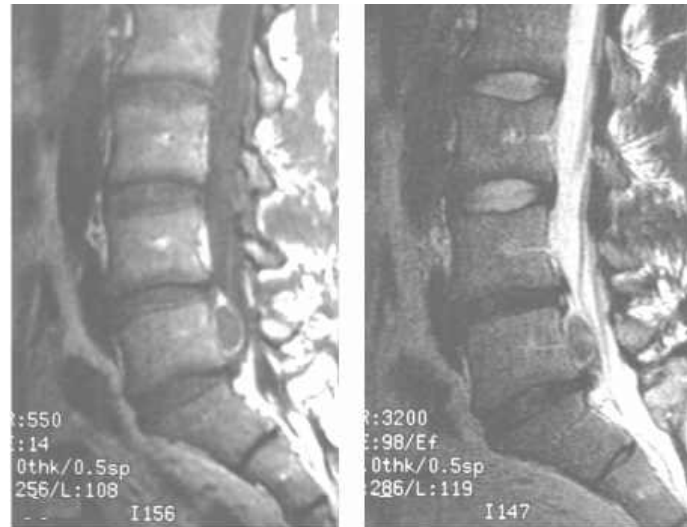
Constrained postures cause chronic degenerative alterations of the cervical, thoracic, and lumbo-sacral spine (Graf et. al. 1995; Hunting et. al., 1980; Occipinti et. al., 1987; Polus et. al., 1985).

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).

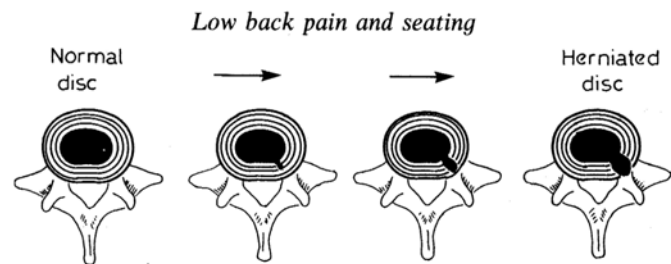
One reason that it is so important to move is that after the age of ten, our spine loses its ability to actively feed itself (or, rather, feed the inter-vertebral discs) and eliminate waste products (Adams and Hutton, 1983; Grandjean, 1987; Maroudas, et al, 1975; Schoberth, 1978). After this age, the 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.



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



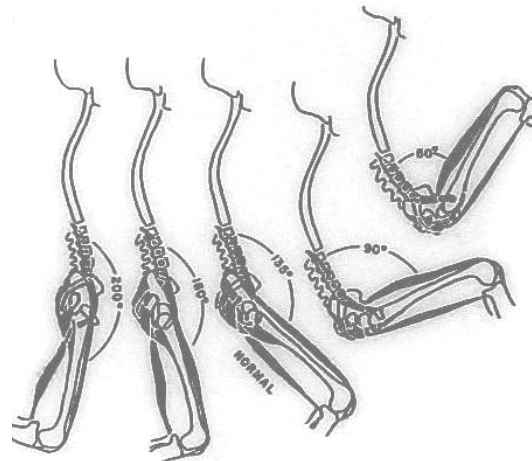
Progression of disc herniation (Bendix, 1994)

Sitting flattens our lumbar curve

When we sit down, our hamstrings flex, causing the pelvis to rotate back. This excessively⁵ flattens the lumbar curve⁶. 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).

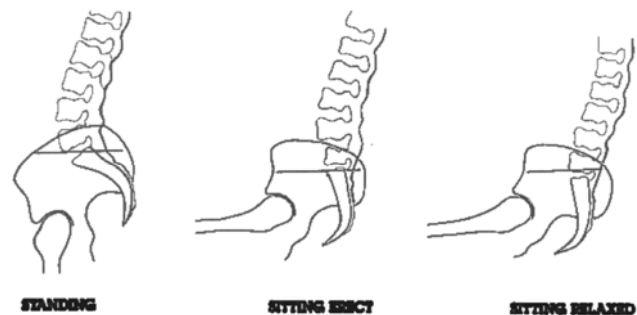
Keegan (1953) demonstrated that changes in the angle between the torso and the legs tilts the pelvis forward and flattens the lumbar area (see his graphic on the right)⁷.

He reported that the discs seem more evenly distributed when the legs are approximately 135° from the torso⁸.



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.

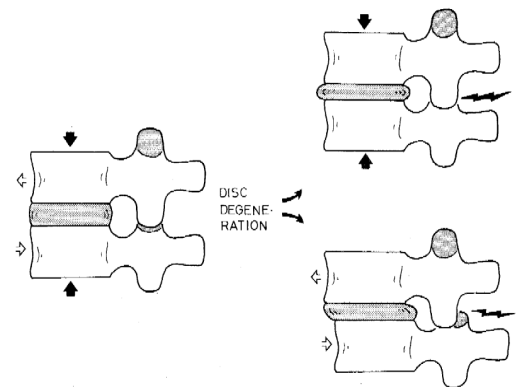
Constrained postures and back pain

Sitting increases intra-discal pressures (Andersson et al). But 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).

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.



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

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

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

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).

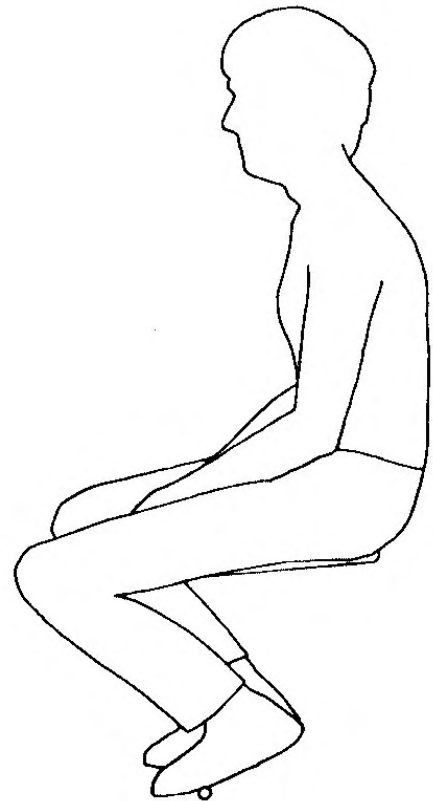
But fit or not, postural support shifts from the muscles to the ligaments that support the spine. The ligaments deform, and there is an increased risk of damage to the spine and joints.

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 backrest¹⁰. (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).

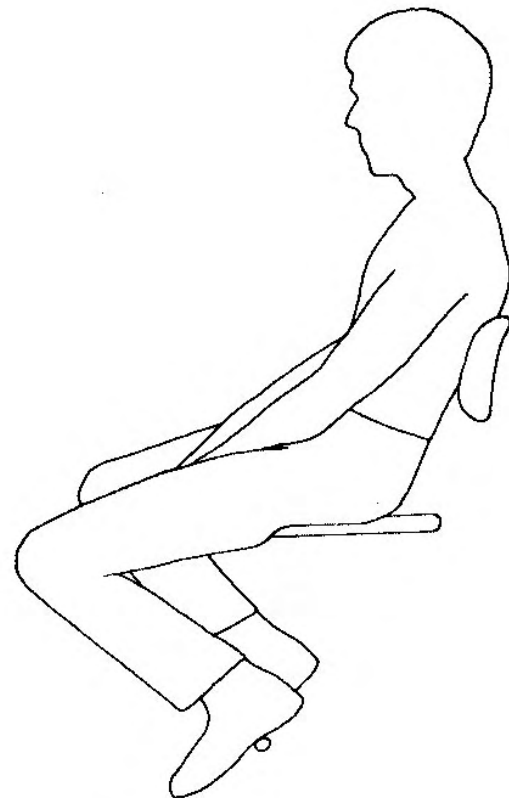
Backrests stabilize posture by relieving the amount of effort required as we fight gravity.

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).

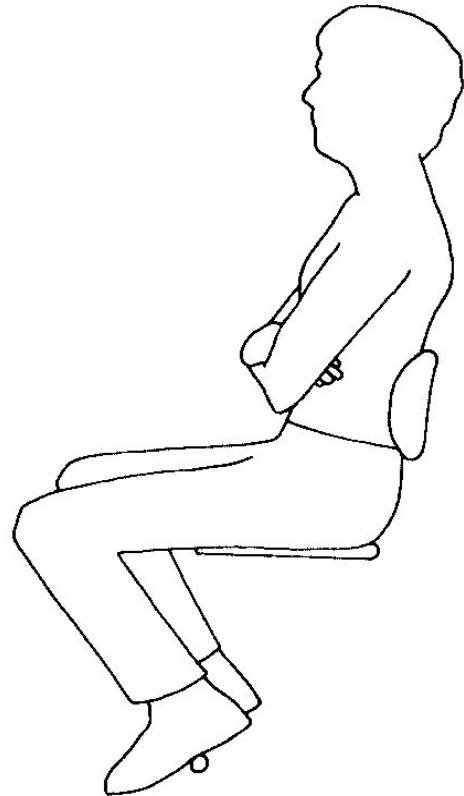
Brodeur and Reynolds (1990) used cadavers to analyze the motion of the vertebra. They concluded that contour of the lumbar spine is little affected by the lumbar support. Rather, it results from the position of the thorax relative to the pelvis, and its' impact on pelvic angle.

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.

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.



Supported upright posture
(Corlett and Eklund, 1984)

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 chair¹¹. 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.

But 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 field¹².

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 seat¹³. 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 al¹⁴ (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.

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

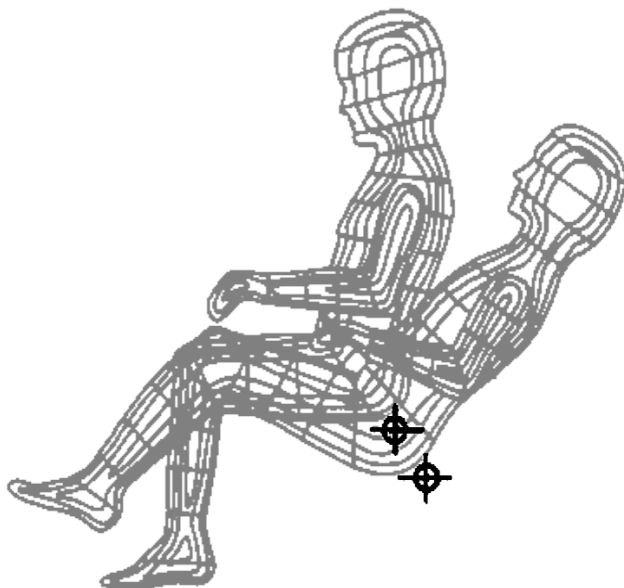
One of our cultural icons is President John F. Kennedy rocking on his chair in the Oval office.

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.

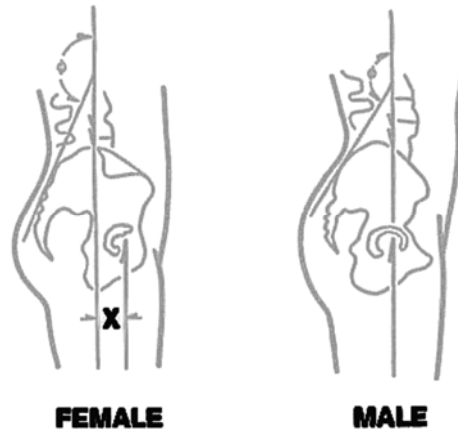
Another feature that affects the fit of the user and the chair is if the pivot point of the chair is markedly different from the pivot point of the user¹⁵. If the chair's pivot is close to that of the user, the chair responds in concert with the user.

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 SwingSeat. 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 SwingSeat 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 performed¹⁶.

Another study of a chair with rotary movements¹⁷ (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 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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About Rani Lueder

Rani Lueder, MSIE, CPE is President of *Humanics ErgoSystems, Inc.* an ergonomics consulting firm in Encino, California that she established in 1982. She has consulted, performed research and served as an expert witness in occupational ergonomics, posture and the design and evaluation of products and places for adults, children and people with disabilities for more than two and a half decades. She has consulted for corporations, governments and universities in seven countries and has provided expert testimony on a range of cases related to product design, occupational health and accommodating people with disabilities.

She has performed large-scale evaluations for organizations and served on retainer for numerous organizations. She continues to serve on retainer to the Japanese Scientific University, the University of Waseda. She also served on retainer for several years with the Japan Institute of Human Posture (Tokyo), The University of Waseda and ErgoSeating in Japan. She was a member of the ANSI committee revising the American National Standard for workstation design.

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