Rethinking design parameters in the search for optimal dynamic seating

Dynamic seating design purports to lessen damage incurred during sedentary occupations by increasing sitter movement while modifying muscle activity. Dynamic sitting is currently defined by O'Sullivan et al. (2013a) as relating to "the increased motion in sitting which is facilitated by the use of specific chairs or equipment" (p. 628). Yet the evidence is conflicting that dynamic seating creates variation in the sitter's lumbar posture or muscle activity with the overall consensus being that cu ...
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RETHINKING DESIGN PARAMETERS IN THE SEARCH FOR OPTIMAL DYNAMIC SEATING

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ABSTRACT
Dynamic seating design purports to lessen damage incurred during sedentary occupations by increasing sitter movement while modifying muscle activity. Dynamic sitting is currently defined by O’Sullivan et al (2013) as relating to ‘the increased motion in sitting which is facilitated by the use of specific chairs or equipment’ (p. 628). Yet the evidence is conflicting that dynamic seating creates variation in the sitter’s lumbar posture or muscle activity with the overall consensus being that current dynamic seating design fails to fulfill its goals.

Research is needed to determine if a new generation of chairs requiring active sitter involvement fulfills the goals of dynamic seating and aids cardio/metabolic health. This paper summarises the pursuit of knowledge regarding optimal seated spinal posture and seating design. Four new forms of dynamic seating encouraging active sitting are discussed. These are 1) The Core-flex with a split seatpan to facilitate a walking action while seated 2) the Duo balans requiring body action to create rocking 3) the Back App and 4) Locus pedestal stools both using the sitter’s legs to drive movement. Unsubstantiated claims made by the designers of these new forms of dynamic seating are outlined. Avenues of research are suggested to validate designer claims and investigate whether these designs fulfil the goals of dynamic seating and assist cardio/metabolic health. Should these claims be efficacious then a new definition of dynamic sitting is suggested; ‘Sitting in which the action is provided by the sitter, while the dynamic mechanism of the chair accommodates that action’.
RETHINKING DESIGN PARAMETERS IN THE SEARCH FOR OPTIMAL DYNAMIC SEATING

INTRODUCTION
Studies worldwide demonstrate that sitting accounts for 51-68% of an adult’s waking day (Healy et al 2008, 2011). Days spent at work are associated with two hours more sitting and therefore less standing and walking time than leisure days (McCraday & Levine 2009). The greatest part of daily energy expenditure is more often related to light intensity activities such as standing, slow walking, lifting light objects, rather than moderate or vigorous activity e.g. brisk walking or running. However, light activities have become significantly reduced because of improvements or changes in technology, including dynamic chairs that encourage prolonged sitting in the workplace as well as the home (Dunstan et al 2012).

Dynamic chairs were introduced to address ramifications from prolonged sitting by facilitating movement while decreasing static muscle activity. However, in their systematic review of dynamic sitting, O’Sullivan et al (2013a) concluded that there was no evidence to ‘support the use of dynamic sitting approaches as an effective, or beneficial, means of modifying trunk muscle activation during sitting’ (p 633). The conclusions of the systematic review studies were: joint and muscle activity is affected more by task than dynamic design (Ellegast et al 2012, van Dieën et al 2001), unstable surfaces (e.g. sitballs) do not improve lumbar posture (McGill et al 2006, O’Sullivan et al 2006), cause increased discomfort (Gregory et al 2006, McGill et al 2006), spinal shrinkage and increased (Kingma & van Dieën 2009) or unchanged superficial trunk muscle activity (McGill et al 2006, O’Sullivan et al 2006). The few advantages; sitballs increase trunk movement (O’Sullivan et al 2006), pneumatic lumbar support improves upright and reclined lumbar posture (McGill & Fenwick 2009), dynamic seats with backrests decrease spinal shrinkage (van Dieën et al 2001), are overridden by the disadvantages.

To date therefore, dynamic seating design has failed to attain its objectives. This finding suggests the need to rethink design parameters in the search for optimal chair design. The current ergonomic paradigm is design that minimises load and muscle activity. Instead, Straker and Mathiassen (2009) propose increasing joint movement and muscle activity, citing the use of sit/stand tables as one method of achieving more activity. However Gallagher et al (2014) calculate it would require standing or walking for 5.5 hours of a 7.5 hour working day to gain metabolic benefits from light activity proposed by Owen et al (2011) and that standing stationary at a desk for 45 minutes causes low back pain (lbp) unrelieved by 15 minutes of sitting.

This paper explores the proposition that by making sitting more active, incidental activity may be increased without musculoskeletal penalty, thus addressing cardio/metabolic and postural health. Research pertaining to seated posture and seating design optimal to lumbar postural health is summarised. Future research options are proposed using a new generation of dynamic seating, the claims of which are largely unsubstantiated.
THE QUEST FOR THE LEAST DAMAGING SEATED POSTURE/S

Table 1 outlines the circuitous route of the pursuit for optimal seated posture and design that was impacted variously by experiential, anecdotal, sociocultural and scientifically validated advice. Table 2 and Figure 1 compare the damage caused by sitting in a) sustained kyphosis, b) lordosis same as standing c) individual neutral. In summary, in the absence of spinal anomaly (e.g. symptomatic lytic/degenerative listhesis or canal stenosis) seated postures that maintain some degree of lordosis are the least damaging to spinal health. The question in the last decade has been: how much lumbar lordosis is optimal?

There is a strong body of evidence in the current literature that a neutral position of the lumbar spine is least damaging for those historically free of non specific chronic lbp (NSCLBP) (Claus et al 2008, O’Sullivan et al 2010, Scannell & McGill 2003), particularly when stationary (McGill 2004). A neutral posture is balanced midway between individual full kyphosis and lordosis (McGill 2004, Scannell & McGill 2003) neither flexed nor extended (McGill & Fenwick 2009), achieved by tilting the pelvis slightly anteriorly while maintaining a relaxed thoracic spine (O’Sullivan et al 2010) or, in the absence of a backrest, a position with flat thoracic and lumbar spines that retains minimal lordosis (Claus et al 2008, 2009). O’Sullivan et al (2010, 2012) quantify their definition of neutral position as 30% off individual maximal sitting lumbar lordosis where maximum lordosis is 100% of lumbar range and maximum kyphosis is 0% of sitting lumbar range.

However, O’Sullivan et al (2012b) concur with Callaghan and McGill (2001) that providing a posture is not maintained at end of range and does not require damaging muscle activity, then chair designs affording ease of movement between multiple postures are preferable to those that constrain to one ‘optimal’ position.

**Advising on individual optimal postures**

Individuals with NSCLBP history unnecessarily increase spinal load by choosing painful end-range kyphosed or hyperlordosed sitting postures (Dankaerts et al 2006b) and moving in dysfunctional, pain producing patterns (McGill et al 2003a, McGill 2004) in the direction they know causes them pain, thus increasing their pain and preventing recovery.

Finding the optimal sitting posture/s for an individual requires examining for motor control aberrations, muscle impairments and dysfunctional movement patterns contributing to pain production (Astfalck et al 2010, Dankaerts et al 2006a b, Dankaerts & O’Sullivan 2011, McGill et al 2003a, McGill 2004) given that such aberrations increase muscle activity and loads, predisposing the back to further injury (McGill et al 2003b). Other variables to consider include, but are not limited to, direction of movement that improves or worsens symptoms, physical individual ranges of motion in the thoracic and lumbar spines in sitting, the natural degree of hypo/hyperlordosis in standing and the impact that sitting, which increases lumbar kyphosis compared to standing, has on posterior tissue strain, the frequency/ease of movement permitted by the seat and tasks
pursued while seated (Claus et al 2009, Keegan 1953, McGill 2004, O’Sullivan et al 2012b). Psychosocial issues such as coping mechanisms and depression contributing to chronicity are also important (McGill 2003a).

It is essential to correct poor postural habits and retrain motor function in order to avoid daily chronic cumulative trauma that hinders/prevents recovery (McGill 2004). Lay term advice is required that in the short term pain from sustained kyphosed sitting may be caused by creep irritating pain receptors in ligaments and lumbodorsal fascia (Callaghan & Dunk 2002) and in the long term may be the result of accumulation of microtrauma in the ligaments (Solomonow 2012). Kyphosis also causes decreased proprioceptive control and spinal stability, decreased resistance to damaging shear forces (McGill 2004), reduced spinal extensor endurance and prevents movement (Dankaerts & O’Sullivan 2011). Increasing patient awareness of the correlation between pain provoking flexion or extension movements in standing and sustaining kyphosed or hyperlordosed postures in sitting may be necessary.

**Importance of movement when seated**

Clinically, those who suffer NSCLBP have been shown to move less frequently than those without back pain (Telfer et al 2009, Vergara & Page 2002), emphasising the need for seating design that encourages movement, even when an individual is maintaining optimal posture.

Lack of spinal movement decreases fluid exchange and nutrition in the intervertebral discs (IVD) (Holm & Nachemson 1983). Disc spaces narrow with potential impingement of zygapophysial joints and compression of nerves supplying the lower limbs. Sustained kyphosed postures result in diminished load carrying capacity of the spinal segment (Owen et al 2009), posterior migration of the nucleus pulposus with posterior annular deformation (Alexander et al 2007, Nazari et al 2012) leading to increased compressive loads in the already vulnerable posterior surface of the IVD (Adams et al 1996). Intermittently moving the spine between kyphosis and lordosis is a useful sitting exercise. For those who find flexion movements painful, initiating movement from the lumbopelvic region creates less joint moment and compression than if initiated from the thoracic spine (Castanharo et al 2014).

Sustained sitting can also create buttock discomfort due to prolonged ischial tuberosity contact pressure [when greater than 50 mm Hg (Noro et al 2012)] with the chair’s seat-pan. Sustained leg immobility can reduce popliteal vein blood flow by almost 40% (Hitos et al 2007). Calf exercise increases blood flow and decreases oedema (Hitos et al. 2007, Stranden 2000).

Sedentary life-styles, by virtue of decreased muscle contraction, slow lipid clearance from blood and decrease insulin’s effect. Both are risk factors for obesity, type 2 diabetes, cancer and cardiovascular disease. As such, this is a profound public health concern that deserves consideration by both the individual and society (Hamilton et al 2007, Katzmarzyk et al 2009, Owen 2012, Owen et al 2010).
How has research impacted on seating design?

The introduction of the desktop computer increasingly tethered workers to their chairs (Nelson 1997) resulting in complaints of pain related to computer use. Ergonomists responded with investigations into the impact of behaviour and task on seat design (Branton 1969, Grandjean 1970), thus introducing psychosocial research into sitting and seating design. By 1980 Stumpf observed that because people move frequently when seated no one sitting posture was ideal. Adjustable mechanisms were introduced to encourage movement (Nelson 1997). When it was evident that many people failed to adjust their chairs from the factory settings or at best changed only the height (Lueder 1994), lever adjustment was replaced with a kinematic tilt system that automatically responded to changes of bodyweight, thus introducing dynamic seating in the 20th century. Tables 3 traces the development of office seating design.

The goals of dynamic seating designs are to generate motion, decrease static muscle activity, fatigue, spinal load, spinal shrinkage and pain. However, in their systematic review of dynamic sitting research, O’Sullivan et al (2013a) conclude that from the 7 studies that fulfilled their research criteria, there is conflicting evidence caused by lack of methodological standardisation regarding backrests (Gregory et al 2006, Kingma & van Dieën 2009) and tasks (Beach et al 2003) that confound findings that dynamic seating affords postural variation or muscle activity modification. Studies that compared backless dynamic seating with back supported fixed seating found higher trunk activity and discomfort with dynamic seating (Gregory et al 2006, Kingma & van Dieën 2009), while those that compared backless dynamic and fixed seating found no difference (McGill et al 2006, O’Sullivan et al 2006). Those studies using back supported dynamic seating recorded decreased back muscle activity (Beach et al 2003, Ellegast et al 2012, van Dieën et al 2001). In addition, greater spinal shrinkage was associated with increased muscle activity, fatigue and increased low back pain in dynamic seats without a backrest (Gregory et al 2006, Kingma & van Dieën 2009) while in supported dynamic seats spinal shrinkage was decreased (van Dieën et al 2001). O’Sullivan et al (2013a) concluded that these conflicting findings related to the presence of a backrest as opposed to dynamic design. As a result O’Keeffe et al (2013) proposed ‘if dynamic sitting has a benefit, it may be through preventing static spinal loading … rather than by altering trunk posture or trunk muscle activation’ (p 655). In addition, Ellegast et al (2012) studied 4 dynamic chairs with various mechanisms facilitating sitter movement and concluded that the level of physical activity ‘was very low during sitting and almost independent of the type of office chair used in this study’ confirming that ‘sitting is largely static, even during sitting on a specific dynamic chair’ (p 305).

These findings emphasise the need to rethink dynamic design parameters. Would designs that require the sitter to actively move the chair avoid static postures, improve movement, and lessen muscle fatigue and spinal loading?

Dynamic seating design requiring active sitter involvement

The first design requiring the sitter to actively promote chair movement may be the rocking chair that appeared in America in 1760 (Cranz 1998). Using newly invented technology, rocking chairs underwent functional improvements in the Victorian patent
era, and in 1897 an office rocking chair was patented (Pynt 2003). It was not until President Kennedy used a rocking chair for relief of low back pain that rocking chairs became popular (Cranz 1998). Having noted this fact Udo et al (1999) set up a study in which subjects performed one word processing task while seated on a rocking chair, comparing the results with the same chair in a fixed position. They investigated thoracic and lumbar back muscle activity using electromyography (EMG), lower leg swelling using bioelectric impedance plethysmography, frequency of seat and postural changes using videography and pain perception using subjective questionnaires. They concluded that general activity of the entire back and the resulting pain from fatigue were decreased when using the rocking facility compared with the chair in the fixed position.

Interestingly, subjects moved less between forward and reclined postures on the rocking chair when compared with research by Bendix et al (1985) investigating subjects on a seat that tilted via a mechanism. Udo and colleagues concluded that this finding may have reflected the tasks, or the fact that the rocking chair required ‘substantial trunk movement for tilting’ provided by alternating muscle group activity, whereas ‘Bendix’s chair facilitates trunk movement because it is placed on a rotating axis’ (p 378).

Summarised below are four current seat designs that require the sitter to generate chair movement using alternating muscle group activity. To the author’s knowledge, of these four the Back App design is the only seat to have undergone published research (O’Sullivan et al 2012a). Therefore there is research potential to investigate whether these designs fulfil the goals of dynamic seating and impact on cardio/metabolic health. Each design can be compared either by the fixed and stationary protocol used by Udo and colleagues or by comparing an active sitting design with a similar static design.

1) The Core-flex chair (Figure 2) features a longitudinally split seatpan that allows lumbo/pelvic/hip motion driven by alternating active ankle plantar/dorsi flexion and a 10° range of alternating hip flexion/extension in a simulated walking action. The hip flexion/extension movement creates pelvic obliquity with concomitant lumbar spine lateral flexion and rotation. These parameters require laboratory validation.

Walking creates alternating contractions between the trunk muscles (Callaghan et al 1999). In standing the body has a natural medial-lateral sway controlled by the hip muscles, and an antero-posterior sway controlled by the calf muscles (Prado et al 2011). This research underpins the designer’s proposal that activating the seatpan in a walking action alternates muscle activity, avoiding fatigue.

This proposal lends itself to studies performing the same task while operating, and not operating the seatpan to investigate the effect of a) alternating muscle group activity on fatigue, spinal shrinkage and loading b) leg driven movement on peripheral blood flow c) alternating psoas major activity on the lumbar curve (see Park et al 2013) d) the degree of alternating hip flexion and the effect on pelvic obliquity, zygapophysial joint loading and intradiscal nutrition (see Popovich et al 2013), on buttock pressure distribution (see Shabshin et al 2010), and on disruption of concentration.
2) **The Duo balans** is a modern day rocking chair that uses trunk movement to vary between reclined, upright and forward inclined postures. It is the current evolution of the original HÅG balans and Variable balans (Figures 3a,b,c).

Research opportunities exist to investigate the effects on spinal shrinkage, spinal loading, muscle fatigue, movement frequency, discomfort (general and shin), ability to maintain upright posture comparing a) stationary (HÅG balans) with dynamic unsupported sitting (Variable balans) b) unsupported (Variable) with supported (Duo) dynamic seating c) all 3 designs. Opportunities also exist to validate the designer’s claims that a) Duo balans lumbar support increases in recline (Opsvik 2008 p68) b) Variable balans requires the user to find trunk equilibrium, thereby strengthening the trunk muscles through ‘active’ sitting (p64).

3) **The Back App** seat (Figure 4) revisits ergonomic design and recommendations that forward tilt seating encourages lumbar lordosis and facilitates forward oriented tasks (Colombini et al 1985, Corlett & Gregg 1994, Gale et al 1989, Mandal 1976, 1981). This stool features a saddle shaped forward tilt seat mounted on a circular base and ball that can be adjusted for varying degrees of multi-directional mobility. The Back App seat has been demonstrated to facilitate neutral lumbar posture and decrease superficial paraspinous muscle activity in comparison with use of a standard office chair in those without NSCLBP (O’Sullivan et al 2012a) and those with NSCLBP relieved by lumbar extension or standing/walking (O’Keeffe et al 2013). These authors propose that such a seat could reduce lbp caused by fatigue from static spinal loading. Investigating pain free subjects performing a typing task for 10 minutes they determined that trunk muscle activation was reduced to as low as 4% maximum voluntary isometric contraction (MVIC) for external oblique. However, superficial lumbar multifidus and thoracic erector spinae recorded 5.3% and 10.2% MVIC respectively. These are unacceptably high readings given that after 30 minutes of sustained use, spinal extensor muscles fatigue even when working at 2% of their MVIC (van Dieën et al 2009). When spinal extensors fatigue the back slumps, which, if sustained, leads to musculoskeletal ill-health. Potential research options exist using the same wireless posture monitor as O’Sullivan et al (2012a) to a) examine muscle fatigue, and the ability of the sitter to maintain some degree of lumbar lordosis for 30 minutes sitting on the Back App b) compare the effect of the Back App and the Variable balans on trunk muscle activity, upright posture and pedal circulation given that the former uses the feet and the latter the trunk to move the seat.

The manufacturers also advertise that by altering the tension of the ball to increase seat instability, the Back App may be used to promote muscle activation and trunk stability training. Research opportunities exist for this claim using surface EMG to record activity of external and internal obliques and thoracic and lumbar erector spinae (see Jackson et al 2013) and fine wire electrodes for recordings of coordination and endurance of deep multifidus and transversus abdominis (see Tsao et al 2010).

4) **The Locus Seat** (Figure 5) is a perch sit/stand stool with a spring loaded leg providing forward and return movement driven by flexion and extension of the knees. It is claimed that the design places the sitter in a neutral posture creating equilibrium between spinal
and abdominal musculature, decreases muscle activity, fatigue, leg oedema, and pain, increases motion, respiratory and circulatory function. Opportunities exist using the Locus seat at a sit/stand desk to a) research these claims by comparing standing only with this active sit/stand seat using the methods previously discussed b) pursue the effect of this sit/stand seat on spinal posture, and postural and muscle activity as proposed by, and using the same methodology, as Ellegast et al (2012) c) replicate the protocol of Dunstan et al (2012) to determine whether using an ‘active’ sit/stand stool is more beneficial in maintaining musculoskeletal and cardio/metabolic health than the stationary sit/stand stool used in their study.

CONCLUSION
Medical research currently supports the case that a neutral posture maintaining some degree of lumbar lordosis in sitting, as well as movement while in the seated position, is less damaging to spinal postural health than sustained kyphosed postures. Neutral is individually determined and is impacted by many factors including the presence or absence of lbp history. In the presence of lbp advice regarding individual neutral posture must consider anomalies of muscle control and movement, pain provoking/relieving movements and ranges of natural lordosis in standing and sitting, as well as psychosocial issues related to posture and pain.

Dynamic sitting is currently defined by O’Sullivan et al (2013a) as relating to ‘the increased motion in sitting which is facilitated by the use of specific chairs or equipment’ (p. 628). However these and other researchers have concluded that in addition to failing to fulfill goals of dynamic seating, dynamically designed chairs do not cause dynamic sitting. Designers of a new generation of chairs requiring alternating muscle activity to activate chair movement have made largely unsubstantiated claims that their designs variously decrease static muscle activity, fatigue, spinal load, spinal shrinkage, pain, maintain neutral lumbar posture and improve trunk muscle strength. Research potential exists to determine if these claims are valid. The outcome of this research may redefine design parameters for dynamic seating and a new definition of dynamic sitting may more accurately become ‘Sitting in which the action is provided by the sitter, while the dynamic mechanism of the chair accommodates that action’.
Acknowledgements
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Table 1 Outlines the circuitous pursuit for optimal seated posture and design

<table>
<thead>
<tr>
<th>Advised by</th>
<th>Recommendation</th>
<th>Rationale/Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borelli 1680</td>
<td>Importance of movement while sitting to avoid impedance of blood flow and nutrition (3), and prevent backache (15)</td>
<td>Anecdotal advice based on newfound attempts to understand the function and structure of the body. No impact on seat design (12)</td>
</tr>
<tr>
<td>Ramazzini 1713</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andry 1743</td>
<td>Anecdotal advice that maintaining lumbar lordosis prevented childhood scoliosis (2)</td>
<td>Convex contoured backrests and posture advice</td>
</tr>
<tr>
<td>Socio-cultural perceptions</td>
<td>Slouched posture emulating that of the ancient Greeks indicated status and a return to the perceived idealism of ancient Greece (14)</td>
<td></td>
</tr>
<tr>
<td>18th century</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineers 1850-1900</td>
<td>Multipostural, multi adjustable patent seating using newfound technology affording the best posture through the medium of adjustability. Task appropriate e.g. typist, sewing, barber/operating chairs (14)</td>
<td>Engineering based concepts. Forward/reclined/lateral tilt dynamic seating using springs, screw, lift, hydraulic height adjustment. Overlooked (13)</td>
</tr>
<tr>
<td>Sociocultural perceptions</td>
<td>Upright immobile postures indicating willpower and sophistication required rigid upright uncomfortable seating (13)</td>
<td>Patent seating was subjugated to perceptions of morality and aesthetics (13)</td>
</tr>
<tr>
<td>19th century</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staffel 1884</td>
<td>Anecdotal advice that maintaining lumbar lordosis in school seating improved respiratory and intestinal health (16)</td>
<td>Height adjustable lumbar roll, forward tilt seats and desks, forehead restraint, footrest (14)</td>
</tr>
<tr>
<td>Schindler 1892</td>
<td>Promoted movement interspersing standing with sitting (12)</td>
<td>Perch/sit/stand school seat with backrest US Patent 483,265</td>
</tr>
<tr>
<td>Various medical practitioners</td>
<td>Maintain lumbar lordosis to prevent constipation and pelvic disease (9). Recognition of a variety of sources of back pain, emphasis on diagnosing source of pain (5), rise of the disc as source of pain (11)</td>
<td>Right angled seating reflecting sociocultural concepts that an upright posture represented upright character (14)</td>
</tr>
<tr>
<td>1900-1948</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Williams 1948 1974,</td>
<td>Anecdotally flawed promotion of kyphosed seating postures proposing reduced pressure on nerves by opening the posterior structures (4, 6,17)</td>
<td>Coincided with new socio cultural concept that relaxed postures reflected control, amiability, informality (14)</td>
</tr>
<tr>
<td>Fahmi 1966,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cailliet 1988</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keegan 1953,</td>
<td>Scientific research using radiographic (8), in vivo (10), in vitro (7), EMG (1), disc pressure transducer studies (1) that lent evidence to the importance of maintaining lumbar lordosis</td>
<td>Search for postural variation leading to forward tilt, lumbar support reclined seating. Start of modern ergonomic design (12)</td>
</tr>
<tr>
<td>Farfan 1972,</td>
<td></td>
<td></td>
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<tr>
<td>Andersson 1974, 1979</td>
<td></td>
<td></td>
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<tr>
<td>Mandal 1976</td>
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</tbody>
</table>
References
1713 (16) Staffel 1884 (17) Williams 1948
### Table 2 Effects of sitting postures

<table>
<thead>
<tr>
<th>Structure</th>
<th>Sustained Kyphosis</th>
<th>Standing Lordosis</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior spinal muscles</td>
<td>Invokes flexion relaxation response (FRR) (19,20,21) decreasing muscle protection</td>
<td></td>
<td>Decreases multifidus and internal oblique activity in unsupported sitting (10)</td>
</tr>
<tr>
<td>Posterior spinal ligaments and dorsolumbar fascia</td>
<td>Maximal flexion (12) generates high tensile forces (1,6). FRR increases anterior shear forces exerted by ligaments on discs (6,18)</td>
<td>Ligament/elastic stress at their least (9,10,30)</td>
<td></td>
</tr>
<tr>
<td>Iliolumbar ligaments</td>
<td>Creates high tensile forces (1,6). Stressed to near failure due to FRR (31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar discs</td>
<td>Intradiscal pressure (IDP) 0.83 MPa (34). If sustained encourages disc prolapse (17)</td>
<td>IDP 0.55MPa (without backrest) (34). Compressive peaks of pressure in already vulnerable posterior disc (2)</td>
<td>Insufficient increase in IDP in undegenerated discs to cause lbp (9)</td>
</tr>
<tr>
<td>Zygaphophysial joints</td>
<td>Load reduced, but FRR puts joints at risk (21,26)</td>
<td>Stretching of capsule (35), increased joint contact and load (3,22,30) possibility of impinged soft tissue (4,13,35), IVF narrowing (15)</td>
<td>Best position to bear joint loads (16) which are at their least (30)</td>
</tr>
<tr>
<td>Sacro-iliac joints</td>
<td>At risk from FRR (31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visco-elastic tissues (See Figure 1)</td>
<td>Creep disrupts sensorimotor function (27,32), causing a neuromuscular response inhibiting multifidus reflex (5,32). NSCLBP patients unable to reposition to neutral after 5 seconds kyphosed (23). Those without pain unstable after 5 minutes</td>
<td>Permits neuromuscular control of flexion, rotation and anterior shearing without damaging compressive forces (10,30). Passive tissue stress minimized (8,17). Stability uncompromised.</td>
<td></td>
</tr>
<tr>
<td><strong>Pelvic floor muscles</strong></td>
<td>Decreases tensioning of deep abdominal muscles and weakens pelvic floor activity (28,29)</td>
<td></td>
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<td>--------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td></td>
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<tr>
<td><strong>Muscles of respiration</strong></td>
<td>Diaphragm activity compromised (24) creating inverse breathing pattern using accessory respiratory muscles (33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cervical/thoracic spines</strong></td>
<td>Increases joint flexion and extensor muscle activity (7) Reduced static muscle activity (7,14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Miscellaneous benefits</strong></td>
<td>Some degree of flexion may be the posture of choice in presence of symptomatic listhesis or canal stenosis Easily learned in those historically free of lbp (9). Those with non-neutral posture and lbp can be retrained (25). Effective lbp preventive measure (30)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**References:**
### Table 3: The development of office seating in 20th century

<table>
<thead>
<tr>
<th>Date/designer</th>
<th>Chair</th>
<th>Innovation/rationale</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1902 Chichester</td>
<td>Patented Type-Writer’s Chair</td>
<td>Patent seating preempted modern ergonomic seating</td>
<td>Failed; considered too comfortable to be moral (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height adjustable lumbar support. Weight sensitive sprung recline. Ratchet seat height adjustment</td>
<td></td>
</tr>
<tr>
<td>1904 Frank Lloyd Wright</td>
<td>3 legged Women’s Typist chair</td>
<td>Planar right angled backrest and seatpan. Armrests, castors.</td>
<td>Prioritised aesthetics to fit office décor. Unstable design required chair to be bolted to desk yet commissioned for mass office seating (14)</td>
</tr>
<tr>
<td>1904 Frank Lloyd Wright</td>
<td>Executive Swivel Chair</td>
<td>Large. Screw height adjustment. 4 legged base on castors.</td>
<td>Large for status (14)</td>
</tr>
<tr>
<td>1963 Jacobsen</td>
<td>Oxford chair for Oxford dons</td>
<td>Lumbar contouring. Waterfall front to seatpan. Armrests. Screw height adjustment. 5 castors</td>
<td>High backrest indicating prestige. Jacobsen received honorary doctorate for this design</td>
</tr>
<tr>
<td>1970s Mandal</td>
<td>Forward tilt perch chair</td>
<td>Radical design emulating horseriding posture. Based on research that open hip/trunk posture reduces tension in hamstrings/gluteals, facilitates anterior pelvic tilt, restores lumbar lordosis (9). Higher than normal chair. Forward tilt seatpan. No backrest. No height adjustment</td>
<td>Negative research: forward slip increased weight on feet, clothing drag (1,2,7) Positive research: decreased lumbar muscle activity and intradiscal pressure sitting on a 20° forward tilt stool compared with sitting on a right angled chair with or without lumbar support (4)</td>
</tr>
<tr>
<td>1970-1979 Opsvik, Menghoel, Gusrud</td>
<td>balans kneeling chair</td>
<td>Radical design (5). Name indicated neutral, balanced spine (12). Weight shared between forward tilt seat and shin rests. No height adjustment, backrest/armrests. Proposed that lack of backrest strengthens trunk muscles (12).</td>
<td>Research demonstrated increased static paraspinal muscle activity with forward body lean beyond the vertical (10) and resultant kyphosis as back extensors tired (3,10)</td>
</tr>
<tr>
<td>1976 Stumpf</td>
<td>Ergon</td>
<td>Anthropometric design to suit 90% of population.</td>
<td>Accommodated sitter behaviour and task.</td>
</tr>
</tbody>
</table>
Contoured backrest, height adjustable armrests, gas cylinder height adjustment absorbed sudden weight impact, lever recline adjustment with locking device, castors (15)

<table>
<thead>
<tr>
<th>Year</th>
<th>Designers</th>
<th>Model</th>
<th>Feature</th>
<th>Note</th>
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</thead>
<tbody>
<tr>
<td>1977</td>
<td>Ambasz &amp; Piretti</td>
<td>Vertebra Operational</td>
<td>Automated synchronised seat tilt/backrest adjustment using counter springs and movement. Concave backrest supporting thoraco-lumbar region. With or without armrests.</td>
<td>First chair to respond to body movement (6)</td>
</tr>
<tr>
<td>1984</td>
<td>Stumpf</td>
<td>Equa</td>
<td>Independent seat and back action, 3 sizes of chair to suit small, average, large statures, kinematic tilt, castors</td>
<td>Improved ease of movement facilitating posture change and task management. Beginning of dynamic seating accommodating preferred postures (18)</td>
</tr>
<tr>
<td>1984</td>
<td>Opsvik</td>
<td>HÅG Capisco</td>
<td>Saddle seat facilitating lordosis, backrest, horizontally projected armrests. Lever height, recline adjustment.</td>
<td>Encourages interaction with chair allowing postural variation. Based on concept ‘next posture is the best posture’ (12)</td>
</tr>
<tr>
<td>1991-2006</td>
<td>Opsvik</td>
<td>Thatsit balans, Duo balans</td>
<td>Backrest, adjustable shin supports, armrests, rockers. Headrest on Duo balans. Encourages postural change</td>
<td>Anecdotal proposals that designs address the problems of the original balans (12)</td>
</tr>
<tr>
<td>1992</td>
<td>Chadwick &amp; Stumpf</td>
<td>Aeron</td>
<td>Height and depth adjustable lumbar support, height and angle adjustable armrests, contoured seatpan to anteriorly rotate pelvis, kinematic tilt allowing incline and recline by shifting body weight, castors. 3 sizes</td>
<td>Aims to accommodate long periods of sitting by facilitating ease of movement. Lumbar rest adjusts vertically to maintain correct position of lumbar support during forward/backward tilt. Breathable mesh upholstery. 94% recyclable (16,17)</td>
</tr>
<tr>
<td>Late 1990s</td>
<td></td>
<td>Sit balls</td>
<td>Large ball of various materials some with backrest</td>
<td>Claimed to encourage upright posture, improve spinal stability. Refuted by research (8,11)</td>
</tr>
</tbody>
</table>
References:
**Figure 1** The effect of sustained kyphosed sitting on visco-elastic tissues (Pynt & Higgs, 2009)
Figure 2 Core-flex chair
Figure 3a Duo balans (Opsvik 2008, p192)
Figure 3b Original balans
Figure 3c Variable balans (Opsvik 2008 p192)
Figure 4 Back App
Figure 5 Locus sit/stand/perch seat