

Every Back Is Different

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Accommodating various sizes and shapes of humans has long been a familiar user comfort issue for chair designers. In addition to anthropometric variation between individuals, e.g., tall and small persons, it is also common to find asymmetry, or variation in size and shape of body parts, within a single individual. Emerging research suggests that this asymmetry may be an important new dimension in the design of low back support for chairs. A recent study to quantify the amount of support users wanted in the lower back found that approximately 70 percent of seated individuals were more comfortable when allowed to self-select asymmetric low back support - more support to the left side of the back or vice versa. Thus, it now appears that designers of lumbar supports for chairs may need to consider asymmetry in order to maximize comfort while sitting.

Asymmetric Back Support and Comfort

Emerging research suggests that asymmetry may be an important new dimension in the design of low back support. Fredericks and Butt (2005), in a study of 125 individuals, found that these individuals self-selected asymmetric lumbar support, which was associated with greater comfort.

In order to better understand and quantify the relation between comfort and lumbar support, the subjects were allowed to adjust their chair backrests to achieve maximum comfort. They were able to simultaneously vary the lumbar support in two dimensions: height above the seat and left or right of the centerline of the body. This study found that the ability to provide different amounts of support to each side of the back resulted in greater comfort ratings for approximately 70 percent of the study group. The magnitude of the differences in preferred support for the left and right sides is quite striking. Seventy percent of the participants preferred asymmetric support in which the support force setting for one side of the back was at least 120 percent of the support provided to the other side and forty percent preferred support settings in which the ratio was 150 percent or greater. More than twenty percent favored asymmetric support that was almost twice as much for one side compared to the other.

One might raise the question as to whether or not the differences in the level of support were within the range of the individual's ability to judge differences

in force or pressure applied to their back. If this were so, the preference as to which side received more support would be expected to vary randomly between seating trials. However, retesting at a second date found the results to be consistent and stable. The general preference appeared to be for greater support to the left side; individuals who self-selected asymmetric support chose greater support for the left side by almost a two to one margin.

Asymmetry is Common

Some degree of asymmetry in the shape and size of paired body parts is described as the norm for humans (All-Eisa et al, 2004) and, indeed for all vertebrates (Varlet & Robertson, 1997). In addition to the variation in back size and shape between individuals (inter-individual variation) there are also normal differences between or within body structures (e.g. right and left arms and right and left sides of faces) within an individual (intra-individual variation) with regard to the size and shape of the body parts. Such differences have been noted for the face (Koehler et al, 2004), limb bones (Dahl, 1996), arms (Steele & Mays, 2005), pelvis (Badii et al, 2003), (Juhl et al, 2004; Friberg, 1983), spine (Dickson et al, 1984), and legs (Hellsing, 1988). Significantly, this intra-individual variation in the size and shape of the left and sides of the body has been linked with low back pain (Friberg, 1983; All-Eisa et al, 2004). All-Eisa et al (2004) showed that the higher the degree of asymmetry in the upper and lower limbs, the greater the likelihood of low back pain.

A recent anthropometric study of individuals from the United States, Canada, the Netherlands and Italy documents the asymmetry of the human body. In this study dimensions of several body parts were measured on both the left and right side of the participants (Robinette et al, 2002).

The data describing the US population demonstrates asymmetry in left-right body dimensions for anatomic structures that are commonly referenced when designing chairs such as the height of the trochanters (hip) above the seated surface and seated elbow height (Harrison & Robinette, 2002). These data (Table 1) show that the left and right shoulders were at different heights above the seating surface (pertinent to the design of the chair backrest), as were the left and right elbows (pertinent to the design of armrests) and the left and right trochanters (pertinent to the design of the seat pan). Dickson et al (1988) report that asymmetry in the structure of the spine in one plane is normal, becoming pathological only when it is asymmetric in two orthogonal planes. In contradiction to the previous assumption of back symmetry in chair design, human bodies and human backs are structurally asymmetric.

Sitting is an example of human motor behavior. Similar to anthropometric asymmetry just described, there are instances in which human motor behavior is also known to have asymmetric features (Maupas et al, 1999; VanZant et al, 2001; Childs et al 2003).

Maupas et al (1999) observed that studies of walking generally treat it as a symmetrical activity and gather data on only one side of the body. However, they found that there was asymmetry in knee flexion angles for more than one-half of all individuals while walking, and concluded that such asymmetry is normal and that asymmetry should be considered when working with both healthy and pathological individuals. Childs et al (2003) noted that subjects with low back pain tend to stand in such a way that they carry their body weight asymmetrically.

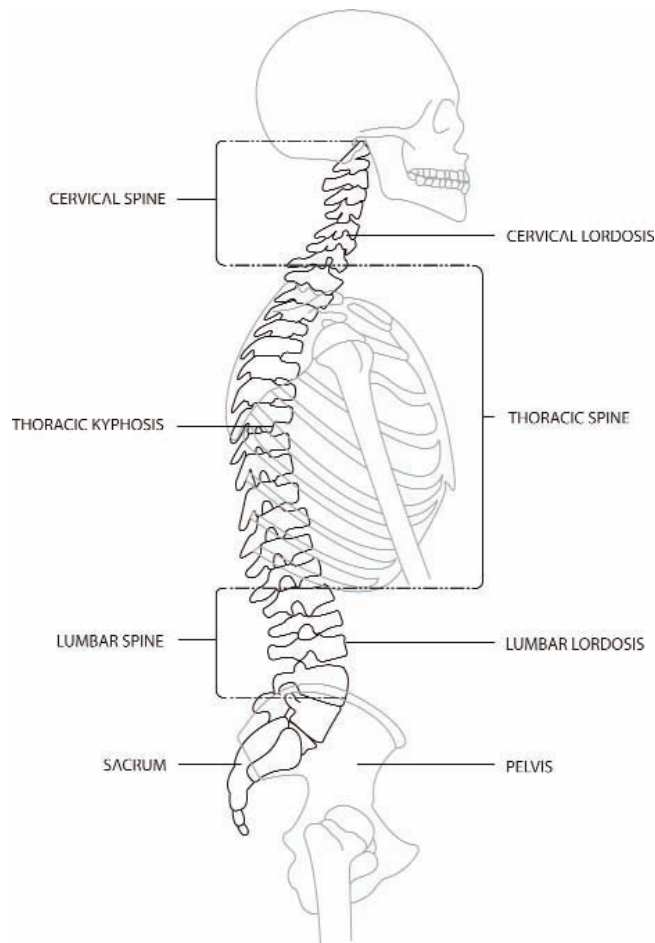


Figure 1: Side view of spine illustrating S-shape (Images used with permission and adapted from Chaffin & Andersson, 1984, Occupational Biomechanics).

This evidence of anthropometric and motor behavior asymmetry is consistent with the preference for asymmetric low-back support identified by Fredericks and Butt (2005). Given that asymmetry is common in both the physical structure and motor behavior of human beings and that there is a preference for asymmetric low back support while seated, what impact does this have on seating comfort and seating design, particularly on the design of backrests?

Designing for Comfort

The function of the backrest is to support the upper part of the body and to make the seated individual comfortable. Given the importance of the backrest in chair comfort, and the importance of a comfortable chair for people that spend most of their workday sitting, a thorough understanding of the human back is essential in designing a backrest for an office chair.

In side view, the human spine is an S-shaped column attached to the pelvis (Figure 1). It has four curves (Chaffin & Andersson, 1984) that correspond to the neck (cervical curve), chest (thoracic curve), low back (lumbar curve) and the sacrum/coccyx. The upper three segments are composed of 24 bones (vertebrae) separated by disks, which act as shock absorbers for compressive loads imposed on the spine by the weight of the body.

Table 1: Asymmetric body dimensions relative to seating design

Paired Body Part	Left	Right
Trochanter (Hip)	5.3 inches above seat	5.4 inches above seat
Elbow	11.2 inches above seat	10.9 inches above seat
Shoulder	23.5 inches above seat	23.2 inches above seat

The vertebrae and disks support the weight of the upper body — arms, head and torso — which is about two-thirds of total body weight (Chaffin & Andersson, 1984) while an intricately woven system of muscles and ligaments works to keep the torso aligned and balanced.

Biomechanical models of the spine show that the back muscles play a critical role in balancing the torso. To visualize this, think of a seated person as balancing his/her weight on the sitting bones of the pelvis (ischial tuberosities). As he or she leans forward, the weight shifts away from the balance point, and the back muscles must provide the counterforce necessary to keep the torso balanced (Figure 2). Without their effort, a person would fall on his/her face!

The lumbar curve, which first develops as individuals begin to stand upright, is especially important with regard to the design of a backrest. This graceful, lordotic arch brings the weight of the torso closer to the balance point over the ischial tuberosities and helps to minimize the effort required of the back muscles to balance the weight of the torso.

Moving from a standing to a sitting posture causes the pelvis to rotate, which in turn flattens the lumbar curve until it becomes kyphotic (bowed out instead of curved in) (Figure 3).

This has two adverse consequences that a backrest designer must consider: it shifts the torso weight forward of the balance point, requiring the back muscles to work harder in order to support the torso, and it unevenly compresses the disks of the lumbar spine (Nordin & Frankel, 1989). Not surprisingly, a flattened or kyphotic lumbar curve is associated with greater discomfort (leg and back pain) when seated, while maintaining the lordotic lumbar curve while sitting is associated with increased comfort — significant reduction of back and leg pain (Williams et al, 1991).

Two methods are typically used to support or maintain the shape of the lumbar curve while seated. The first method is to provide a support for the lumbar curve in the chair's backrest (lumbar support); the second is to prevent or reduce the rotation of the pelvis. The most common method of limiting the movement of the pelvis has been to increase the angle between the seat and back. More recent approaches use supports to limit or prevent pelvic rotation.

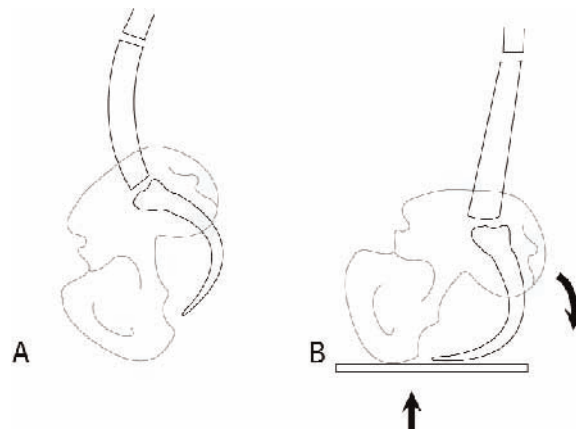


Figure 2: Rotation of pelvis and flattening of lumbar curve as the individual moves from standing (A) to sitting (B) (Images used with permission and adapted from Chaffin & Andersson, 1984, Occupational Biomechanics).

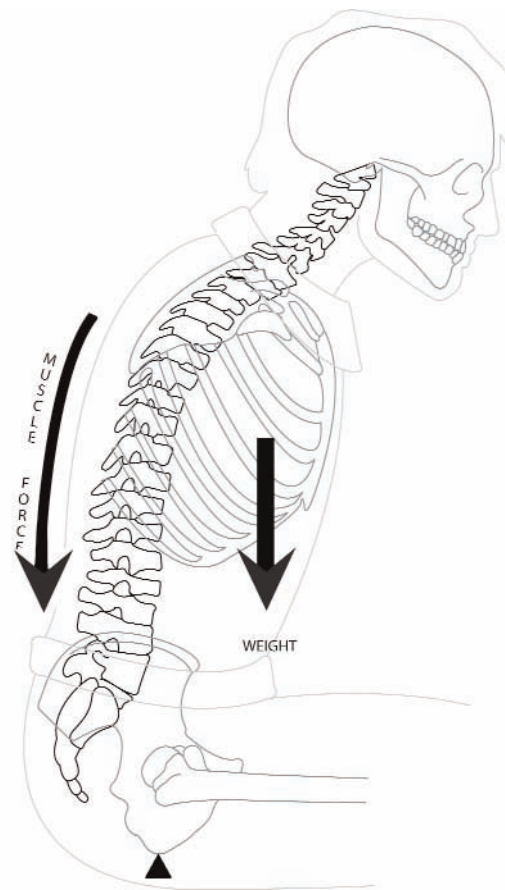


Figure 3: The back muscles exert force to balance body weight (Images used with permission and adapted from Chaffin & Andersson, 1984, Occupational Biomechanics).

A typical lumbar support is designed to support and hold a lordotic curve in the lumbar spine. This maintains disk pressure and back muscle exertion at low levels, particularly when the backrest is reclined from the vertical (Nordin & Frankel, 1989; Chaffin & Andersson, 1984).

The design of a lumbar support must take into account that each individual body is different as is each individual lumbar curve. To facilitate the design of things (such as chairs) that are meant to fit a range of people, e.g. from small to tall, scientists have gathered data that describe the variations in the size and shape of thousands of individuals. These data have been collected in anthropometric databases.

Chair designers use these databases to design seatbacks that will adjust to accommodate a wide range of sizes and shapes of individuals, typically between a small female (5th percentile) and a large male (95th percentile)¹.

¹Percentiles describe relative rankings. A woman whose height was equivalent to the 5th percentile would be as tall as, or taller than, 5% of the female population. A male whose height was equivalent to the 95th percentile would be as tall as, or taller than, 95% of the male population.

The first and fifth lumbar vertebrae form the ends of the lumbar curve; as people vary in size, so does the distance between these two endpoints. As might be expected, the size and shape of a chair's lumbar support will also need to vary in order to accommodate a range of sizes and shapes of individuals (Coleman et al, 1998).

If you looked at an x-ray of a spine with a lordotic lumbar curve and drew a straight line between its endpoints, the point where the distance between the straight line and the vertebrae is greatest is the maximum depth of the lumbar curve. When seated, the height of this point above the chair seat is the lumbar height.

Although they appear to be based as much on industry practice as on anthropometric data, two measurements, lumbar height and lumbar depth are of particular interest to chair designers. Common practice for the height adjustments for lumbar supports in chairs has been a 6 to 10 inch range in vertical height of the center of the support above the compressed seat pan (BSR/HFES 100, 2002; BIFMA G1, 2002; CAN/CSA-Z412, 2000) and a range of 0.4 inches to 1.8 inches for the lumbar depth (thickness

or in-and-out adjustment) (Tilley, 2002; BIFMA G1, 2002; CAN/CSA-Z412, 2000).

The left-right shape of the back and of the lumbar support has typically been assumed to symmetrically curve so as to uniformly wrap around the user's back (BSR/HFES 100, 2002; BIFMA G1, 2002; CAN/CSA-Z412, 2000; Tilley, 2002). However, the new data provided by Fredericks and Butt (2005) indicates that an asymmetric back support may provide more comfort.

Seating Comfort

What do we mean when we say that a chair is comfortable? Although it is common to think of comfort and discomfort as the opposite ends of a continuum, some researchers assert that they are two separate entities, one affective or aesthetic in nature; e.g., "I feel at ease, I like the chair" and the other more biomechanical in nature; e.g., "I feel as if my legs are heavy" (Zhang et al, 1996). While there may be disagreement as to whether comfort/discomfort is unidimensional or multidimensional, there is general agreement that it is subjective to each individual and that both physical and psychological factors will affect the perception of comfort (de Looze et al, 2003; Zhang et al, 1996).

Studies also suggest that the perception of comfort may be deceptive and that with repeated use or exposure, something that was initially comfortable may become uncomfortable. In a short chair evaluation checklist developed from the earlier Zhang et al (1996) study, Helander and Zhang (1997) found that statements such as "I like the chair, Chair looks nice, Chair feels soft, and Chair is spacious" were associated with a perception of comfort. These are very immediate in regard to the effect on the chair user. However, discomfort, associated in that study with statements such as "I have sore muscles, I feel stiff, I feel tired" is more likely to be reported after the passage of time. Helander and Zhang (1997) noted that there is an inverse relationship between high comfort and discomfort ratings, that is, high discomfort ratings are associated with low comfort ratings and high comfort ratings are associated with low discomfort ratings. They describe this as discomfort having dominance over comfort. Helander (2003) summarizes the distinction between comfort and discomfort as "Discomfort is based on poor biomechanics (chair design features such as seat pan depth, etc) and fatigue. Comfort is based on aesthetics

and plushness of chair design and a sense of relaxation and relief."

These findings underscore the need to carefully consider both comfort and discomfort when selecting an office chair. While a chair may be initially perceived as comfortable, poor biomechanics leads to an increase in the perception of discomfort over time driving away the initial perception of comfort (Zhang & Helander, 1997; de Looze et al, 2003; Chaffin and Andersson, 1984). Consequently, it is important to select a chair based on the experience of sitting in it for several hours rather than making a decision based on a first impression (Fernandez & Poonawala, 1998).

Objective Prediction of Comfort and Discomfort

DeLooze et al (2003) reviewed the literature regarding chair comfort and discomfort. They found 21 studies in which both subjective comfort or discomfort ratings were obtained at the same time as objective measures of comfort or discomfort. The seating studies looked at objective measurements such as posture, number of body movements, muscle activity via electromyography, pressure at the seat pan and backrest, spinal loading estimates, spinal shrinkage and foot volume change in both vehicular and office seating situations with regard to objective predictors for subjective comfort and discomfort.

Of all these, pressure distribution over the seat and back was the best objective predictor of subjective evaluations of comfort and discomfort for automotive and office seating. They also found that a lumbar support was required for both automotive and office seating; absence of lumbar support was associated with low back discomfort.

Consistent with the findings of Fredericks and Butt (2005), two of these studies associated varying pressure levels on the seat and back with comfort/discomfort. Yun et al (1992) found that uniform pressure was associated with discomfort and Kamijo et al (1982) found that varying levels of pressure on the seat and back were associated with comfort.

Summary

Providing support to help maintain the shape of an individual's lumbar curve while seated reduces the compressive loading to the structure of the spine as well as reducing the muscular

effort necessary to support the torso and decreases low back discomfort. Lumbar supports in chairs are generally designed with the assumption that humans are perfectly symmetric; however, asymmetry appears to be the norm rather than the exception. So new research indicating that seated chair users self-select asymmetric low back support in order to achieve maximal comfort indicates that asymmetric support appears to offer a new dimension in achieving comfort for seated office workers. Just as shoemakers learned to consider differences between the left and right feet in order to provide a comfortable pair of shoes, it now appears that designers of lumbar supports for chairs may need to consider asymmetry in order to maximize comfort while sitting.

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