# The Ergonomics of Adult Car Seat Design and Comfort

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## History of Ergonomics

The word ergonomics comes from two Greek words. Ergo meaning work and nomos meaning laws. Ergonomics can be thought of as the application of science in human life for comfort and safety.[1] Ergonomics studies the human fit and looks for ways to decrease fatigue and discomfort through product design.[2] When products fit the user, and are in line with the user's activity, the result can be increased productivity and less stress.

Ergonomics came about as a scientific discipline in the 1940s with the realization that the benefits of increasingly complex technical equipment would not be actualized if the users did not fully understand how to use these devices.[3] These user-machine issues first became prominent in the military sector where machine operators experienced increasingly physical and cognitive demands.[4] For example, concern about fatigue in munitions factories in the UK during WWI led to the creation of the Industrial Fatigue Research Board, which examined the effect of working conditions on health and efficiency.[4] In 1949 physiologists and psychologists came together to establish the Ergonomics Research Society (ERS), which became the first such professional body in the world.[4] Although early research was focused on work environments, the importance of ergonomics has become increasingly recognized in the design of consumer products such as cars and computers.[3] Over time, some differences in terminology came about in different countries.[4] In the USA the term human factors was used interchangeably with the UK term ergonomics. Popular usage of the terms resulted in human factors referring more to the cognitive areas of the discipline (perception, memory, etc.) whereas ergonomics may refer more specifically to the physical aspects (workplace layout, light, heat, noise, etc.).[4] In 2009 the Ergonomics Research Society was renamed the Institute of Ergonomics and Human Factors (IEHF) to demonstrate the popular usage of both terms and to highlight the breadth of the growing discipline.[4]

## On the Road

A new (2016) survey from the AAA Foundation for Traffic Safety found that American drivers spend an average of more than 293 hours behind the wheel each year.[5] That is roughly equivalent to seven 40-hour weeks at the office.[5] The number of miles driven for 2015 was a 2.4% increase from 2014.[5] A comparison of drivers in the USA and in Sweden found that 50% of those questioned in both countries, reported low back pain.[6] With increasing amounts of time spent driving, researchers are putting more effort into understanding the physiological and psychological consequences.

The term repetitive driving injury has been used to describe complaints such as foot cramps, low back pain, stiff neck, sore shoulders from poor posture, stress, and tension, which have been reported by drivers.[7] Repetitive driving injuries are a form of work-related musculoskeletal disorder (WMSD).[7] WMSDs are described as disorders of the muscles, joints, nerves, tendons, ligaments, cartilage, or spinal discs which mainly occur in the neck, back, arms, and wrists.[7] These disorders reflect gradual or chronic development.[7]

Epidemiological studies have shown that low back pain and lumbar disc herniation are positively associated with the amount of time spent driving. [8] In addition, prolonged exposure to driving cars has been identified as a risk factor for other musculoskeletal disorders (MSDs).[9] Individuals who drive cars as part of their job are at significant risk. This risk is increased for those who drive for 20 hours per week or more.[10] Increasing use of the car as a mobile office (e.g. using a laptop and making business calls), has other associated health risks.[9] Driving occupations make up several of the top 15 occupations with associated musculoskeletal disorders.[11] Gyi et al. found that within a group of business drivers, 65% reported low back discomfort, 43% neck discomfort and 40% shoulder discomfort.[9] Extended time behind the wheel has been correlated with low back trouble at greater risk than sitting and standing jobs or activities.[12] Gyi found that that people exposed to over 4 hours of driving per day were more than twice as likely to suffer from low back pain compared to those with over 4 hours of sedentary work per day.[13] From an economic perspective, low back pain related to driving contributes to the over $100 billion spent on low back pain each year in the United States.[11]

## Seating in Motion Versus Stationary Seating

There are quite a few important differences between what the body experiences while stationary sitting, for example at a desk, and sitting in a car seat. Stationary sitting allows body to be supported by both feet flat on floor and arms resting by sides or supported on arm rests. When a driver uses a steering wheel, their hands and arms are higher than while working at a desk.[14] Operating the brake and accelerator pedals requires extending the legs to a greater degree than stationary sitting.[14] The use of upper and lower extremities can be even more involved if driving a vehicle with manual transmission.[14] Driving places greater restrictions to posture in a more confined space than in a non automobile workspace.[15] Drivers experience the forces associated with deceleration and acceleration. Unlike individuals in non moving seats, drivers of automobiles are subjected to vibrations which are directly related to characteristics of the vehicle and of the road surface or terrain.[8] Vibrations are transmitted to driver's "buttocks and back of the occupant along the vertebral axis via the base and back of the seat".[8] The pedals and steering wheel transmit additional vibrations into the driver's body through the feet and hands.[8] Prolonged exposure to vibration can result in a range of physiological issues such as postural instability (weakening of lumbar musculature), cramps, motion sickness, and numbness, which can be exacerbated by being in a seated posture.[8,16] The presence of vibration in the motor vehicle environment has been cited as a potentiating factor in the increased presence of low back pain and disc herniations in drivers.[17] There is quite a bit of variation in the perception and tolerance of vibration.[17] General guidelines have been developed that suggest minimizing vibration transmission in the 4 to 8 Hz range.[17] In addition to vibrations, drivers also experience bumps, lateral forces as the vehicle turns, and awkward postures as they attempt to interact with items in the vehicle.

## Ergonomic Design Principles

Anthropometry is the science that seeks to measure the range of body sizes in a population.[2] The idea that the seat should fit the sitter is the most universally employed concept in seating ergonomics.[17] Anthropometric data vary considerably between regional groups.[2] For example, anthropometric data reflect that Scandinavian populations tend to be taller, while Asian and Italian populations tend to be shorter.[2]

Anthropometric measures for a given population are ranked by size and described as percentiles [2] In contrast to the idea of the seat fitting the sitter, it is common practice in ergonomic design that seats should accommodate the 5th percentile (small) female to the 95th percentile (large) male.[2,17] Modern vehicle marketing often takes a “one size fits all” approach and requires that seat designs accommodate more than 95 percent of the target user. [2,17]

Anthropometric databases compare people of different ages and occupations.[2] Databases can include information about static dimensions, such as lower leg length or functional dimensions such as reach.[2] The most commonly referenced database used in design is from military data collected in the1970s and 1980s, and is known as the ANSUR database.[2] However, there are important differences between the military and civilian populations, especially with regard to body weight and related dimensions.[18] In 2000, the Civilian American and European Surface Anthropometry Resource (CAESAR) was created by the Society of Automotive Engineers (SAE) to measure civilian populations in North America and Europe.[2] Many manufacturers utilize both databases to guide ergonomic design.[2]

In addition to fit parameters, which take into account ranges of population anthropometric measures, feel parameters and support parameters are also associated with seat comfort and ergonomic seat design.[17] Feel parameters are related to the physical contact between the sitter and the seat, affecting the local sensation of comfort. Examples of these parameters include pressure, shear stress, temperature, humidity, and vibration.[17] The sitter’s body detects the effects of the design feel parameters through nerve receptors in the skin and superficial underlying tissues.[17] Feel parameter levels are set using subjective user assessments and objective measurements made with tools which measure factors such as pressure and sweat impulse.[17] Due to the difficulty of obtaining objective measurements, these parameters are poorly understood.[17] One of the most frequently investigated feel parameter is the pressure distribution where the sitter meets the seat. Support parameters are intended to influence posture. [17] These parameters include the contour of the seat, the junction between the seat cushion and backrest, and seat adjustments.[17] An alteration in the contour of the backrest can change the backrest pressure distribution and may affect sitters differentially depending on their anthropometric dimensions.[17] In this example lumbar support brings about reaction forces which are directed into the sitter's lumbar spine.[17] This serves to highlight the interaction between the support parameters and the fit and feel parameters previously mentioned. Further discussion of research into feel and support parameters is provided later on in this section.

The growing rate of obesity in this country leads to different levels of discomfort and ergonomic risk for obese and overweight populations.[19] Research has shown that when ergonomic solutions have been implemented, the level of discomfort experienced by overweight and obese individuals may not decrease to the same level of normal weight individuals.[19] This concept highlights the importance updating anthropometric databases in an effort to create appropriately designed products, which can help to prevent pain and discomfort in this population.

It can be expected that different individuals sit in a variety of different postures and even the same person may greatly vary their seated posture over time.[20] Furthermore, particular cars and car seats may cause drivers to adopt a coping posture.[21] For example, limited headroom may cause a driver to assume a more reclined posture, making it more difficult to reach to the steering. [21] This setup leads to excessive forward bending of the head and neck and a slouched posture.[21]

## "Correct" Seated Posture

Correct seated posture is still debated amongst ergonomic professionals and researchers.[2,17] The objective is to reduce muscular activity and disc pressure and to distribute body weight over a large surface area in order to reduce surface pressure and increase comfort.[20] Some suggest that sitters need to have a 90-90-90 degree placement for the elbow, hip, and knee joints, respectively.[2] Andersson and Ortengren suggest that the backrest be reclined 20–30° from vertical, the seat cushion be inclined 14° from horizontal, and a 5 cm lumbar support in order to be optimally adjusted.[20] Others feel that a variation in this placement is better, as long as it does not lead to slouching or hunching over.[2]

## EMG and Disc Pressure

Electromyography EMG is a commonly used tool in the study of muscle activity as it provides a non-invasive index of the level of muscle activation. Andersson et al. conducted disc pressure measurements in conjunction with the EMG analyses.[22] They found that disc pressures were substantially higher in sitting than in standing.[22] Furthermore, they discovered that when the backrest angle is increased, a greater proportion of upper-body weight is transferred to the backrest, which reduces the amount of load carried by the lumbar spine.[22] Increasing lumbar support reduced disc pressure by producing a more lordotic lumbar curve and by slightly reducing back muscle exertion.[22] Results from this early study have shaped much of today's seating principles by showing the high disc loads experienced in sitting and demonstrating that disc pressure and muscle exertion can be reduced by altering the level and type of lumbar support.

## Studying Comfort

Studies suggest that there may be a link between discomfort and biomechanical and physiological measures.[23] These relationships have led to a multitude of recent research into how to make seating design and comfort more objective.[23] In order to objectively quantify discomfort, it is important to understand the potential causal mechanisms leading to reports of discomfort.

A successful seat design can be said to reduce discomfort and subsequent pathology due to poor sitting postures/positions.[17] Currently, published literature suggests that ergonomics criteria, particularly those related to physiology, cannot purely satisfy consumer comfort and may limit automobile seat design.[24] Kolich found disagreement between published anthropometric accommodation criteria and occupant preferences related to the height of the apex of the lumbar contour, seat back width, cushion length, and cushion width.[24] This highlights the continued need for research that takes into account target population comfort preferences.

Studies aimed at quantifying discomfort considered various factors such as anthropometry, physiological changes, vibration, pressure distribution, temperature, aesthetics, and kinematics.[23,25] Peter et al. found that anthropometric categories of age, height and weight were key dimensions that resulted in different levels of physiological responses in association with subjective discomfort values.[23] The neck, back, and lower extremities were identified as the main body regions found to have quantifiable connections to discomfort.[23] Physiological discomfort in the trapezius, upper and lower erector spinae, gluteus maximus and biceps femoris muscles was associated with these body regions.[23] Taller subjects were found to report more neck, upper back, and upper thigh discomfort.[23] Older subjects tended to report more low back pain.[23] Discomfort in the buttocks region was correlated with lighter subjects. [23] The authors suggest that there is a link between lighter people, higher pressure on the ischial tuberosities (due to less fat and muscle to pad the area), the shortening of the hamstring over time to adapt to increased pressures, a reduction in blood flow, and motion in order to alleviate the pressure from discomfort.[23] This study highlights the influence of anthropometric factors on physiological responses which lead to discomfort reporting during prolonged sitting.[23]

## Ideal Body Segment Angles

Overall body posture can be described by taking into account angles at the various joints that divide the body into a mechanical linkage.[17] A recent (2013) systematic review examined literature in the field of optimum and preferred human joint angles in automotive sitting posture.[25] The authors found distinct differences in methodological study designs, including angle definition and reference coordinate systems.[25] Results suggest a lack of consensus concerning the definition of optimum and preferred position.[25] Results also reflect a lack of consensus in the literature with regard to defined joint angles that are associated with improved comfort.[25]

## Seat adjustment and Gender Differences

Research by Jonsson et al suggests that when adjusting their own seats, females tend to sit more upright than males.[20] Females sit higher than males in both the frontal and rear part of the seat cushion.[20] The authors suggest that these findings may be due to females having shorter arms and torsos than men of the same stature.[20] In addition, every time they get in the car, females are more accurate in reproducing their seat settings than males.[20] Younger drivers can replicate their adjustments better than older drivers.[20] All drivers seem to be able to replicate the longitudinal (horizontal) component and backrest angle more reliably than other adjustments such as the height adjustment of rear edge of the seat cushion or the height adjustment of front edge of the seat cushion.[20]

## Replacement and Aftermarket Car Seat Options

Often times, the seat that comes stock in a new or used car may not be an ideal match for the driver. In this case, consumers may seek out more comfortable alternatives. Companies such as JC Whitney offer car seats (aftermarket and replacement) and car seat components so that consumers can modify and customize their seats for ideal comfort.[26] Sparco, Recaro and Corbeau are independent manufacturers of car seats which claim to incorporate ergonomic design, promote spinal alignment, and protect, for example, against lateral forces.[27–29] Several of Recaro's products have received the AGR (German Campaign for Healthier Backs) seal of approval.[28] Greiner is a small German company which seems to be one of the few makers of car seats designed specifically for tall individuals.[30] Companies such as Ride-Away and The Mobility Resource offer products like swivel seats, lift-up seats, and extended and lowered mobility seats which allow drivers with mobility limitations to access the driving environment with limited to no assistance.[31,32] These options are important for drivers regardless of the chronicity of their impairment (e.g. joint replacements versus partial paralysis).

## Car Seat Modifications/Accessories

While gels, foams and air do provide some relief of discomfort through perpendicular pressure reduction, they cannot protect against the harmful effects of friction, vibration, and shear stress present in the driving environment.[16] Research shows that wedge shaped seat cushions can reduce lumbar flexion and help users maintain lumbar lordosis.[33] Research suggests that lumbar seat supports that cyclically inflate and deflate may effectively reduce the development rate of low back discomfort experienced by equipment and vehicle drivers.[34] These findings are supported by earlier research showing that creep is developed in the viscoelastic tissues, when a static posture is maintained for 20 min with a constant load.[34] This displacement does not completely recover even after 7 hours of rest.[34] Grondin et al. found that lumbar support pillows improved an objective measure of comfort in healthy individuals as well as patients with low back pain.[35]

Companies such as Back Designs Inc., and Relax the Back offer car seat supports which are designed to fit a wide range of anatomies and car seat types.[36,37] Ergonomic accessories such as the McKenzie® Lumbar Roll™ have been developed for use in any seat that does not provide adequate lumbar support.[38] As the car itself can be difficult to alter, taller individuals can seek out resources such as Tall Life, which is a website which provides consumer reviewed information on how individuals can adapt their ergonomics to better suit their stature.[39] Detailed descriptions are provided for raised rear-view mirrors, extra tall car seats, car seat rail extensions, Fresnel lenses (which help to see traffic lights), and seat modifications to get more headroom.[39]

## Areas for Future Research and Development

Ergonomic design in the automotive industries is a huge area of research with many potential directions. Further research is needed to develop knowledge of how to quantify and predict comfort. Studies should consider the physiological responses to discomfort in conjunction with perceptual influences due to design, in order to further develop the understanding of the influence of seat design on discomfort.[23] Instructions for standardized measurement of reference lines and joint centers should be determined for use in future studies into optimal joint angles for automotive sitting posture.[25] More intelligent seat systems that attempt to improve comfort by continuous monitoring and modification of the seat surface pressure distribution should be developed. Further research is warranted in the realm of smart keys which retain anthropometric dimensions for different drivers of a given vehicle. Furthermore, seats that sense occupant dimensions and respond to driver comfort preferences may have a role in reducing discomfort. Increasingly intelligent seat systems that attempt to improve comfort by continuous monitoring and modification of the seat surface pressure distribution should be developed.

## Summary and Recommendations

Current research reflects little consensus on many components of car seat design principles. Furthermore, individual comfort preferences are difficult to assess and incorporate into ergonomic design. Based on analysis of information from research studies, automotive engineering reports, and the National Library of Medicine a series of requirements for “optimal” car seat design have been developed. The ideal car seat should have as many of the following capabilities as possible: [6,17]

1. Adjustable seat back incline
2. Changeable seat bottom depth (from seat back to front edge)
3. Adjustable seat height
4. Adjustable seat bottom incline
5. Seat bottom cushion with firm foam
6. Adjustable lumbar support (horizontally and vertically adjustable)
7. Depth pulsating lumbar support to reduce static load
8. Adjustable bilateral arm rests
9. Adjustable seat back incline
10. Adjustable head restraint with lordosis pad
11. Seat shock absorbers to dampen frequencies between 1- 20 Hz
12. Linear front-back seat travel to allow differently sized drivers to reach the pedals
13. Seat back damped to reduce rebounding of the torso in rear-end impacts

The author of this paper has created a guide to ergonomic car seating principles and evaluation.[40] The guide was developed for patients but can be utilized by anyone who would like to learn about how to improve their car seating experience.[40] Please refer to the attached guide for detailed figures and evidence based recommendations on car seat adjustments and modifications.[40]

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