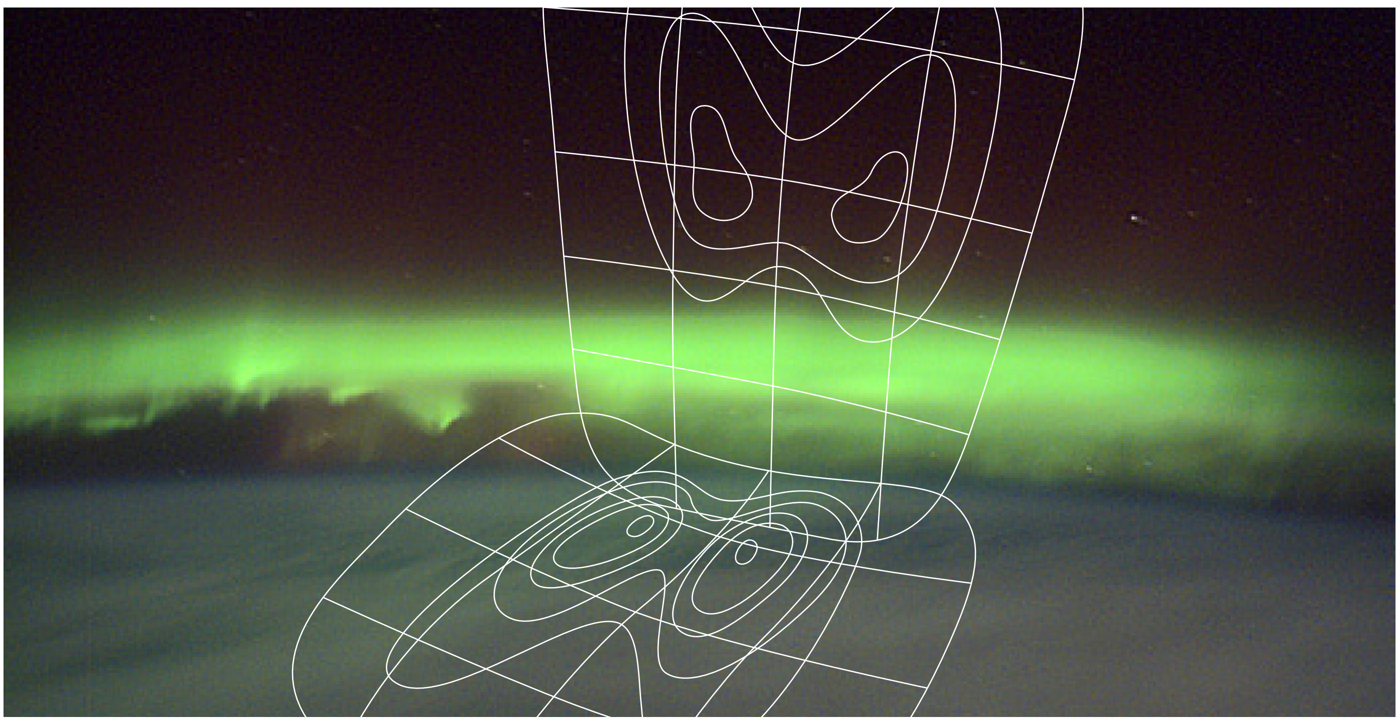
The Art and Science of Pressure Distribution

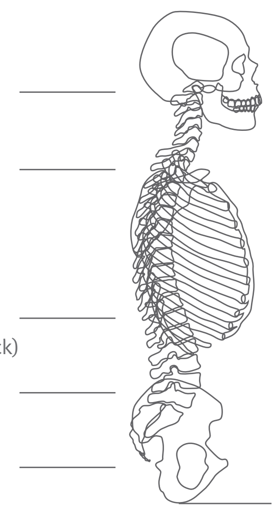
ERGONOMIC CRITERIA FOR THE DESIGN OF WORK CHAIRS



A chair should be topographically neutral. It should conform equally well to all body shapes, sizes, and contours without applying circulation-restricting pressure anywhere. While people of different body weights and builds distribute their weight on a chair in similar patterns, they are different when it comes to pressure intensity; this varies from person to person. The challenge is to engineer a chair so its structure and materials provide dynamic support. This allows the sitter's body, rather than the chair's structure, to dictate pressure distribution.

What We Know

Surface pressure can cause discomfort while sitting. People of different body weights and builds distribute their weight on a chair in similar patterns, but pressure intensity and areas of distribution vary from person to person. Good pressure distribution in a chair focuses peak pressure under the sitting bones in upright postures and in the lumbar and thoracic areas in reclined postures / See Figure 1 /.



/ Figure 1 / The human spine and pelvis

Correct pressure distribution is critical to seated comfort (Grandjean et al. 1973). A high level of surface pressure can constrict blood vessels in underlying tissues, restricting blood flow, which the sitter experiences as discomfort.

What may seem like a small interference in pressure distribution can have a profound effect. For example, sitting on a wallet may seem harmless, but Gunnar Andersson M.D., an orthopedic surgeon specializing in spinal and back injuries and chairman of orthopedics at Rush Presbyterian/St. Luke's Medical Center in Chicago, advises that there are severe consequences. "The wallet is in a place where, when you sit, it's pushing right on the sciatic nerve, and because of the position of the wallet, you're sitting off center, with one side higher than the other, so to sit up straight, you have to curve your spine. This puts an uneven load on the sacroiliac joints and on the lower back. It's a terrible idea to sit with your wallet in your back pocket."

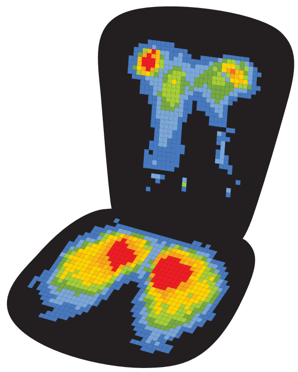
To measure these small differences in pressure distribution and their relationship to chair comfort, researchers have experimented with a number of technologies. Most recently, thin, flexible, pressure-sensitive mats connected to computers have been used to "map" the pressure-distribution properties of seating elements in office, automotive, and medical applications. These sensor-lined mats are draped over the chair's seat pan and backrest; when a test subject sits in the chair, pressure gradients show up as different colors on the computer screen, mapping the peak pressure zones experienced by the sitter (Reed and Grant 1993).

Using pressure maps to evaluate chair design is not a straightforward process; different people sitting in the same chair may exhibit very different pressure maps, depending on their weight and build. For instance, while heavier people generally show higher pressure peaks than lighter people, a heavy, pear-shaped person may exhibit lower pressure peaks than a lighter person with less internal padding to sit on (Reed et al. 1994).

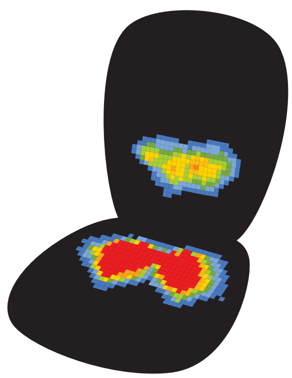
Because of the large variance in peak pressure patterns among people of different sizes and shapes, it is difficult to prescribe ideal seat and backrest contours or softness levels that would minimize uncomfortable pressure points for all sitters. We do know, however, that the skin and fat tissue under the ischial tuberosities, or "sitting bones," are less sensitive to pressure than the muscle tissue surrounding the tuberosities and better suited to carrying load than the other tissues of the buttocks and thighs (Reed et al. 1994).

In addition, chairs with backrests that exhibit pressure peaks in areas of the lumbar away from the spine have been judged more comfortable than chairs that show lower pressure gradients in these regions (Kamijo et al. 1982), although pressures resulting from a very firm lumbar support can cause discomfort (Reed et al. 1991a, 1991b). Our own research has found a strong correlation (r=.638; n=978) between overall seated comfort and the degree to which the sitter perceives the chair as providing good lower back support.

As a sitter changes postures from upright to recline, however, pressure distribution patterns change. How these patterns change is also a function of the chair's kinematics—the mechanics of how a body moves through space and the range of postures that the chair supports.



/ Figure 2 / Sitting in a reclined position in a chair with topographically neutral support distributes pressure across the thoracic area and away from the spine.



/ Figure 3 / Sitting in a sling-type chair puts pressure on the gluteus maximus muscles at the sides of the buttocks as well as on the heads of the femur bones and sciatic nerves.

Pressure mapping shows how seated body pressure is distributed. Red indicates peak pressure areas; orange, yellow, green, blue, and purple indicate decreasing pressure areas.

Therefore

A comfortable chair will produce pressure distributions for a wide range of users that show peaks in the area of the ischial tuberosities when the sitter is in an upright posture and areas of the back away from the spine when the sitter is in a reclining posture / See Figure 2 /.

Design Problem

Design a chair that is topographically neutral, so that the sitter's body, and not the underlying structures of the seat pan and backrest, determines peak pressure areas.

Chair designers try to minimize circulation-restricting pressure with the right combination of contour and padding, curving the chair's structure away from pressure-sensitive areas of the body and cushioning it with foam. This is difficult to achieve in a design that must serve a diverse user population. Seat shapes that work well for the bone structure and leg length of a tall male are likely to hit a short female in all the wrong places. Foam density that provides optimal comfort for a small, plump woman may "bottom-out" under a heavier but leaner man.

Extra padding does not necessarily solve the problem, because a too-soft seat can put pressure on the gluteus maximus muscles at the sides of the buttocks as well as on the heads of the femur bones and the sciatic nerves, resulting in the kind of discomfort experienced when sitting in a sling-type playground swing or a director's chair / See Figure 3 / (Zacharkow 1988, Hertzberg 1958).

Design Solutions

Engineer the chair so the structure and materials provide dynamic support for the sitter and fit differently proportioned persons.

Instead of foam cushions that may impose improper contours, a work chair with a topographically neutral suspension will conform to the shape of the person who sits in it. Using pressure-mapping technology, we experimented with different tensions across the backrests and seats, fine-tuning our designs to produce the desirable distribution patterns: peak pressure zones under the ischia, with wide distribution of lower values along the thighs and across the back, avoiding the spine and the area behind the knees.

We were particularly interested in achieving a wide distribution of pressure across the backrest. While the seat of a chair typically carries most of the body's weight, the more one reclines, the more weight is transferred to the backrest. We also know that a chair's tilt range and kinematics—and the extent to which they mimic the body's natural pivot points and more naturally transfer weight from the seat to the backrest—will encourage or discourage reclining. So the backrest may be called on to support a higher percentage of the sitter's body weight. During development of our work chairs, we tested subjects of varying heights, weights, and critical body dimensions in different chair prototypes, controlling seat height and back-angle reclinations. Experimenting also with varying levels of perforation and tension of the suspension material, we worked to achieve a pressure-distribution pattern for a variety of body types across the sitter's back, distributing weight away from the spine.

A topographically neutral seat and backrest, when designed to support a wide range of weights and proportions, ensured that people would get the benefits of the chair's carefully tuned pressure distribution. Positioned comfortably on a topographically neutral suspension material, the sitter's body, rather than the chair's structure, dictates pressure distribution.

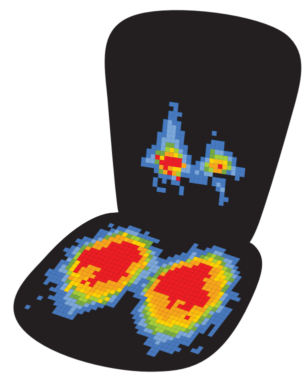
Pressure mapping technologies that measure the distribution of pressure across a chair's backrest and seat pan have been refined since they were first used in the development of the Aeron® chair. They now provide more detailed and accurate readings of the levels of pressure experienced by the sitter.

Although early pressure distribution maps were made with subjects always sitting in reclined postures, we now know that small changes in the tilt of the backrest can result in large differences in the way pressure is distributed across the sitter's back (Aissaoui et al. 2001). Using more advanced technology, we are now able to map and compare pressure distribution patterns in upright as well as reclined positions.

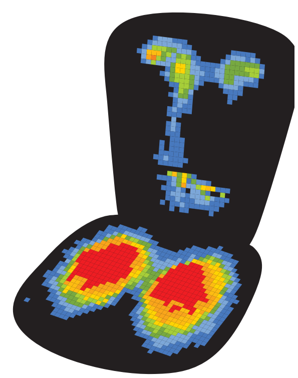
Understanding comfort and pressure distribution for sitters in upright postures has become more critical as a growing percentage of office tasks are accomplished using computer technology. Sitting behaviors research conducted by Herman Miller indicates that people performing computer-related tasks spend a greater percentage of their time in upright rather than in reclined postures (Dowell et al. 2001). Our understanding of optimal distribution patterns for people sitting in an upright posture has prompted us to look for particular patterns of pressure distribution depending on the sitter's posture.

Pressure map studies of sitters in upright positions show bands of localized pressure where the lower back comes into contact with the chair's lumbar support, but little pressure distribution across the rest of the back / See Figure 4 /. This stands in sharp contrast to pressure maps of sitters in reclined postures, which show distributed pressures in the thoracic area near the scapula and away from the spine / See Figure 2 /.

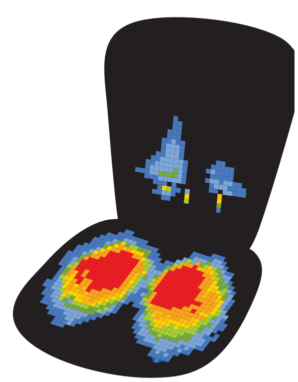
Hypothesizing that improved back support for upright postures would produce pressure distribution that more closely resembles that of reclining postures, we did pressure map studies of people sitting in topographically neutral suspension chairs with postural support. Chairs with sacral-pelvic support, designed to stabilize the



/ Figure 4 / Sitting in an upright position in a chair with lumbar support shows bands of pressure where the lower back comes in contact with the lumbar support.



/ Figure 5 / Sitting in an upright position in a chair with postural support distributes pressure across the sacral-pelvic, lumbar, and thoracic areas.



/ Figure 6 / Sitting in an upright position in a chair without postural support limits the distribution of pressure across the sacral-pelvic, lumbar, and thoracic areas.

pelvis, help to maintain natural spinal curvatures without applying pressure to the lumbar area.

Maps of chairs with postural support show that pressure is distributed over a greater area, including the sacral-pelvic and thoracic as well as lumbar regions of the back / See Figure 5 / than in chairs without posture support / See Figure 6 / or those with lumbar support only. Subsequent research investigated the possibilities for a "load-leveling" design for both a chair's seat and backrest. This work resulted in the development of the Pixelated Support™ system. In it, each component, or pixel, inherently conforms to the sitter's weight, distributing the mass evenly on the seat and backrest. As a result, sitters experience a sensory experience of flotation.

To test the combination of the Pixelated Support system and the kinematics used in the Embody™ chair, we commissioned a study by the ergonomics laboratory at a leading university. Subjects sat in an Embody chair and four other chairs with various backrest designs and performed four tasks in a random order. Pressure-sensitive mats draped across the chairs' backrests recorded the dynamic distribution and intensity of pressure throughout the trials.

As subjects' torso angles became more reclined, the center of pressure shifted vertically regardless of chair. The increase in the average contact area, from upright keying to reclined video watching, was greatest for the Embody chair. This suggests that, when reclining, the Embody backrest provides greater support to the sitter's upper back compared to other chairs. (University of California Berkeley, 2008).

The shift in the center of pressure that varies from person to person is certainly one consideration for work chair design. Another is the challenge of designing a topographically neutral chair. It conforms equally well to all body shapes, sizes, and contours. Yet, it doesn't apply circulation-restricting pressure anywhere. Reaching this goal requires successive advances in structure and materials that provide dynamic support. As these advances are commercialized, they bring us closer to the ideal—when the sitter's body, not the chair—dictates pressure distribution.

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Credits

Jerome Caruso is the designer of Celle® chair. Caruso's designs extend beyond seating and the workplace. As Sub-Zero's designer for over 20 years, Caruso has been influential in shaping the look and function of kitchen products and appliances. The innovative mind and design expertise of Caruso is evident in the more than 75 design patents he holds. Jerome and his son, Steven, designed Herman Miller's Reaction® chair in 1998.

Don Chadwick co-designed, along with Bill Stumpf, the groundbreaking ergonomic Equa® and Aeron® chairs for Herman Miller. He has been instrumental in exploring and introducing new materials and production methods to office seating manufacturers.

Bill Dowell, C.P.E., leads a team of researchers at Herman Miller. His recent work includes published studies of seating behaviors, seated anthropometry, the effect of computing on seated posture, the components of subjective comfort, and methods for pressure mapping. Bill is a member of the Human Factors and Ergonomic Society, the CAESAR 3-D surface anthropometric survey, the work group that published the BIFMA Ergonomic Guideline for VDT Furniture, and the committee that revised the BSR/HFES 100 Standard for Human Factors Engineering of Computer Workstations. He is a board-certified ergonomist.

Gretchen Gscheidle is a product researcher at Herman Miller. Educated as an industrial designer, Gretchen now applies her creativity and problem-solving skills in her role as researcher on cross-functional product development teams. She has been the research link in the company's seating introductions beginning with the Aeron® chair in 1994. Her research focuses on laboratory studies of pressure distribution, thermal comfort, kinematics, and usability, as well as field ethnography and user trials. Gretchen is a member of the Human Factors and Ergonomics Society and represents Herman Miller on the Office Ergonomics Research Committee. Her work has been published in peer-reviewed journals.

Studio 7.5, located in Berlin, Germany, designed the Mirra® chair. Studio 7.5 is composed of Burkhard Schmitz, Claudia Plikat, Carola Zwick, Nicolai Neubert, and Roland Zwick. With the exception of engineer Roland Zwick, the designers are cofounders and partners of the firm, which opened in 1992, and also teachers of industrial design and product design at universities in Germany. An interest in the tools that define how people work has led Studio 7.5 to design software interfaces, office seating, and medical equipment. Studio 7.5 has been collaborating with Herman Miller since the mid 1990s.

The late Bill Stumpf studied behavioral and physiological aspects of sitting at work for more than 30 years. A specialist in the design of ergonomic seating, his designs include the Ergon® chair, introduced by Herman Miller in 1976 and, with Don Chadwick, the equally innovative Equa and Aeron chairs. He contributed significantly to the design of the Embody chair prior to his death in 2006. In that same year, he posthumously received the National Design Award in Product Design presented by the Smithsonian's Cooper-Hewitt, National Design Museum.

Jeff Weber credits his love of furniture design to working with Bill Stumpf, who designed for Herman Miller for 30 years. Weber joined forces with Stumpf's Minneapolis firm in 1989. That led him to his association with Herman Miller. Weber worked with Stumpf on the Embody chair and, after Stumpf died in 2006, Weber evolved the design at his Minneapolis-based Studio Weber + Associates. In addition to the Embody chair, Weber's designs for Herman Miller include the Intersect® portfolio, Caper® seating, and the Avive® table collection.

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