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SURVEY OF AUTO SEAT DESIGN RECOMMENDATIONS FOR IMPROVED COMFORT

TECHNICAL REPORT

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16. Abstract

Seat design recommendations from a large body of literature are reviewed. Emphasis is given to Fit parameters related to anthropometric measurements, Feel parameters, including pressure distribution and vapor permeability, and Support parameters defined with respect to seated posture. Particular attention is given to appropriate lumbar support configurations. A discussion of the limitations of the basis for current design recommendations points to the need for future study of postures and spine contours selected by drivers. A comprehensive bibliography of related literature is provided in the Appendix.

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1.0 INTRODUCTION

There is a large body of literature devoted to the study of seating comfort. Åkerblom is widely credited with beginning the modern, scientific study of seating with his 1948 monograph on posture and chair design (Åkerblom 1948), although he cited over 70 previous publications related to his work. Since 1948, hundreds of papers on topics related to seating comfort have been published, many of which include recommendations for seat design to enhance comfort.

The seating literature contains more papers concerned with office and industrial seating than with automotive seating, probably because of the economic costs associated with discomfort and injury in the office and factory. However, the motor-vehicle environment is also a workplace, with the difference between the situations of a commuter and a professional driver being primarily the length of time in the seat, both cumulative and at a single sitting. Epidemiological studies have shown that low-back pain and lumbar disc herniation risk increase with the amount of time spent driving (Kelsey and Hardy 1975). The presence of vibration in the motor-vehicle environment has been suggested as a potentiating factor (Troup 1978).

Most of the research findings concerning industrial and office chair design can be applied to auto seat design. However, there are several important considerations unique to the mobile environment that should influence design recommendations. In particular, the control locations and sight line requirements serve to constrain postures to a greater extent than in most other seated environments. Safety concerns dictate that the driver be alert and continually responding to changing road conditions, and be positioned in such a way that the occupant restraint systems offer maximal protection in a crash. Passenger cars generally require a more extended knee posture than is necessary in other types of seating. This has important implications with regard to the orientation of the sitter's pelvis and lumbar spine. Additionally, vibration imposes tissue stresses that are not generally present in a stationary environment.

When attempting to specify design characteristics of a comfortable seat, it is important to have in mind a functional definition of comfort as it applies to seating. Branton (1969) has pointed out that it is unreasonable to assume, as some researchers have, that comfort extends in a continuum from unbearable pain to extreme feelings of well-being. Since a seat is not likely to impart a positive physical feeling to a sitter, the continuum of interest reaches from indifference to extreme discomfort. The best a seat can do is to cause no discomfort to the sitter. As Branton points out, this definition is useful, not only in the design of subjective assessment tools such as questionnaires, but also in consideration of strategies to improve comfort. The aim of chair design should be to reduce or eliminate factors causing discomfort rather than to elicit feelings of well-being. For the purposes of this report, comfort will refer to the absence of discomfort, so that an increase in comfort implies a decrease of stimuli leading to discomfort.

This report identifies seat design parameters that have been demonstrated to be, or are likely to be, associated with seat comfort, and recommends levels for these parameters. These recommendations are based on the cited sources and the experience of the authors. The design parameters are divided into three categories.

1. *Fit* parameter levels are determined by the anthropometry of the occupant population and include such measures as the length of the seat cushion.

2. *Feel* parameters relate to the physical contact between the sitter and the seat and include the pressure distribution and upholstery properties.

3. *Support* parameters affect the posture of the occupant and include seat contours and adjustments.

There is considerable interaction between parameters, both within and among these categories. For example, a change in backrest curvature (Support) will affect the pressure distribution (Feel) and also change the effective cushion length (Fit). However, this parameter categorization is useful because the knowledge required to specify parameter levels in each of these categories comes from distinct areas of research. Fit parameter levels are set with reference to anthropometric measures using data on the distributions of particular body dimensions in the population. Feel parameter levels are set using a combination of subjective assessments and objective measurements made with tools, such as pressure measurement mats and sweat impulse testers. Support parameters, which include lumbar support and backrest angle, are specified with reference to physiological measures related to internal body stresses associated with various postures. Data to support these parameter specifications have come from studies of back muscle activity, lumbar disc pressure, and spine radiographs.

For Fit parameters, there is considerable agreement among various researchers concerning the methodology to select an appropriate design value, if not the actual value. In these cases, the recommendations are adapted from those in two summaries of ergonomic seat design practice: Chaffin and Andersson (1991), and Reynolds (1993). Chaffin and Andersson present recommendations for office and industrial chair design; Reynolds discusses auto seats. As indicated above, there is considerable overlap between these areas. Where necessary, reference is made to the original source materials used in these summaries. Additional consideration is given to a contemporary design guide from General Motors (Maertens 1993). Comparisons are made between the auto recommendations in Maertens and the body of ergonomic literature directed toward general seating. In some cases, deviations from the Maertens design guide are recommended.

Feel parameters are the least understood because research tools to make objective measurements in this area have only recently become available, and because the subjective and complex nature of these parameters makes them difficult to specify in quantitative terms. The most frequently investigated of the Feel parameters is the pressure distribution at the interface between the sitter and seat. There is little agreement in the literature concerning desirable characteristics of a pressure distribution, except that areas of high pressure should be avoided. In Section 3 of this report, the findings and recommendations from a number of researchers are presented, along with the recommendations of the authors for applying the current body of knowledge to seat design.

The most controversial Support parameters pertain to "lumbar support," which generically refers to the contour of the lower half of the backrest that is assumed to provide stabilization to the lumbar portion of the spine. Although some seats are referred to as lacking lumbar support, any seat that contacts the sitter in the lumbar region provides some support to the lumbar spine. Consequently, the question is not whether a seat should have "lumbar support," but rather how the lower part of the backrest should be constructed to support the lower back optimally. Most research in this area has focused on physiological stresses associated with various spine postures. Backrest contours have been recommended that correspond to the back shapes found to result in reduced muscle and spine stress. However, evidence that these backrest contours actually produce the desired postures is sparse. Section 4 of this report describes some of the more influential studies concerning lumbar contour, backrest angle, pan (cushion) angle, and a few other seat design parameters related to support, along with recommendations based on the current state of knowledge in this area.

The following sections present a discussion of the relevant literature and recommended design values for each parameter. The recommendations are compiled in Section 6.0, along with figures illustrating the parameter definitions. The Appendix contains a large bibliography of literature related to comfort in automobile seats.

2.0 FIT PARAMETERS

The principle that the seat should fit the sitter is the most universally employed concept in seating ergonomics. People had used chairs for centuries before Åkerblom's 1948 monograph, relying on the experience of furniture makers to produce a match between the sitter and the seat. If a chair is to be used by only one sitter, careful measurements of that person's body will yield appropriate dimensional specifications for the seat. However, in the passenger car market, where a single seat must accommodate a large percentage of the population, knowledge of population anthropometry is required.

The constraints on Fit parameter design values are usually imposed by the desire to accommodate a sufficient range of the population on one anthropometric measure. A widely used design criterion is that the seat should accommodate the members of the population who lie between the 5th-percentile-female and 95th-percentile-male values on some anthropometric measure of interest. Note that it is not meaningful to refer to accommodating, for example, a 5th-percentile female, without specifying the dimension that is accommodated. For example, a woman who is 5th percentile in sitting height might have thighs that are shorter than 5th percentile for thigh length, so that she might be accommodated with respect to her view of the instrument panel, but experience uncomfortable pressure on the back of her knees from a seat cushion that is too long.

In general, Fit parameter levels are specified by noting the constraining values among the set of 5th-percentile-female and 95th-percentile-male values for particular anthropometric dimensions. In the case of cushion width, the 95th-percentile-female hip width is used as a specification limit, since this measure exceeds the 95th-percentile-male hip width. The case of cushion width is a good example of how parameter levels might appropriately be selected in practice. Using the methodology described above, the minimum cushion width would be chosen to be greater than the 95th-percentile-female seated hip breadth of 432 mm (Gordon *et al.* 1989). However, a larger minimum cushion width would be desirable, mainly because the anthropometric measure does not include clothing. Since an auto seat must generally be suitable for use in cold climates where heavy clothing is worn, a margin must be included for clothing thickness. Grandjean (1980) recommended a minimum cushion width of 480 mm, including clothing and an allowance for leg splay. A good design practice would be to provide clearance for a width of 500 mm at the hips. Note that this does not mean that the cushion itself must be this wide, but only that the clearance at the hip point should meet or exceed this value.

Other parameters should be considered in the same way as the cushion width. The procedure followed here is to (1) identify the members of the population who represent the extreme of the accommodation range (*e.g.*, small women), (2) select the relevant anthropometric values, (3) determine appropriate values for the selected anthropometric measurements, and (4) provide for *at least* that level of accommodation.

Some anthropometric values cited in this report are obtained from Gordon *et al.* (1989), a comprehensive anthropometric survey of military personnel. To the extent to which these data can be compared with civilian data (*e.g.*, Abraham *et al.* 1979), the data appear suitable for predicting U.S. population anthropometry. The much larger number of anthropometric measures available in the military survey make those data more useful than the civilian data for specifying seat fit dimensions. However, in comparison with the driving population, the military sample has a narrower age range and probably includes subjects who are more physically fit, on average, than the general population. These limitations should be considered in applying recommendations based on these numbers.

2.1 Cushion Width

Cushion width is specified to accommodate the largest sitting hip breadths in the population, with additional clearance for clothing and movement. The constraining population segment is large females, who have a 95th-percentile seated hip breadth of 432 mm in the Army data. However, Chaffin and Andersson (1991) cite a study of 143 women aged 50–64 years who had a 95th-percentile hip breadth of 457 mm. The higher number might be more representative of the driving population than the military data taken from younger subjects. Schneider *et al.* (1985), in a study of driver anthropometry, reported an average seated hip breadth of 439 mm in 25 males who were approximately 95th-percentile by stature and weight. This is slightly larger than the 95th-percentile-female hip breadth in the Army data. Grandjean (1980) recommends 480 mm as a minimum clearance at the hips to accommodate large females with an allowance for clothing. The 480-mm value should be considered to be a minimum to accommodate the population at a single position on the seat. Maertens (1993) recommends a minimum overall cushion width of 500 mm, but does not specify the position at which this dimension is to be measured. Chaffin and Andersson (1991) cite recommendations from a variety of sources for office chair widths between 400 and 480 mm. Since freedom of movement is desired to allow for posture changes, 500 mm is recommended as the minimum clearance at the hips.

This does not mean that the seat cushion itself must be 500-mm wide at the hips. An actual cushion width of 432 mm should be adequate for a single posture, provided that 500-mm clearance is provided for the hips in the area between 50 and 150 mm above the depressed cushion surface. This requirement primarily constrains the positioning of side bolsters and frame components within 250 mm of the seat centerline. In considering lateral clearance, it is important to make measurements with reference to the depressed seat surface. Seat structures that do not pose a lateral obstruction on the undepressed seat may contact the sitter's hips when the seat cushion is depressed. Further, the seat cushion should deflect evenly across a lateral section at the hips. If the cushion is stiffer at the outer edges because of interference from seat structures, a hammocking effect will constrict the sitter's buttocks, causing the seat to feel too narrow even if the dimensional specifications are met.

The forward part of the cushion should allow the legs to splay at least as wide as the recommended minimum hip clearance of 500 mm. Leg splay can be used by the sitter to change the pressure distribution on the buttocks by redirecting load away from the ischial tuberosities (see Section 3.1) and should not be overly restricted by side bolsters.

Summary

Seat cushions should be a minimum of 432 mm wide, with 500 mm minimum clearance at the hips. The front of the cushion should be a minimum of 500 mm wide to allow for comfortable leg splay.

2.2 Cushion Length

Cushion length is an important determinant of comfort for several reasons. First, a cushion that is too long can put pressure on the back of the sitter's legs near the knee, an area that has many superficial nerves and blood vessels. Pressure in this area will lead to local discomfort and restricted blood flow to the legs. Second, a cushion that is too long will pull sitters forward, away from the backrest, eliminating the possibility of providing appropriate lumbar support. Third, a long cushion can restrict leg splay by interfering with knee movement, and may impede posture changes that alter pressure distributions under the buttocks and upper thighs.

Cushion length is constrained by the buttock-to-popliteal length of the small-female segment of the population. This dimension is measured on the seated subject from the rearmost projection of the buttocks to the popliteal fold at the back of the knee. Gordon *et al.* (1989) report a 5th-percentile-female buttock-to-popliteal length of 440 mm. For general chair design, Chaffin and Andersson (1991) cite recommendations for cushion length, measured from the furthest forward contact point on the backrest to the front edge of the chair, of 330 to 470 mm. Grandjean (1980) recommends 440 to 550 mm, while Keegan (1964) recommends 432 mm. Maertens (1993) specifies that the cushion should not extend more than 380 mm forward of the H-point (hip point), which is a seating reference point approximating the hip-joint center location of a male sitter who is 50th percentile by height and weight (see SAE J826). Some calculations are necessary to compare the Maertens recommendations with those of other researchers.

In a study of driver anthropometry, Schneider *et al.* (1985) recorded the postures of small females, mid-sized males, and large males in representative passenger car seats. The small-female sample in that study was approximately 5th percentile by height and weight. Buttock-to-knee length (measured to the *front* of the knee, rather than the popliteal fold) was 527 mm, compared with a 5th percentile for that measure in the Army data of 542 mm. The latter subjects can therefore be considered reasonably representative of the U.S. small-female driver population with respect to thigh length. From the Schneider *et al.* (1985) measurements taken with small-female subjects in a contoured hardseat, the distance from the H-point to the back of the buttocks on a line connecting the knee joint and hip joint is approximately 135 mm (*cf.* the same measure on the "Oscar" 2-D seating template (Geoffrey 1961) of about 145 mm). Maertens' maximum cushion length recommendation is measured horizontally from the H-point to the forward-most point on the cushion. Assuming a thigh angle of 15 degrees, Maertens' 380-mm horizontal measurement represents 393 mm along the thigh. Adding 135 mm to account for the distance from the H-point to the back of the buttocks, the buttock-to-popliteal clearance is 528 mm as shown in Figure 1. Since 528 mm is substantially greater than the 5th-percentile-female buttock-to-popliteal length of 440 mm, this analysis suggests that the Maertens recommendation is not sufficiently conservative to accommodate smaller subjects. In fact, 528 mm is greater than the buttock-to-popliteal length of 80 percent of the male subjects in the Army survey (80th-percentile male = 523 mm).

Summary

The cushion length, measured along the thigh line, should not exceed 440 mm from the depressed backrest, or 305 mm from the H-point. An adjustable-length cushion could be used to provide more under-thigh support for larger people, but only a small range of adjustability is needed. The 95th-percentile-male buttock-to-popliteal length is 545 mm, 105 mm greater than the 5th-percentile-female length, so a seat-cushion length increase of 105 mm should be considered the maximum necessary. For sitters with long legs, the cushion may feel too short if the thigh angle relative to the horizontal is substantially greater than the cushion angle, so that only the buttocks are in contact with the seat. These sitters will be accommodated better by an adjustable cushion angle than by a greater cushion length.

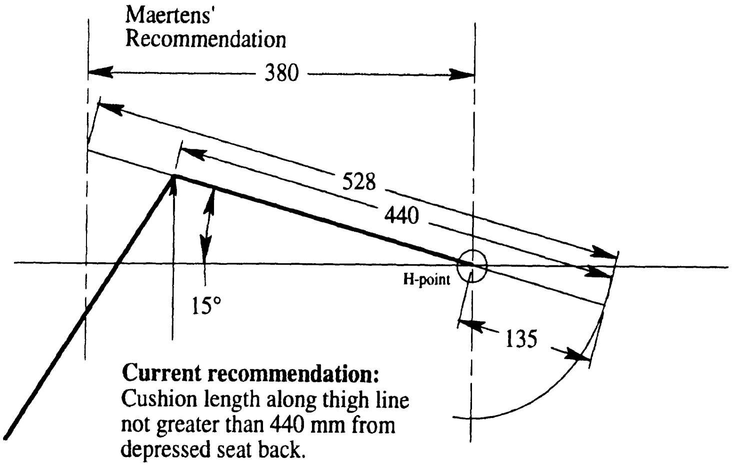

Figure 1. Comparison of Maertens' (1993) and current recommendations for maximum cushion length. (Dimensions in mm -- see text for explanation.)

2.3 Backrest Width

Minimum backrest width at the waist level is constrained by the back width of the large-male segment of the population. At waist height, 95th-percentile-male back width measured on a standing subject is 360 mm in the Army survey. In the Army survey data, 95th-percentile-male seated waist height (above the rigid seat surface) is 315 mm. Schneider *et al.* (1985) report a seated waist breadth of 361 mm for large males (approximately 95th percentile by height and weight). Consequently, the recommended width at the narrowest part of the backrest, 315 mm above the depressed seat cushion or 220 mm above the H-point, measured along the H-point manikin backrest line, is 360 mm. (The vertical distance relative to the H-point was calculated by assuming a 95-mm distance from the point of maximum deflection of the seat surface to the H-point.) In practice, the minimum backrest width should be larger to allow for posture changes and clothing.

The backrest width above and below the waist level should be larger to accommodate the greater hip width below and chest width above. In the upper part of the backrest, the minimum backrest width should provide support for the width of the chest of a large male when reclining. The interscye distance, measured across the back between the posterior axillary folds, is an appropriate anthropometric reference measurement. In the Army data, the 95th-percentile-male interscye distance is 456 mm. (Although this measurement was taken with a tape measure held against the skin, it is sufficiently close to the linear distance to be used for current purposes.) The sitting height of the posterior scye was not measured in the Army survey, but Schneider *et al.* provide posterior scye height for large males in an automobile seating posture. Using the trochanterion height from Schneider *et al.* as an approximation of H-point height, the vertical distance from posterior scye to H-point for large males is approximately 295 mm. Assuming a

22-degree back angle, the measurement along the back line is 318 mm. These data suggest a minimum backrest width of 456 mm at a distance of 318 mm above the H-point measured along the manikin back line. As with the seat cushion width recommendations, a value larger than the minimum presented here is desirable to allow for a range of postures.

Since the effective backrest width is integrally tied to the backrest contour, some discussion of lateral contour is necessary in this context. The contour of the backrest behind the shoulders of the sitter should be nearly flat to avoid interference with arm movement. The sitter should be able to extend his or her inboard arm straight to the side without interference from the seat. The maximum height of lateral supports or "wings" on the backrest can be determined by estimating the posterior scye height of small women. Using data from Schneider *et al.*, the posterior scye height for small females (approximately 5th-percentile female by height and weight) is about 30 mm lower along the back line than the large-male scye height, or about 288 mm above the H-point along the back line. Consequently, any lateral contouring or wings should not extend more than 288 mm above the H-point along the manikin back line.

Reynolds (1993) uses the 95th-percentile-male chest width of 367 mm to specify minimum width in the upper part of the backrest. However, the chest width in the Army data cited by Reynolds is an anterior measurement that is smaller than the posterior measurement, which includes the width of the latissimus muscles. Grandjean (1980) recommends 480 mm for backrest width, which is compatible with the upper-back width obtained from the above analysis of large-male anthropometry. Most of the recommended ranges for backrest width cited by Chaffin and Andersson (1991) for office chairs range between 360 and 400 mm. Typically, a narrower backrest would be desired in an office chair than in an auto seat to provide for greater upper-torso mobility in a larger work envelope. In an auto seat, a wider backrest provides more lateral stability for the sitter during cornering maneuvers.

Maertens (1993) specifies lateral radii of curvature rather than widths for the backrest, and specifies different radii for different vehicle types, from sporty to luxury cars. These radii may be compared to the widths specified above by considering a particular body depth and calculating the clearance provided at that depth by the specified radius. For sporty cars, Maertens recommends a minimum lateral contour radius of 300 mm at a lumbar height of 250 mm above the depressed seat surface. From the Army survey, the 95th-percentile-male abdominal extension depth is 290 mm. Taking one-half this value as a representative depth for the widest part of the abdomen gives 145 mm as shown in Figure 2. On a line 145 mm forward of the maximum backrest indentation, the effective backrest width with a 300-mm radius is 514 mm, substantially greater than the 360 mm necessary to accommodate the 95th-percentile-male waist width. Since the Maertens recommendations for other types of cars are 450-mm and 800-mm radii, a large percentage of the population will be accommodated by these recommendations. Maertens also recommends that the thoracic section of the backrest, 321 mm above the H-point along the manikin back line, have a nearly flat lateral contour, specifying a 1-meter minimum radius of curvature for the contour in that area.

Summary

The backrest should be a minimum of 360 mm wide at a point 220 mm above the H-point along the manikin back line, and a minimum of 456 mm wide at a point 318 mm above the H-point. There should be no lateral clearance restrictions (*i.e.*, no side bolsters) extending more than 288 mm above the H-point.

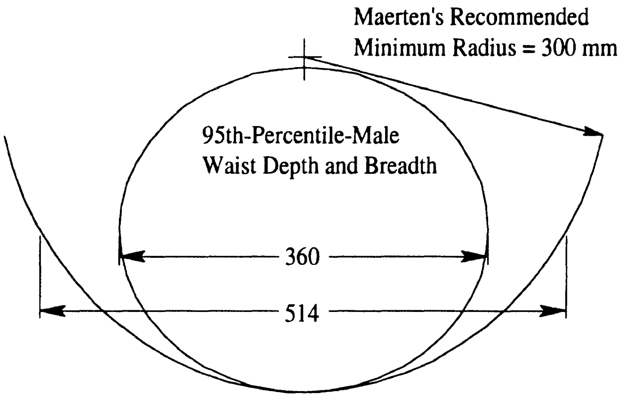

Figure 2. Illustration of compatibility between Maertens' (1993) lateral backrest contour specification for 250 mm above the depressed seat surface and 95th-percentile-male waist dimensions. Waist cross-section is shown as an ellipse--actual configuration is flatter toward the rear.

2.4 Backrest Height

Backrest height requirements are affected by geometric constraints imposed by FMVSS 202 (U.S. Office of the Federal Register 1992) dealing with head restraints for protection in rear impacts. Within these constraints, there is only a small range of backrest heights that can be specified. From strictly anthropometric considerations, the backrest should be as high as possible without restricting rearward vision for small drivers. The acromial (shoulder) height is a reasonable anthropometric measure to use to set the parameter level. The 5th-percentile-female acromial height is 414 mm above the H-point, while the 95th-percentile-male acromial height is 551 mm above the H-point (Gordon *et al.* 1989). For comparison, the 5th-percentile-female eye height is 590 mm above the H-point. Thus, backrest heights within the range of 5th-percentile-female to 95th-percentile-male acromial heights will adequately accommodate the population. Note from the previous discussion of backrest width that the 95th-percentile-male posterior scye height is 318 mm above the H-point, so that a backrest designed to the 5th-percentile-female acromial height (414 mm) will still provide substantial upper-back support to a large male.

Maertens (1993) recommends that the termination of upper back contact with the seat (using a design manikin) should be 450 to 500 mm above the H-point, or 545 to 595 mm above the depressed seat surface, depending on the style of the seat. This range will provide adequate upper-back contact for large males. Grandjean (1980) recommends a 500-mm backrest height, or 405 mm above the H-point.

Summary

The backrest should extend 410 to 550 mm above the H-point, measured along the manikin back line.

3.0 FEEL PARAMETERS

Design parameters that affect the local sensation of comfort at the interface between the sitter and seat are called Feel parameters. As noted above, this analysis assumes that comfort is the absence of discomfort, so that optimal levels for Feel parameters are those that minimize discomfort. The possibility that the surface texture of the seat may promote, for example, a feeling of luxury, is not considered here.

The effects of Feel parameters are detected by nerve receptors in the skin and superficial underlying tissues. Four stimuli applied to the skin surface are important contributors to local tissue discomfort.

Pressure (force directed normal to the skin surface) is generated whenever the tissue bears external load. Of course, the skin is continually under hydrostatic pressure from the atmosphere, but this pressure does not cause discomfort. In fact, the skin and underlying tissues are remarkably impervious to hydrostatic pressure (equal components in all directions) as when submerged in water. Body tissues can readily tolerate up to 240 psi (12400 mm Hg) hydrostatically, equivalent to 500 ft under water. However, uniaxial local pressure of as little as 1 psi (50 mm Hg) can cause pathological changes in body tissues (Chow and Odell 1978; Husain 1953). The physiological effects of surface pressure in seating are due to deformation of the skin and underlying tissues, resulting in occlusion of blood vessels and compression of nerves. Pressure on nerves can cause discomfort immediately, while loss of blood circulation leads to discomfort as cell nutrition is interrupted and metabolites build up in the tissues. The state of stress in body tissues produced by application of external pressure can be decomposed into a combination of hydrostatic and shear stresses. Chow and Odell (1978) point out that since body tissue is relatively impervious to hydrostatic stress, it is the shear stress and accompanying deformation that are harmful.

Shear stress results internally whenever a uniaxial load is applied to the skin, as is the case in sitting when pressure is applied to the dorsal surfaces of the buttocks and thighs. As indicated above, the primary cause of discomfort associated with external pressure is the shear stress and deformation that result internally. Shear stresses applied externally (surface friction) have a compounding effect, producing larger tissue deformations than the surface pressure alone. External shear stress often occurs in seating, particularly under the buttock area when the torso is reclined.

Temperature can affect the local feeling of discomfort, with both high and low temperatures being perceived as uncomfortable. Both the foam padding and surface material of the seat affect the skin temperature at the interface.

Humidity interacts with temperature to influence discomfort. Perspiration that is trapped against the skin by the upholstery can produce a sticky feeling if the skin is warm, or a clammy feeling if it is cold. Both the foam padding and the surface covering of the seat are important determinants of local humidity on the seat.

The Feel parameters described above are discussed in greater detail in the following sections. Pressure and shear stress are considered together because their discomfort-causing mechanisms are closely related. Similarly, local temperature and humidity are usually measured simultaneously and are discussed together. Because of the difficulty in measuring the objective levels of these stimuli, as well as the relationships between the stimuli and discomfort, the recommendations in this section are more qualitative than in those sections dealing with Fit and Support parameters.

3.1 Pressure and Shear

Seat surface pressure has been pursued for decades as an objective measure that might be suitable to predict the comfort of seats (*e.g.*, Lay and Fisher 1940; Ward and Southall 1993). Measurement equipment has included a matrix of spring-loaded nails (Reswick 1961), strain gages (Thier 1963), inductive force transducers (Diebschlag and Müller-Limmroth 1980), a light-transmission Pedobarograph (Treaster and Marras 1989), and flexible tactile sensors (Podoloff 1993).

The appeal of the seat surface pressure distribution as an objective measure of the comfort of a seat is that (a) pressure sensors produce data with high numerical resolution, (b) excessive pressure is anecdotally and experimentally associated with discomfort, and (c) excessive pressure can cause pathology (*e.g.*, decubitus ulcers or bedsores). Consequently, there appears to be a simple linkage between the stimulus, the physiological response, and the psychological response. However, the actual relationship has been found to be more complex.

There are two primary methods by which researchers have attempted to link discomfort and pressure distribution. The first and most common procedure is to measure the pressure distribution for a variety of seats or sitting conditions for which subjective comfort assessments are also obtained (*e.g.*, Lay and Fisher 1940; Kamijo *et al.* 1982; Date 1988; Lee and Ferraiuolo 1993). Regression analysis can be used to identify relationships between discomfort and pressure levels in particular body areas, *e.g.*, under the ischial tuberosities. An alternative method is to evaluate the comfort of a large number of seats and then to compare the overall pressure distributions of seats judged to be "comfortable" with those considered "uncomfortable." Kamijo *et al.* (1982) present an example of the latter method. The pressure distribution produced by a mid-sized Japanese male was recorded on 40 seats that were previously evaluated subjectively by a panel of fifteen people. The authors do not report the duration of the discomfort evaluation trials. The differences in the pressure distributions between seats categorized as "comfortable" and "uncomfortable" were used to recommend levels of pressure at particular seat locations.

There are some important limitations to the method of Kamijo *et al.* First, there is little evidence that the specific aspects of the pressure distribution that were selected for emphasis (*e.g.*, the pressure in the lower-back area) contributed substantially to the overall comfort of the seats. Second, comfort ratings obtained during a short-duration, static assessment may not be representative of the long-term comfort of the seat, which might be affected more strongly by the pressure distribution. These limitations are inherent in the regression method since a linkage between local pressure and discomfort is assumed, but a mechanism is not demonstrated.

The second approach to specifying appropriate pressure distributions is to consider the physiological response of the skin and underlying tissue to the application of pressure. This area of investigation has received considerable emphasis in the medical and rehabilitation literature because of the clinical importance of pressure sores for insensate and paralyzed patients (*e.g.*, Bader *et al.* 1986; Chow and Odell 1978; Drummond *et al.* 1982; Hobson 1992; Rosemeyer and Pförringer 1979; Sacks *et al.* 1985; Shields and Cook 1992). Application of guidelines developed for these purposes to the design of vehicle seats for the entire driving population is problematic for several reasons. Able-bodied sitters detect interference with blood flow as discomfort and shift their postures, if possible, to reduce the discomfort by relieving the pressure. People at risk for pressure sore formation are generally insensate or incapable of voluntary pressure-relieving movement, so the duration of application of high pressures is greater. The duration of pressure application determines the maximum pressure that can be sustained without tissue damage. People who remain in one posture for longer periods of time, *e.g.*, wheelchair users, require lower maximum pressure levels than able-bodied sitters to avoid pressure sore formation. In general, able-bodied sitters can tolerate higher pressure loading, provided they are able to shift postures to relieve pressure. Hence, different criteria should be used to design seating for the able-bodied and insensate/immobile populations.

The aspects of the medical studies of pressure sore formation that are most applicable to seating for the general population concern the physiological effects of surface pressure and shear on tissue ischemia (Husain 1953; Kosiak 1961). Surface pressure has been found to occlude blood vessels in the underlying tissues, particularly near bony prominences such as the ischial tuberosities. The level of pressure necessary to cause occlusion depends on many factors, including the structure of the tissue (muscle, fat, etc.) and the shape of the loading surface.

It may seem that the most reasonable way to use seat surface pressure data to improve seat design would be to modify the seat to reduce the peak pressures and pressure gradients to the extent possible. Underlying such an approach must be an assumption that the various body regions in contact with the seat have equal tolerance to pressure. This, however, is not the case. Many researchers have sought to identify "physiologic" pressure distributions that direct the load to the various body tissues proportionate to their ability to withstand that load without discomfort (*e.g.*, Lay and Fisher 1940; Åkerblom 1948; Rosemeyer and Pförringer 1979; Diebschlag and Müller-Limmroth 1980). The primary finding has been that the tissue over the ischial tuberosities, typically the site of the peak pressure in sitting, is better suited to carrying load than the other tissues of the buttock and thigh.

When a person is seated, the large gluteal muscles are pulled to the side of the ischial tuberosities by flexion of the hip joint and pressure from the seat surface, leaving a flesh margin of only a few centimeters over the ischii. These areas will bear a substantial part of the body weight if the seat surface is flat and firm. Local pressures at the tuberosities have been reported as high as 60 psi for heavy, lean subjects on a flat, rigid pressure measurement device (Hertzberg 1972). Although sustained high pressure over the tuberosities will cause discomfort, the overlying tissue is less sensitive to pressure than the muscle tissue surrounding the tuberosities. Muscle responds to pressure with ischemia and a burning sensation at lower pressure levels than does the skin and fat tissue overlying the tuberosities.

A desirable seat cushion pressure distribution will therefore maintain the peak pressures in the area of the ischial tuberosities. There are few recommendations in the literature for the magnitude of the peak pressure. Diebschlag *et al.* (1988) specifies that pressures under the tuberosities should be 1–3 N/cm^2 (10–30 kPa, 1.4–4.3 psi) and 0.8–1.5 N/cm^2 (8–15 kPa, 1.2–2.2 psi) in the area around the tuberosities. Large variance in peak pressure across sitters can be expected since peak pressure is strongly dependent on body weight and build. For example, heavier people will generally exhibit higher pressure peaks, but heavy people with substantial fat tissue in the buttock area may experience lower pressure peaks than lighter, but leaner, sitters. Because of this variability, it is probably unreasonable to specify a target value for peak cushion pressure without also including a description of the population for which that value is appropriate. Further, some sitters with little internal padding will be more sensitive to peak pressures than others because they will experience greater internal tissue stresses under the same pattern of external stress.

As noted above, surface pressure that is not evenly applied over the skin surface (nonhydrostatic) produces shear stress and strain in the tissue (Chow and Odell 1978). This resultant shear, rather than the normal stress, is probably responsible for the ischemia and discomfort produced by sustained pressure. When shear is applied directly to the surface of the skin, the problem is compounded. Hobson (1992) reported that the application of surface shear can reduce the pressure required to occlude blood vessels by nearly half. Surface shear results when the support force generated by the seat is not normal to the skin surface. The most common site of surface shear is under the buttocks, where a rearward-directed shear force acts to keep the sitter from sliding forward out of the seat. Hobson (1992) investigated the effects of posture on the pressure distribution and aggregate seat cushion shear force for twelve spinal-cord-injured and ten able-bodied subjects. Reclining the backrest while holding the seat-cushion angle constant was found to increase the shear on the seat cushion. For example, a flat seat cushion coupled with a 20-degree back angle increased the cushion shear by 25 percent over the erect seated condition. Angling the seat pan upward as the back angle is increased reduces this effect.

Since back angles in auto seats are typically 20 to 25 degrees, substantial surface shear will be generated on the seat pan if the cushion is not angled and contoured appropriately. When the cushion is angled up, or the cushion is contoured to achieve the same net effect, the normal force against the buttocks and thighs has a rearward component that acts to reduce the surface shear required to maintain the posture. However, the cushion should not be angled excessively because the trunk/thigh angle may become uncomfortably small and posture change (as well as seat ingress/egress) may become difficult. Preferred angles for cushion and backrest in the automotive environment are discussed below in Section 4.

Summary

The lack of consensus regarding the relationship between pressure distribution and discomfort, even after decades of research, may be discouraging for the seat designer. However, there are several seat design guidelines relating to pressure distributions that are justified by the current state of knowledge.

1. A good seat cushion will produce pressure distributions for sitters with a wide range of anthropometry that show peaks in the area of the ischial tuberosities with gradual decreases in pressure toward the front and sides of the cushion. The pressure under the distal half of the thigh (*e.g.*, from 200 mm forward of the H-point to the front of the seat) should be minimal. Åkerblom (1948) and others have pointed out that the under-thigh tissue has minimal resistance to deformation until the tissue nears its compression limit against the femur, leading to considerable restriction of circulation and consequent discomfort. Particular attention should be paid to the pressure distributions of short persons, who are more likely to encounter interference from the front edge of the cushion.

   A reduction in the pressure gradient is also desirable, since the pressure gradient is likely related to internal shear. Typically, a high pressure gradient would be observed near the tuberosities on a very firm cushion. Softening the cushion slightly would reduce both the peak pressures and the gradients.

2. Backrest pressure distributions should show peaks in the lumbar area. Kamijo *et al.* (1982) found lumbar pressure peaks of about 2.5 kPa in seats judged to be comfortable compared with lower values in uncomfortable seats. A backrest with adequate lumbar support will produce pressure peaks in the lumbar area, but excessively high pressures due to a very firm lumbar support can lead to discomfort in long-term sitting (Reed *et al.* 1991a, 1991b).

3. Some sitters will produce relatively even pressure distributions, even on hard seats, because of ample physiological padding, while other more lean subjects will produce high pressure peaks even on a well-padded seat. Since the former are not likely to experience discomfort because of excessive local pressure, it is reasonable to restrict many pressure distribution investigations to specific subpopulations who are particularly sensitive to changes in seat cushioning, namely, heavy, lean subjects, and small subjects for whom cushion-leg interference is more likely. Seats designed to meet the pressure requirements of these sitters are likely to be acceptable to others as well.

4. The use of excessive seat padding to reduce peak pressures by more evenly distributing pressure on the seat pan is likely to contribute to discomfort by restricting pressure-relieving movement (Åkerblom 1948; Grandjean 1980). The design of the seat cushion should allow easy transitions to multiple postures so that sitters can adjust their pelvis placement to alter the pressure distribution patterns. If the cushion is too soft, changing the pelvis position within the constraints imposed by the driving task will not substantially alter the pressure distribution.

Once a pressure distribution with peaks near the tuberosities surrounded by a smooth gradient has been obtained, subjective assessments by sensitive subjects over a long-term sitting session should be used to determine if peak pressure reduction accomplished by the seat padding is sufficient. No local maxima should be found in the pressure distribution outside the tuberosity and lumbar areas.

3.2 Temperature and Humidity

The microclimate at the interface between the sitter and seat is important to the overall comfort of the seat. Glassford and Shvartz (1979) estimate that the metabolic heat production of a driver is approximately 191 W. Considering a typical driver to have 1.81 m^2 of skin surface area, Glassford and Shvartz estimate that the average surface heat flux must be about 105 W/m^2. Heat is transferred away from the body surface by conduction, convection, radiation, and evaporation. At the interface between the sitter and seat, conduction and evaporation are the primary means of removing heat from the skin surface.

The skin temperature in body areas contacting the seat will approach body core temperature because of the insulating effect of the seat padding and covering. Glassford and Shvartz report that an acceptable skin temperature range is 92 ± 2.6 degrees F (33±1.4 degrees C). However, the most important aspect of the microclimate is the humidity, which is determined by the amount of moisture released by the skin and the water vapor permeability of the seat. A buildup of humidity at the skin surface can lead to discomfort, partly because of an increase in the coefficient of friction when the skin is moist. This is particularly important during conditions of high heat loading on the occupant, for example, when driving on warm, sunny days.

Several researchers have addressed the vapor permeability of seat padding and covering materials. Glassford and Shvartz investigated 45 trim-cover materials, 16 trim pads, and five foam-cushion pads for impedance to body heat loss using a laboratory apparatus designed to simulate the temperature and water vapor production of the skin. The authors established a minimum desirable heat flux of 75 W/m^2. The heat flux of the typical seating materials they investigated ranged from 20 W/m^2 to 110 W/m^2, indicating that some of the materials would be unacceptable as seat coverings. Glassford and Shvartz found that small perforations in the surface of an otherwise unacceptable covering could bring the heat transfer capabilities into an acceptable range.

Temming (1993) introduced an advancement of the Glassford and Shvartz technique that utilized a "sweat impulse test" to assess the suitability of car seats for warm-weather use. A heated pad moistened with a fixed amount of water was placed against the seat surface for a period of three hours. Temperature and humidity sensors between the pad and the seat monitored the microclimate as the water diffused into the seat. A weight placed on the pad loaded the surface to a pressure approximating that produced by a seated occupant. The water vapor permeability was evaluated for different seats by comparing the rate at which the humidity at the test site decreased. Large differences in permeability were found among production car seats. The backrests of seats were generally found to have higher permeability than the seat cushions, probably because of thinner foam padding on the backrest. Temming does not specify a particular level of vapor permeability that is acceptable, but suggests that higher permeabilities will lead to greater comfort, particularly under high heat load (summer) conditions.

Diebschlag *et al.* (1988) report studies of the effect of foam type, thickness, and compression on vapor permeability and the resulting effect on the microclimate against the skin. Although different foam compositions varied in their permeability, water vapor transfer increased with foam compression up to about 80 percent of full thickness, above which the permeability dropped markedly. As the foam is compressed, the shorter diffusion distance speeds vapor transfer until the compression is sufficient to occlude the minute passages in the foam and block the water vapor. Diebschlag *et al.* also found that perforations greatly increased the vapor permeability of covering materials. The authors suggest that the vapor permeability of upholstery can be increased up to 85 percent by appropriately placed perforations representing a total of only 10 percent of the seat surface area.

Summary

Few studies have reported quantitative assessments of the microclimate at the sitter-seat interface that can be used to design more comfortable seats. The key findings are:

1. Body heat and water vapor must be allowed to pass through the seat. Seat coverings that substantially impede heat or water vapor transfer are to be avoided.

2. The total heat flux through the seat, including heat transfer due to evaporation, should be about 75 W/m^2. Perforated cover materials are desirable because of reduced resistance to water vapor diffusion.

3. "Bottoming out" of foam padding should be avoided because of the large increase in resistance to water vapor diffusion that occurs when foam compression exceeds 80 percent. Careful investigation of areas where padding is thin, for example, in the lower-back region, should be made to ensure that acceptable vapor permeability is maintained under a wide range of sitting conditions.

4.0 SUPPORT PARAMETERS

Support parameters are defined to be those that are intended to influence the posture of the sitter. These parameters include the contour of the seat and the relative position and orientation of the seat cushion and backrest. Clearly, there is substantial interaction between the Support parameters and the Fit and Feel parameters. For example, a change in backrest contour will change the backrest pressure distribution and may affect sitters differentially depending on anthropometry. In spite of these interactions, it is useful to consider these parameters with respect to their effects on posture, since the specifications are generally driven by a desire to promote, or to provide for comfort in, particular postures.

Although any aspect of seat surface contouring could be considered as a Support parameter, few are quantified in the literature, and most have more importance in consideration of body pressure distribution rather than posture. An important exception is the longitudinal backrest contour, particularly in the lower-back region, where the contour is frequently referred to as the lumbar support because the reaction forces generated by the seat are directed in the vicinity of the sitter's lumbar spine. Lumbar support has become a controversial subject of research, primarily because of the widespread prevalence of lower-back discomfort associated with sitting, particularly in vehicle seats. Section 4.1 summarizes the salient research findings concerning the appropriate function and specification of lumbar support for car seats.

The overall body posture can be characterized by angles at the various joints that divide the body into a mechanical linkage. Several authors have recommended target postures based on these joint angles. Section 4.2 summarizes these recommendations and discusses the physiological motivation behind them. Seat adjustments that can be provided to the sitter for customization of the seat support are also discussed.

4.1 Lumbar Support

There are four primary methodologies that have been used to infer proper lumbar support configuration.

1. *Anthropometry*. Targeting a support to the lumbar area requires an accurate and precise description of the position and orientation of the lumbar spine for a wide range of anthropometry.

2. *Electromyography*. Back muscle activity, as measured by electromyography (EMG) has been used to examine the physiological reactions to various lumbar supports. The hypothesis is that less back muscle activity is desirable because it may lead to reduced muscle fatigue and reduced discomfort.

3. *Intradiscal Pressure Measurement*. In-vivo measurements of lumbar intradiscal pressure have been made to study the effects of different postures and lumbar support configurations on axial spine loading. Lumbar support configurations that reduce intradiscal pressure have been recommended as a result of these experiments.

4. *Subjective Evaluations*. Many researchers have solicited subjective evaluations of lumbar supports to determine configurations that sitters prefer. However, the large

variance in these measurements has been responsible for the appeal of the "objective" measures described previously, which may provide a physiological explanation for the subjective assessments. Ultimately, however, the primary goal of seat design is comfort, so the subjective assessments are the standard against which the objective measures should be compared, rather than the reverse.

The lumbar support recommendations resulting from each of these methodologies are considered in turn, although many studies include more than one of these methodologies.

Anthropometry

The most important characteristic of a lumbar support is that it should be located in close proximity to the lumbar spine of the sitter. Precisely where in the lumbar area the support should be located is the subject of both physiological and comfort studies (see below), but the location of the lumbar spine of the sitter is the subject of anthropometric studies. The data most applicable to the automotive environment are found in Schneider *et al.* (1985). Stereophotogrammetry was used to record the three-dimensional locations of body landmarks, including targets on the pelvis and spine. Twenty-five subjects were selected in each of three categories: small female, mid-sized male, and large male. The small-female subjects were approximately 5th percentile by stature and weight for U.S. females, the mid-sized males were approximately 50th percentile by stature and weight for U.S. males, and the large males were approximately 95th percentile by stature and weight for U.S. males.

Data were recorded with each subject seated in a wooden seat shaped to be representative of the indented contour of a production car seat for similar-size drivers (see Schneider *et al.* 1985, for methods). The positions of the L2 and L5 spinal processes were recorded and averaged for each subject group. The data are presented in Table 1. Coordinates are expressed relative to the H-point (estimated hip joint center), with X positive forward and Z positive upward. Y-axis coordinates (medial-lateral dimension) are all zero since the points lie on the seat centerline. To obtain a useful dimension for locating a lumbar support, the locations of the L2 and L5 surface landmarks are expressed as distances up the torso line from the H-point. The torso line is defined as a line in the midsagittal plane connecting the H-point and shoulder (greater tubercle of the humerus). For each of the subject groups, the torso line is 22 degrees. Table 2 and Figure 3 show the distance up the torso line for L2 and L5 by group.

Table 1
Location of Surface Landmarks Relative to H-point
(Schneider *et al.* 1985)

Landmark	Small Female		Mid-Sized Male		Large Male	
	X	Z	X	Z	X	Z
Shoulder (greater tubercle humerus)	-152	380	-173	421	-185	469
L2	-180	79	-217	87	-246	95
L5	-154	23	-174	13	-202	19

Table 2
Location of L2 and L5 with Respect to Torso Line
(Dimension in mm)

Dimension	Small Female	Mid Male	Large Male
Torso Angle (H-point to shoulder from vertical)	21.8°	22.3°	21.5°
L2 distance up torso from H-point*	158	181	197
L5 distance up torso from H-point*	97	96	110
Range (L5 to L2) from depressed seat cushion*	192 – 253	191 – 276	205 – 292

* Includes 18-mm distance added to correct pelvis position (see text). Calculated using 95-mm distance from H-point to depressed cushion along torso line (see text).

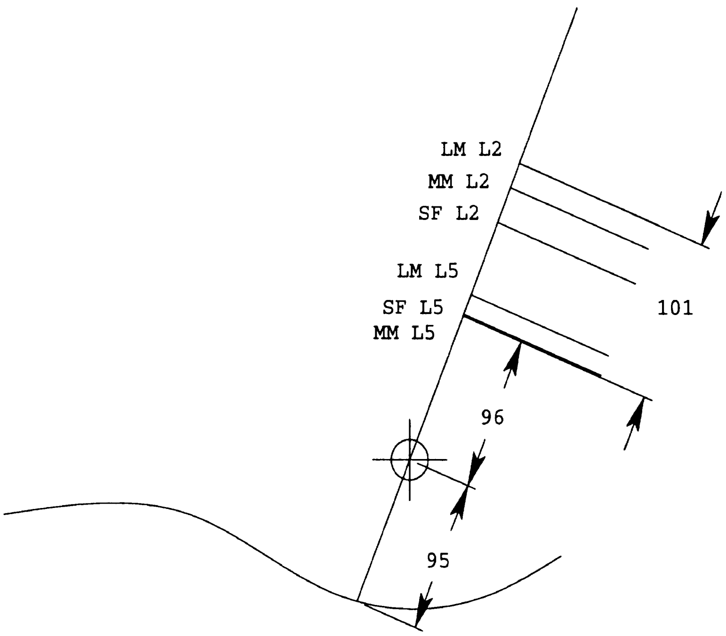

Figure 3. Lumbar surface landmark locations on torso line from Schneider *et al.* 1985. SF = Small Female, MM = Mid Male, LM = Large Male. Dimensions in mm.

Some corrections to the Schneider *et al.* (1985) data have been made in this analysis. The distance from the H-point to the seat surface along the torso line in the Schneider *et al.* data for the mid-sized male is approximately 113 mm, but data recently collected at UMTRI (Manary *et al.* 1994) suggest that the appropriate dimension is about 95 mm, a difference of 18 mm. Thus, 18 mm was added to the lumbar distances from the H-point measured along the torso line (*i.e.*, the H-point was lowered relative to the spinous processes). A similar adjustment has been made by Haas (1989) to make the Schneider *et al.* lumbar-spine length consistent with Snyder, Chaffin, and Schutz (1972), who performed an x-ray study of seated subjects. The adjusted Schneider *et al.* data for lumbar spine locations are reasonably consistent with other work (*cf.* Snyder *et al.* 1972;

Nyquist and Patrick 1976). Several other researchers have used the UMTRI data to make recommendations for lumbar support locations (Hubbard and Reynolds 1984; Robbins 1986).

Another useful anthropometric relationship noted by Cleaver (1954) is that the center of the lumbar spine in a sitting subject is approximately coincident with elbow height. In Gordon *et al.* (1989) the 5th-percentile-female to 95th-percentile-male range for erect seated elbow height above a rigid seat surface is 176 to 274 mm, or 81 to 179 mm above the H-point, using the 95-mm H-point-to-seat-surface offset. The median male elbow height is 232 mm above the seat surface, or 137 mm above the H-point. These estimates are in good agreement with the UMTRI data for lumbar spine location. Porter and Norris (1987) found the average height of L5 above a rigid seat surface of ten men and ten women to be 210 mm, or approximately 115 mm above the H-point. This compares favorably with the average over the three subject sizes in the UMTRI data of 101 mm above the H-point. The vertical measurements taken from subjects in an erect seated position should be compared to measurements made along the back line of the manikin.

Having located the lumbar spine, the questions remain: where in that range should the support be centered and how prominent should the support be? Answers to these questions have been addressed through investigation of back muscle activity and spine loads, as well as by subjective assessments.

Electromyography

Electromyography (EMG) is the recording of the electric impulses in the body generated by the process of muscle activation. Although these signals can be monitored by needle electrodes inserted in the muscle tissue, surface electrodes attached to the skin over the muscle belly are most frequently used in seating research and provide more reliable measures of aggregate muscle activity. The EMG signal amplitude has been found to vary approximately linearly with the muscle force, although it is very difficult to isolate the force produced by many muscles, for example, those in the back. Chaffin and Andersson (1991) present a review of EMG methods.

The hypothesis behind EMG studies of sitting posture and chair design is that lower levels of muscle activity will result in less muscle fatigue and discomfort, so chair designs that result in lower EMG levels are desirable. The most important EMG studies of sitting postures were conducted by Andersson and coworkers (1974a, 1974b, 1974c, 1974d, 1974e), who measured back muscle activity in a variety of seats, including a specially constructed laboratory chair, an office seat, and an automobile seat. Andersson *et al.* (1975) provide a useful summary of this work.

Of the seat parameters studied, backrest angle and lumbar support prominence were found to have the greatest influence on back muscle activity. Increasing the angle of the backrest relative to the horizontal from 90 degrees to 110 degrees reduced muscle activity in the lumbar spine area by about 40 percent. In these studies, backrest angle was described as the angle of the backrest surface, which for the rigid experimental chair was well defined. For the automobile seat, the angle of the backrest surface, presumably measured in an undepressed condition, may not be identical to the seatback angle measured by the H-point manikin (SAE J826), but the trend toward reduced back muscle exertion at increased recline angles is clear, regardless of the angle measurement method.

The prominence of the lumbar support was also found to affect back muscle activity. In studies on a car seat (Andersson *et al.* 1974b), increasing the lumbar support prominence from 0 to 50 mm reduced the EMG amplitude at the L1 level by about 50 percent, with the absolute magnitude of the reduction dependent on backrest angle. The definition of the lumbar prominence on the car seat is not clear, but the definition used in other papers by the same research group is probably applicable. The lumbar support prominence on the experimental chair was measured perpendicular to the plane of the backrest, which the subject's buttocks and thorax contacted during testing. This method of measurement appears to be equivalent to the depictions of the lumbar curve in the specifications provided by Maertens (1993).

Hosea *et al.* (1986) examined the effect of lumbar support prominence and backrest angle on back muscle activity in an on-the-road experiment. The results are consistent with Andersson *et al.*, in that increasing the backrest angle from 100 degrees to 120 degrees resulted in large decreases in the amplitude of lumbar muscle EMG. Lumbar support prominences of 30, 50, and 70 mm were tested. The 30- and 50-mm prominences produced equivalent back muscle activity in the lumbar and thoracic regions, while the 70-mm prominence resulted in an increase in EMG amplitude. The lumbar support prominence was not clearly defined, but references in the paper to Andersson's work suggest that a similar interpretation is appropriate.

Intradiscal Pressure

Andersson *et al.* (1974a, 1975) note that, although the etiology of low-back pain is often unclear, there is considerable evidence that persons with chronic low-back pain suffer more when the mechanical stresses on their lower backs are increased. Reduction in lower-back stress is therefore desirable to aid those with existing back pain, and may help to prevent its occurrence in those currently asymptomatic. Because internal stresses on body tissues are generally difficult to measure, there is considerable research emphasis placed on those measurements that are feasible. One of these methods, EMG, which relates to the stresses produced by muscle activity, has been discussed above. Another method that yields information on spine loading is intradiscal pressure measurement.

The vertebral bodies are separated by flexible discs that provide for the articulation of the spine. Each vertebral disc is comprised of a semigelatinous nucleus pulposus in the center of the disc surrounded by the annulus fibrosus, which consists of layers of collagen fibers. In the lumbar region of the spine, the discs are taller anteriorly, producing the characteristic lordotic curve. The nucleus pulposis in the center of the disc has been found to behave hydrostatically in healthy individuals so that the pressure in the nucleus may be used as a measure of the axial load on the spine. The disc pressure has been found to be affected primarily by three factors: the weight supported above the spine level of interest, the paraspinal muscle activity, and the posture of the spine in the area of measurement. Each of these factors is important in the analysis of disc pressure changes produced by variations in seat design parameters.

Andersson *et al.* (1974a, 1974b, 1974c, 1974d) conducted disc pressure measurements in conjunction with the EMG analyses discussed above. For each test, a needle containing a pressure transducer was inserted into the nucleus of the disc below the L3 vertebra. The disc pressure was recorded simultaneously with EMG signals from back extensor muscles as the subject assumed various postures. In general, disc pressures were found to be substantial higher in sitting than in standing. The type of sitting posture had a strong influence on the disc pressure.

In studies on a laboratory chair (Andersson *et al.* 1974a), the disc pressure decreased as the backrest angle was increased from 90 degrees to 120 degrees. Disc pressure also decreased as the lumbar support prominence was increased from –20 mm to +40 mm (negative lumbar support measurements indicate that the apex of the support was rearward of the plane of the backrest). The amount of change in disc pressure due to changes in lumbar support was independent of backrest angle. Studies on a car seat (Andersson *et al.* 1974b) produced similar results, with disc pressure decreasing as the backrest recline angle and lumbar support prominence were increased.

The disc pressure and EMG data can be interpreted with respect to the stresses placed on the lower back in the various postures examined. When the backrest angle is increased, a greater proportion of upper-body weight is transferred to the backrest, reducing the amount of load carried by the lumbar spine. Additionally, the center of mass of the upper body moves rearward, reducing the restorative (extension) moment that must be produced by the back muscles. Since the back muscle tension is applied approximately parallel to the lumbar spine, reduction in back muscle activity is seen directly as a reduction in disc pressure. The curvature of the lumbar spine also influences the disc pressure. When the normal lordosis of the lumbar spine is flattened, the discs are wedged anteriorly, compressing the anterior aspect of the disc while stretching the posterior aspect. These forces act to increase the pressure in the disc. Thus, moving the lumbar spine away from lordosis toward kyphosis increases the disc pressure even if the muscle activity remains constant.

In the Andersson *et al.* studies, the lumbar support reduced disc pressure by producing a more lordotic lumbar curvature and by slightly reducing back muscle exertion. These findings resulted from changes in the lumbar spine curvature produced by the lumbar support. In a later study, Andersson *et al.* (1979) examined radiographically the influence of backrest angle, lumbar support prominence, and the vertical position of the lumbar support on lumbar lordosis. Neither backrest angle (80 degrees to 110 degrees) nor the vertical position of the lumbar support (L1 to L5) had a significant effect on lumbar lordosis. The prominence of the support did have a strong influence on lumbar curvature. When the lumbar support prominence was 40 mm, the lumbar curve closely resembled the standing lordosis.

The lumbar support used in the Andersson *et al.* (1979) study was constructed to be used as an indicator of position rather than as an actual support surface, so the postural responses of the subjects to the experimental support might not be representative of their responses to actual seats. In particular, the rigid, small-diameter support probably was not conducive to relaxed postures with substantial pressure exerted on the support. Nonetheless, the findings suggest that the rotation of individual vertebral bodies is strongly linked to the motion of the adjacent vertebra, so that the vertical position of the lumbar support may not strongly influence the resulting spine curvature. Consequently, decisions about appropriate lumbar support height might reasonably be based on other considerations, such as the differential sensitivity of back areas to pressure.

Subjective Evaluations

Decisions regarding lumbar support design should ultimately be made to optimize the experience of the sitter. Although EMG and intradiscal pressure measurement can be used to estimate the mechanical stresses produced in back tissues by various seat designs, the success of a design can be judged by two criteria: (1) reduction in pathology due to sitting, and (2) reduction in discomfort. In practice, the first criterion is extremely difficult to employ because of the complex etiology of chronic lower-back disease and the difficulty in ascribing medical outcomes to subtle changes in seat parameters. Subjective evaluations of discomfort are, therefore, the standard by which lumbar supports should be judged. A reasonable hypothesis is that lower-back stresses are manifest in discomfort before producing injury so that a reduction in discomfort should lead to a reduction in the potential for injury.

Few published studies have obtained carefully controlled lumbar support evaluations. As noted above, a lack of standardization in the characterization of lumbar support prominence makes comparisons among studies difficult. Grandjean (1980) cited comfort ratings of auditorium seats to recommend a lumbar support positioned 100 to 140 mm above the depressed seat surface. These values are the lowest found in the literature. It is likely that the posture assumed in this seat results in a substantial rearward tilt of the pelvis and support for a slightly kyphotic lumbar curve. Kamijo *et al.* (1982) found that auto seats rated as comfortable showed backrest pressure peaks in the area from 140 to 180 mm above the H-point, or about 235 to 275 mm above the seat surface, suggesting that the center of lumbar support should be located in that area.

Porter and Norris (1987) investigated subject preferences for lumbar support height in a laboratory chair, simulating a driving environment by placing the subjects in a chair with a 30-degree backrest angle, a 15-degree pan angle, and an extended-knee position. This study was specifically designed to replicate the postures investigated by Andersson *et al.* (1974a) to determine if the lumbar support configurations recommended on the basis of EMG and disc pressure minimization criteria coincided with those preferred by sitters. Thirty-seven male and twenty-five female subjects indicated their preferred lumbar support position. The average preferred support height above the seat pan was 215 mm, or approximately 120 mm above the H-point. The support used in this study was rectangular in cross section, 97-mm tall, and protruded 20 mm from the plane of the backrest. The 20-mm support was preferred over the 40-mm support, suggesting that the preferred lumbar support configuration is less prominent than that which produces the lowest disc pressures.

Other studies of lumbar support preference have likely been conducted by seat manufacturers and others. These studies are rarely published because of the potential competitive advantage associated with the information. However, lacking a consistent way of specifying lumbar support configurations, translating such data into a new seat design would be difficult. Until a reliable method of characterizing lumbar support is available, most subjective data are applicable only to the seats actually tested.

Recommendations

The research findings cited above have been used by a variety of authors to justify recommendations of particular lumbar support configurations. However, the most recent recommendations based on the literature (*e.g.*, Reynolds 1993) do not differ substantially from the design specifications suggested decades earlier (*e.g.*, Åkerblom 1948; Keegan 1953).

Furthermore, recommendations in the literature are difficult to compare because, as noted above, there is a lack of standardization with regard to the specification of the lumbar support parameters. The problem is compounded by the fact that the seat contour of interest is that which results when the sitter is seated in a comfortable, self-selected posture. Since sitter anthropometry and preference vary, a particular lumbar support may produce different effective prominences or vertical positions relative to the lumbar spine depending on the sitter and the posture.

Another issue in lumbar support specification is the stated purpose of the support. Some researchers specify that the intent of the lumbar support is to induce (or retain) lordosis in the lumbar spine (*e.g.*, Hubbard and Reynolds 1984). Keegan (1964) specifies that support should be directed in the area of L4 and L5, because the discs below those vertebrae have the greatest association with low-back pain. In Keegan's view, the purpose of the lumbar support is to prevent the flattening of the lumbar lordosis. He recommends that the seat design should promote a neutral lumbar spine curvature about midway between the standing lordosis and a flattened spine. Andersson (1980), in a summary of the work discussed above, recommends that the lumbar support be used to preserve lordosis because lower disc pressures are observed with lordotic lumbar curvature. He also notes that the position of the lumbar support relative to the lumbar spine has only a minor influence on the degree of lordosis.

Grandjean (1980), Kamijo *et al.* (1982), Porter and Norris (1987), and others have used subjective preferences to recommend lumbar support configurations without reference to desired physiological outcomes. Robbins (1986) follows Hubbard and Reynolds (1984) in recommending centering of the lumbar support at the apex of the lumbar lordosis, midway between T12 and L5. Robbins found that this mid-lumbar point for people ranging in size from small females to large males lies within 33 mm of a point 250 mm from the depressed seat surface, and recommended that the 250-mm dimension be used to locate the lumbar support. Maertens (1993) follows the recommendation of Robbins and also specifies that the support should be centered 250 mm above the depressed seat surface.

Lumbar height recommendations relative to the H-point are summarized in Table 3. Note that all recommendations fall between the average L2 and L5 locations given by Schneider *et al.* (1985).

Table 3
Summary of Recommendations for Vertical Location of Lumbar Support

Reference	Lumbar Support Position above H-point on Torso Line (mm)
Keegan (1964) (mean L5 position in Schneider *et al.* 1985)	101
Andersson (1980)	155
Robbins (1986)	155
Kamijo *et al.* (1982)	160
Porter and Norris (1987)	120
For Reference: L2 mean (Schneider *et al.* 1985)	178

The prominence of the lumbar support is more difficult to specify than the vertical position because of a lack of standardization in measurement. For this discussion, the method used by Andersson, Porter and Norris, and others will be used. These researchers have constructed laboratory chairs with rigid, planar backrests and measured the protrusion of the lumbar support from that plane. This measurement can be approximated for a padded seat by measuring perpendicular to a line tangent to the thoracic curve and the rear of the buttocks (*cf.* Robbins 1986; Maertens 1993).

Andersson *et al.* (1979) measured the effect of lumbar support on lumbar lordosis and concluded that 40 mm was an appropriate prominence. Porter and Norris (1987) found that a 20-mm support was preferred over a 40-mm support in all test conditions. Robbins (1986) recommended 15 to 25 mm prominence while Maertens (1993) indicates that an acceptable range is from 20 to 50 mm. Some researchers specify a longitudinal radius of curvature along with, or instead of, a prominence. Grandjean (1980) recommended a 450-mm radius. Floyd and Roberts (1958) recommend not less than 300 mm and preferably 400 to 460 mm. Robbins (1986) recommends a 250-mm radius, Maertens (1993) specifies 255 mm. Reynolds (1993) cited lumbar curvature radii for cadavers in erect seated postures from 206 to 348 mm, implying that similar radii would be appropriate for drivers.

Evidence Against the Prevalent Recommendations

Most lumbar support design recommendations assume that the posture to be supported includes a lumbar lordosis. As noted above, lordosis is associated with reduced disc pressures, a finding that has been cited as justification for prescribing lumbar lordosis. However, there are two important reasons why a lumbar support designed for a lordotic spine curvature may not always be appropriate. First, there are some advantages to flexed spine postures or periodic changes between flexed and extended lumbar spine postures. Adams and Hutton (1985) cite the advantages and disadvantages of sitting with a flexed lumbar spine.

Advantages

- Reduced stresses at apophyseal joints (posterior contact points between vertebra)
- Reduced compressive stress on the posterior annulus
- Improved transport of disc metabolites (when posture alternates between flexed and extended)
- High compressive strength of the spine

Disadvantages

- Increased compressive stress on the anterior annulus
- Increased hydrostatic pressure in the nucleus at low load levels

The most important advantage to sitting with a flexed spine, cited by Adams and Hutton (1985), is the improved transport of disc metabolites. Intervertebral discs are nonvascular and receive nutrition through diffusion, a process facilitated by fluctuating pressure gradients. When the spine is flexed or extended, the hydrostatic pressure in the disc is changed and diffusion results. As the pressure is alternately raised and lowered through changes in spine posture, disc nutrition is enhanced. The remaining advantages cited by Adams and Hutton are probably not of great importance in quiescent seating.

Adams and Hutton maintain that the disadvantages they cite are not sufficient to merit a proscription of flexed-spine postures. They note that the anterior annulus of the disc is the thickest part of the disc and rarely shows degradation. The increase in disc pressure as a result of lumbar spine flattening is small compared to the levels of spine loads associated with disc pathology (*e.g.*, in heavy lifting). Adams and Hutton conclude that flattened-spine postures should not be discouraged, because the physiological advantages outweigh the disadvantages.

There are some additional advantages to nonlordotic spine postures not mentioned by Adams and Hutton. When the spine is flexed, passive resistance to further flexion is generated by the stretching of muscles and ligaments and by the resistance of the intervertebral discs to wedging. These passively generated extension moments reduce the need for active erector spinae activity. The observation of reduced muscle activity in postures approaching full lumbar flexion has been noted by many investigators (see Schultz *et al.* 1985, for a review). Any flattening of the lumbar spine beyond its "physiological" lordotic curvature results in an increase in passive extension moment and a consequent decrease in active muscle tension needed to maintain the posture. Thus, choosing a posture that flattens the lumbar curve can reduce back muscle activity and potentially reduce muscle fatigue and discomfort. This effect may be noted in the EMG data of Andersson and Örtengren (1974e), which show that increased lumbar support prominence (increased lordosis) results in *increased* back muscle activity at the L3 level for backrest angles of 80 and 90 degrees. As the backrest is reclined, the differences are no longer statistically significant. However, in other work by Andersson *et al.* (1974b), lumbar EMG was reduced as lumbar support prominence was increased in an auto seat. The authors suggest that the differences in the design of the laboratory chair and auto-seat lumbar supports were responsible for the difference in results. Since pelvis orientations and spine postures were not monitored in the auto-seat study, it is possible that the increased lumbar support prominence in the auto seat had the effect of increasing the effective backrest angle by moving the subject's pelvis forward. As noted above, increasing the recline angle strongly reduces back muscle activity.

The second reason that the typical prescriptions for longitudinally convex lumbar support may be inappropriate is that sitters may not choose postures with lumbar lordosis. Reed *et al.* (1991a, 1991b), in a study of long-term driver comfort, found that sitters tended to choose postures with flat or kyphotic lumbar curvatures even in seats designed with prominent, convex lumbar supports. Instead of mating with the spine curvature, the support instead protruded against the upper lumbar area of the sitter's back, producing an area of high pressure. The convex shape also left the lower part of the sitter's spine unsupported, and may have increased discomfort in that area.

Other researchers have noted that sitters often do not sit in erect postures with lumbar lordosis as seat designers intend. Grandjean, Hünting, and Pidermann (1983), in a study of office workers, found that computer users frequently adopted a slouched posture even when sitting in seats designed with lumbar supports for erect postures. This evidence suggests that the physiological criteria that have been used to specify lumbar support configurations are insufficient in the absence of data on postures actually chosen by sitters.

Summary

Lumbar support should be firm but sufficiently padded to avoid discomfort due to high pressure. Ideally, the support should be adjustable. The depressed contour should adjust from flat to convex up to approximately 50 mm prominence, with a radius adjustable from about 250 to 400 mm. The vertical position of the apex should be adjustable between 100 and 200 mm above the H-point along the manikin back line, or between 195 and 295 mm above the depressed seat cushion. If a fixed lumbar support is to be provided, the prominence should be about 20 mm and the radius 300 mm for a mid-range or higher seat height (*i.e.*, higher than about 240 mm). The apex should be positioned between 105 and 155 mm above the H-point along the manikin back line (200 to 250 mm above the depressed seat surface). For lower seat heights, fixed lumbar supports should have minimal longitudinal curvature.

4.2 Body Segment Angles and Seat Adjustments

The posture of the body is described by the relative orientations of the various articulating segments that make up the body linkage. Reynolds (1993) stresses the usefulness of abstract linkage representations of the human body as design tools. Hubbard *et al.* (1993) discuss computerized kinematic models that increase the fidelity of simple link models by including descriptive geometry for the links, *e.g.*, legs, torso, and arms. Such link models are used to define joint angles that are associated with improved comfort.

The assumption implicit in these joint angle recommendations is that the least discomfort will result when all joint angles are within a neutral range for which tissue stresses are minimized (Keegan 1953). These ranges are typically in the middle of the full passive range of motion for the joint, where muscles are approximately at their resting lengths. Rebiffé (1969) presents a summary of recommendations for body segment angles in the automotive environment. Figure 4 shows the definitions of body segment angles for which recommendations are listed in Table 4.

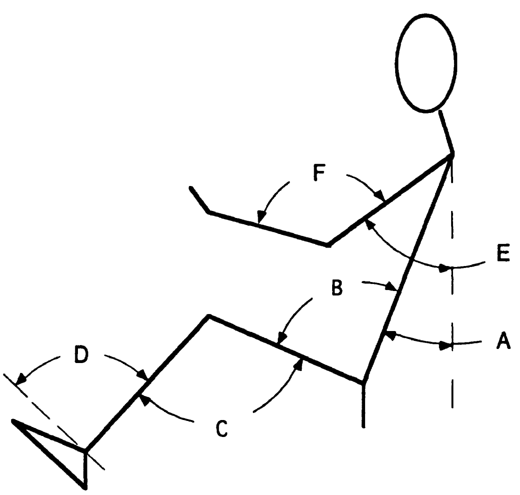

Figure 4. Definitions of posture angles in Rebiffé (1969).

Table 4
Recommended Ranges for Body Segment Angles from Rebiffé (1969)
(See Figure 4 for angle definitions.)

Angle	Recommended Range (degrees)
A. Back	20 – 30
B. Trunk/Thigh	95 – 120
C. Knee	95 – 135
D. Ankle	90 – 110
E. Upper Arm	10 – 45*
F. Elbow	80 – 120

*These values are dependent on hand support and seat-back configuration.

The Rebiffé linkage expresses body posture in terms of line segments in a sagittal plane connecting joint centers. The trunk angle is represented as a line connecting the shoulder joint with the hip joint. The most important angles for comfort are the back, trunk/thigh, and knee angles, which represent the relative orientations of the trunk, thigh, and leg. The research summarized in Section 4.1 demonstrated the importance of maintaining a reclined trunk posture to reduce spine and back muscle loads. The Rebiffé recommendations for 20- to 30-degree recline angles are consistent with the EMG-based recommendations of Andersson *et al.* and contemporary practice. Angle B is the trunk/thigh angle, which Keegan (1953) demonstrated to have a strong effect on the lumbar curve. The Rebiffé recommendations for trunk/thigh angle fall short of the 135-degree angle cited by Keegan (1953) as producing a neutral spine curvature, but are in keeping with the recommendation by Grandjean (1980) of 100 degrees to 120 degrees. With specific reference to auto seating, Keegan (1964) specified a trunk/thigh angle of 105–115 degrees, with 115 degrees preferred for long-term comfort.

The determinants of trunk/thigh angle are the backrest angle and the seat cushion angle. Backrest angle can be adjusted on most current driver seats, while seat cushion angle adjustment is generally available only on more expensive models. Although backrest angle is widely defined using the SAE J826 H-point manikin and procedure, there is currently no widely accepted and biomechanically useful method of characterizing cushion angle. The angle of the undepressed surface may be a poor measure of the influence of the seat cushion on the thigh angle. Recently, Manary *et al.* (1994) have reported a procedure developed by Ron Roe of General Motors that employs the H-point manikin without legs in a procedure to measure the cushion angle. This experimental technique has shown good correlation with driver thigh angle in preliminary trials, but more research is needed to determine if the procedure accurately measures the influence of cushion angle on thigh angle.

Knee angle is an important determinant of comfort. Rebiffé recommends that the angle not exceed 135 degrees. When the knees are extended (*i.e.*, knee angle increases) tension can develop in the hamstring muscles in the back of the thigh. Because these muscles are attached both below the knee and above the hip joint (on the pelvis), tension in these muscles resulting from extended-knee positions constrains motion at the hip joint (Stokes and Abery 1980). If the pelvis is forced to rock rearward because of tension in the hamstrings, then a lumbar lordosis is difficult to obtain without extreme seat recline angles. Thus, knee angle is an important factor to consider in the specification of a lumbar support (see Section 4.1).

The ankle angle is depicted in Figure 4 in a sagittal plane, but in actuality the driver's foot orientation can vary considerably while still maintaining control of the accelerator pedal. Currently, vehicle interior design tools (*e.g.*, the H-point manikin and the 2-D "Oscar" template) do not consider these variations in posture. But there may be important comfort implications of allowing such motion. As noted in Section 3.1, leg splay can be an effective way of altering the pressure distribution under the buttocks and thighs. Allowing the driver a range of right leg positions involving varying degrees of leg splay and medial-lateral foot rotation may reduce the potential for leg discomfort.

The most important restriction on the body segment angles available to the driver is the seat height, measured from the horizontal plane of the heel point to the H-point. When seat heights are low, extended knee positions, which induce rearward rotation of the pelvis, become necessary. Rearward pelvis rotations create a need for large recline angles to avoid excessive lumbar flexion. There are advantages to the reclined trunk posture, most notably reduction in back muscle activity (see Section 4.1). But the extended knee position can reduce the range of pelvis and lumbar spine postures to those involving flat or slightly kyphotic curvatures. In contrast, higher seat heights allow more flexibility in posture, primarily because the knee angles are smaller.

Seat adjustments are supplied to provide for some customization of the interior environment to the preferences of the occupant. The minimum set of adjustments for passenger cars is the seat track, which adjusts fore-aft position, and the seatback recliner. (Some trucks still do not have recline angle adjustment.) The range of seat track travel is recommended to be about 150 mm (Grandjean 1980; Rebiffé 1969), although data collected at UMTRI suggest that 200 mm or more may be necessary to accommodate short and tall drivers (Schneider and Manary 1991). Most seat tracks are angled several degrees to the horizontal so that moving the seat forward also raises the seat. This is appropriate since occupants with shorter legs usually also have shorter torsos, and the added height helps to achieve good eye position. However, a flatter cushion angle is usually necessary to preserve a comfortable reach to the pedals.

Cushion angle adjustment is also useful in conjunction with height adjustment. Smaller drivers may find it preferable to flatten out the seat as it is raised, while long-legged drivers might increase the cushion angle to allow a more reclined backrest angle while preserving reach to the steering wheel. Many problems of occupant positioning relative to the controls could be solved more satisfactorily from the driver's perspective if the steering wheel and dashboard remained fixed relative to each other while both the seat and pedals moved fore and aft. The technology to move the pedals exists and might result in greater comfort and more flexible occupant packaging. Drivers could sit at a more comfortable and safe distance from the steering wheel, since the shoulder-to-wheel distance could be adjusted independent of the hip-to-pedal distance. The recline mechanism should allow trunk angles up to 30 degrees behind the vertical with a larger range preferred. Although most drivers will not use the full range, the extra adjustability is useful for those with long arms or for those who prefer large recline angles.

Lumbar support adjustment is desirable to accommodate differences in anthropometry and preference. The research findings presented in Section 4.1 suggest that a vertical adjustment of about 100 mm centered about 150 mm above the H-point along the manikin back line will accommodate a large percentage of the population. The prominence of the lumbar support should be adjustable to obtain depressed seat surface contour prominences ranging from 0 (flat) to 50 mm, measured as described in Section 4.1.

Summary

Body joint angles should be maintained near the center of the passive range of motion for the joint. The most important angles related to auto seat comfort are the trunk angle relative to the vertical and the knee angle. Reclining the trunk 20 degrees substantially decreases back muscle activity and opens the trunk/thigh angle, decreasing the necessity for lumbar flexion. Large knee angles can cause tension in the hamstring muscles and rearward rotation of the pelvis, which moves the lumbar curve toward kyphosis. Higher seat heights allow more flexed knee angles and reduce the constraints on posture.

5.0 DISCUSSION

Research related to seating comfort has been conducted for over 100 years, and chair-makers have worked for centuries to increase the comfort of their products. Åkerblom (1948) provides a thorough review of work that preceded his own. In spite of the large body of research published in the intervening decades, recent recommendations on seat design echo those published in articles from the 1940s and early 1950s (*e.g.*, Lay and Fisher 1940; Åkerblom 1948; Keegan 1953; Cleaver 1954). And yet the number of journal articles published on seating research shows no sign of abating. What has been learned in the past few decades? Is there an advantage to using recommendations from, say, Reynolds (1993) rather than Åkerblom (1948)?

Some ergonomic knowledge is being applied in automotive seat design. Most current seats appear to be designed more in keeping with ergonomic recommendations than seats from previous decades. For example, at the time Keegan (1964) raised the issue of lumbar support in auto seats, most seats had fixed backrest angles and a uniform stiffness along the vertical length of the backrest or "squab" as it was then called. Keegan pointed out that such seats produced kyphotic lumbar postures and were more likely to cause back discomfort than seats that provided a firm lumbar support in the lower-back area. But Åkerblom (1948, 1954), Keegan (1953), Cleaver (1954), and others had specified a decade earlier that firm support should be directed to the lumbar area. Indeed, Lay and Fisher (1940) measured the pressure distribution preferences of 250 people in an auto-seat mockup and reported that preferred backrest pressure distributions contained peaks in the lumbar area similar to those reported by Kamijo *et al.* (1982). One reason for continuing seating research must certainly be that the recommendations that are made are not always followed by those designing seats. In recent years, however, there has been an increased design emphasis on seat comfort in automobiles, partly because of epidemiological data showing that prolonged driving is associated with increased risk of lumbar disc herniation (Kelsey and Hardy 1975), but primarily because driver and passenger comfort have been seen as an increasingly important aspect of the competitive marketing of vehicles.

Of the design recommendations discussed in this report, those related to *Fit* parameters are the most readily applied. Although most current vehicle seats fit a large percentage of the driving population well, two parameters on which many seats could be improved are cushion length and width. As discussed in Section 2.1, cushion width should be sufficient to avoid constricting hips as wide as the 95th percentile. This means an unobstructed width of about 500 mm at a distance of 100 mm above the depressed seat surface. Some seats, particularly sporty bucket seats, have the required clearance, but have cushion side bolsters that constrict the buttocks of larger drivers as the cushion deflects, reducing the effective cushion width below that required. Although some manufacturers might find it reasonable to trade off accommodation of larger drivers for a more sporty feel for others, all drivers are likely to find a narrower seat more uncomfortable because it restricts posture change more than a wider seat. Shifting the pelvis laterally allows drivers to change the pressure distribution on their buttocks, potentially delaying the onset of discomfort.

Many car seat cushions are also too long. As the data in Section 2.2 indicate, a seat in which the distance from the depressed seatback to the front edge of the cushion is more than 440 mm is likely to restrict the postures of small drivers and reduce their comfort.

Although some small sitters may not report that the seat cushion is too long, they may nonetheless be prevented from using the backrest properly by the need to sit further forward on the seat to avoid uncomfortable pressure behind the knees. Shorter cushions are advantageous even for those whose thigh lengths are closer to the population median. Shorter cushions allow for greater flexibility in leg posture and, in particular, allow the legs to splay to a greater extent than does a longer cushion. Leg splay changes the pressure distribution under the buttocks and can be a useful way of delaying the onset of buttock discomfort. One way to make a short cushion more comfortable for long-legged subjects is to include a cushion angle adjustment. Long-legged subjects can tilt the cushion up to obtain the desired contact pressure on their thighs, rather than obtaining similar support by sinking into a longer, softer cushion.

Feel parameters, particularly body pressure distribution, have received substantial attention in recent years because advances in sensor technology have made it possible to measure the pressure at the interface between the sitter and production car seat without substantially interfering with the normal performance of the seat. Early systems required extensive seat modifications that made it difficult to apply the findings to production seats and to compare results among different seat designs. The primary appeal of pressure distribution studies is that they give an objective measurement of some of the stresses applied directly to the skin. Since pressure distributions are clearly related in general ways to discomfort (*e.g.*, high pressures lead to discomfort more quickly than lower pressures), it is tempting to conclude that an ideal pressure distribution can be described that will produce minimal discomfort. However, the research evidence suggests that the pressure distribution alone does not give enough information about the discomfort stimuli perceived by the sitter to serve as an objective measure of the potential for discomfort. For example, the pressure distribution measurement does not give a useful measure of surface shear, which has been determined to be an important factor in determining the critical pressure at which blood vessel occlusion will occur (see Section 3.1). Two identical pressure distributions accompanied by differing surface shear exposures would probably have different outcomes with respect to tissue ischemia and discomfort.

In spite of these limitations, the emerging pressure measurement technology has the potential to be a useful tool in assessing the interaction between sitters and seats. For example, seat-cushion firmness can affect long-term buttock comfort, but will affect heavy sitters with little fat tissue more than lighter sitters with more substantial fat tissue in the buttock area. Pressure distribution measurement could be a useful way of selecting subjects for seat-cushion comfort testing that are likely to be sensitive to changes in foam density. Another important use for pressure measurement is the assessment of lumbar support function. The support forces produced by a lumbar support can be observed on a pressure map of the backrest. The optimal lumbar support configuration for a particular sitter might be identified by the pressure distribution in addition to the contour of the seat.

Support parameters, particularly lumbar support location and curvature, will probably continue to receive the greatest emphasis, both from researchers and manufacturers, because of the importance of low-back pain to consumers and the importance to seat makers of alleviating that pain. The research findings presented in Section 4.1 show considerable consensus with respect to the location of a sitter's lumbar spine and the desirability of providing a firm reactive surface to prevent excessive flexion in that area. There is also general agreement in the literature that the protrusion of the lumbar support should be between 20 and 40 mm, with adjustability provided for different anthropometry and preference, and that the height above the depressed seat surface should be between 200 and 250 mm. These recommendations, however, are based primarily on static physiological assessments of spine biomechanics. Lumbar support was found to have only a small effect on back muscle activity. Reclining the backrest by an additional 10 degrees produces a greater reduction in back muscle activity than addition of lumbar support. Changes in spine posture due to lumbar support reduce lumbar intradiscal pressure substantially, but no link has been established between the low levels of disc pressure associated with quiescent seated postures and disc pathology. People who spend a large amount of time driving do have higher incidences of low-back pain and disc herniation than those who spend less time driving (Kelsey and Hardy 1975), but there is no epidemiological evidence that adding a lumbar support will reduce that incidence.

The appropriate design for lumbar support in auto seating is not currently clear because of incongruities between spine postures that have been identified as physiologically desirable and those postures that are prevalent and possible in automobiles. One defining characteristic of passenger car seating is the extended-knee position that results from low seat heights (compared to office seating) and the driver's requirement to operate the foot controls. Knee extension places a restriction on the forward rotation of the pelvis through the action of the hamstring muscles that extend both below the knee and above the hip joint. Stokes and Abery (1980) demonstrated that the knee position alters the range of motion of the pelvis in sitting postures. Boughner (1991) developed a computer model to describe the constraints that the resting hamstring muscle length imposes on pelvic orientation. When the knees are extended, an upright pelvis orientation can put passive tension on the hamstrings and thereby result in sharp discomfort at the backs of the thighs for people with tight hamstrings. The extended knee posture therefore constrains the pelvis angle, which in turn constrains the lumbar spine posture. Particularly for low seat heights, a lordotic lumbar curvature may not be possible for many drivers. Consequently, the appropriate function of a lumbar support in such seats cannot be to maintain a lordosis, and thus a convex lumbar support contour would be inappropriate. A lumbar support designed for a flat spine curve might be more comfortable in such seats.

A primary limitation of the physiological research on which the present lumbar support recommendations are made is that the particular postures studied were induced by the experimenters and not spontaneously selected by the sitters as comfortable postures. Data indicating that actual users of the seats respond to the test configurations with similar postures is lacking. Indeed, there is evidence that suggests that sitters frequently choose postures other than those for which their seats were designed. Grandjean *et al.* (1983), in a study of office workers, found that computer operators tend to assume reclined postures, often by sliding their hips forward in the chair, even in chairs designed with lumbar supports intended for upright postures. Reed *et al.* (1991a, 1991b) found that spine postures observed in a long-term driving simulation did not conform to a prominent, convex lumbar support. These observations indicate the need for a greater understanding of how people respond posturally to changes in support. Current lumbar support specifications tend to be prescriptive, in that they are intended to support postures that have been identified as physiologically desirable. Improvements over current designs will require a greater understanding of how sitters interact dynamically with the seat contour so that seats can be designed to support postures that are both physiologically desirable and subjectively preferred.

6.0 SUMMARY

The recommendations discussed in the previous sections are summarized here in tabular and graphical form. The reader is referred to the body of the report for more detail and the rationale behind the recommendations.

6.1 Fit Parameters

Fit parameters are linear dimensions related to sitter anthropometry.

Table 5
Summary of Fit Parameter Recommendations

Parameter	Recommendation (mm)	
	Should not be less than:	Should not be more than:
Cushion Width		
• Actual width at H-point	432	--
• Clearance at H-point	500	--
• Width at front of cushion	500	--
Cushion Length		
• Forward of H-point on thigh line	--	305
Backrest Width		
• At waist (220 mm above H-point)	360	--
• At chest (318 mm above H-point	456	--
• Height of side bolsters above H-point	--	288
Backrest Height	410	550

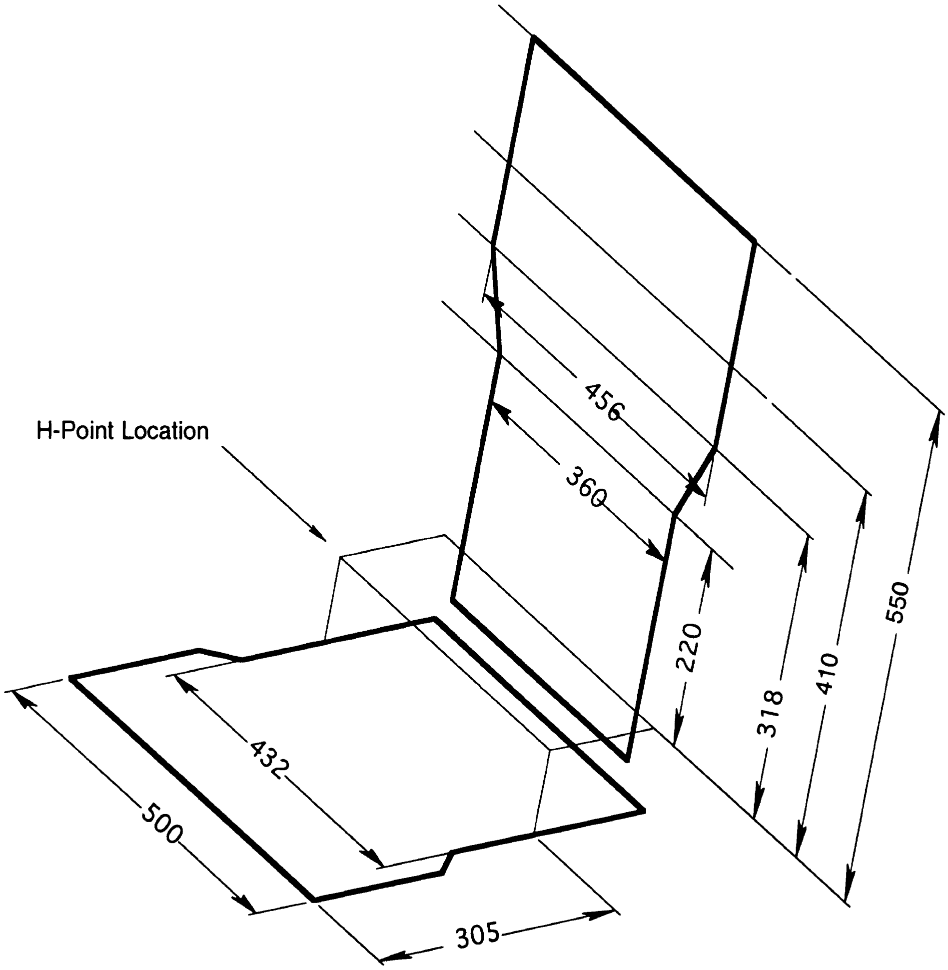

Figure 5. Schematic representation of Fit parameter recommendations.

6.2 Feel Parameters

Feel parameters affect local comfort and are related to stimuli detected primarily in the skin and subcutaneous tissues.

Table 6
Recommendations for Feel Parameters

Parameter	Recommendation
Pressure Distribution	
• Seat cushion patterns	Peaks should be located only in the areas of the ischial tuberosities. No other local maxima should be found.
• Backrest patterns	Peaks should be located only in lumbar area. No local maxima should be found in the shoulder area.
• Peak levels	Peak levels should be determined by subjective comfort testing with target populations. Large differences in pressure distributions and sensitivity among individuals make specifying a quantitative "optimal pressure distribution" difficult.
Surface Shear	Surface shear on the seat cushion should be minimized by increasing the cushion angle and/or by contouring the cushion to achieve the same effect.
Temperature and Humidity	The seat covering should allow heat transfer of at least 75 W/m^2 by conduction and diffusion of water vapor. Foam should not be compressed to more than 80% to allow for maximum vapor diffusion.

6.3 Support Parameters

Support parameters are intended to influence the posture of the sitter and are related to body segment angles.

Table 7
Recommendations for Support Parameters

Parameter	Recommendation
Lumbar Support (Fixed)	
• Vertical position	Locate apex 200–250 mm above depressed seat surface, or 105–155 mm above H-point along back line.
• Prominence	Support should protrude 20 mm in front of backrest plane (see Figure 6) for seat heights above about 240 mm. Support should be nearly flat for lower seat heights.
• Radius	The 20-mm support should have a depressed-contour, convex radius of about 300 mm.
Lumbar Support (Adjustable)	
• Vertical position	Apex should be adjustable between 100 and 200 mm above the H-point along back line.
• Prominence	Prominence should be adjustable between 0 and 50 mm.
• Radius	Radius should be adjustable between 250 and 400 mm. If only a prominence adjustment is provided, higher prominences should be achieved with smaller radii.
Knee Angle	Included angle between leg and thigh should be less than 135°.
Trunk/Thigh Angle	Angle formed by the knee, hip, and shoulder joints should be larger than 90° and preferably close to 135°.
Trunk Angle	Angle relative to the vertical of line from hip joint to shoulder joint should be between 10–30°.

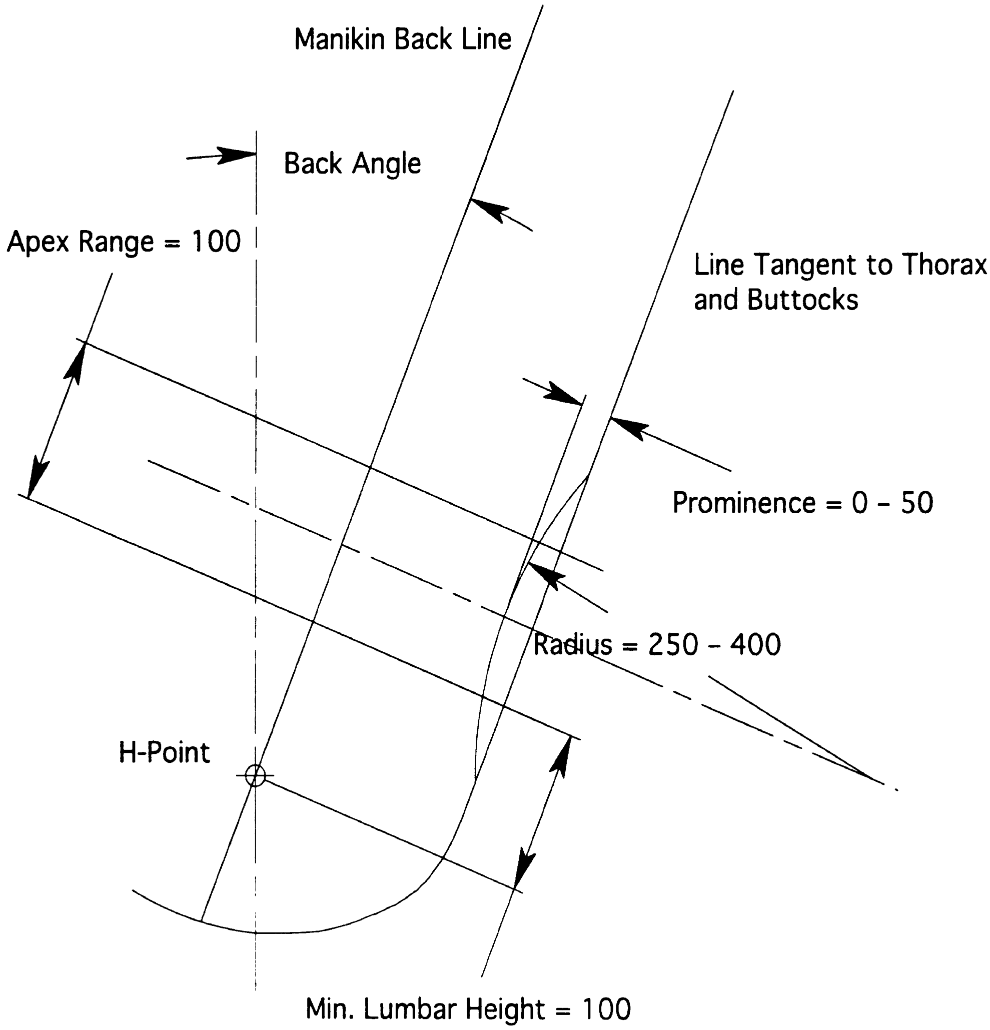

Figure 6. Schematic illustration of lumbar support recommendations (dimensions in mm).

REFERENCES

Abraham, S., Johnson, C.L., and Najjar, M.F. (1979) Weight by height and age for adults 18-74 years: United States, 1971-74, Vital and health statistics, Series 11, No. 208 (DHEW Publication No. 79-1656). Hyattsville, MD: U.S. Department of Health, Education, and Welfare.

Adams, M. A., and Hutton, W. C. (1985). The effect of posture on the lumbar spine. Journal of Bone and Joint Surgery, 67-B(4), 625-629.

Åkerblom, B. (1948). Standing and sitting posture with special reference to the construction of chairs. Doctoral dissertation, Karolinska Institutet, A.B. Nordiska Bokhandeln, Stockholm.

Åkerblom, B. (1954). Chairs and sitting. In W.F. Floyd and A.T. Welford (eds.), Symposium on Human Factors in Equipment Design, (pp. 29-35). London: H.K. Lewis and Co., Ltd.

Andersson, G. B. J. (1980). The load on the lumbar spine in sitting postures. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 231-239). New York: Academic Press.

Andersson, G. B. J., Örtengren, R., Nachemson, A., and Elfström, G. (1974a). Lumbar disc pressure and myoelectric back muscle activity during sitting. I. Studies on an experimental chair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 104-114.

Andersson, G. B. J., Örtengren, R., Nachemson, A., and Elfström, G. (1974b). Lumbar disc pressure and myoelectric back muscle activity during sitting. IV. Studies on a car driver's seat. Scandinavian Journal of Rehabilitation Medicine, 6(3), 128-33.

Andersson, G. B. J., and Örtengren, R. (1974c). Lumbar disc pressure and myoelectric back muscle activity during sitting. II. Studies on an office chair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 115-121.

Andersson, G. B. J., and Örtengren, R. (1974d). Lumbar disc pressure and myoelectric back muscle activity during sitting. III. Studies on a wheelchair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 122-127.

Andersson, G. B. J., and Örtengren, R. (1974e). Myoelectric back muscle activity during sitting. Scandinavian Journal of Rehabilitation Medicine, Suppl. 3, 73-90.

Andersson, G. B. J., Örtengren, R., Nachemson, A. L., Elfström, G., and Broman, H. (1975). The sitting posture: An electromyographic and discometric study. Orthopedic Clinics of North America, 6(1), 105-120.

Andersson, G. B. J., Murphy, R. W., Örtengren, R., and Nachemson, A. L. (1979). The influence of backrest inclination and lumbar support on lumbar lordosis. Spine, 4(1), 52-58.

Bader, D. L., Barnhill, R. L., and Ryan, T. J. (1986). Effect of externally applied skin surface forces on tissue vasculature. Archives of Physical Medicine and Rehabilitation, 67, 807-811.

Boughner, R. L. (1991). A model of average adult male human skeletal and leg muscle geometry and hamstring length for automotive seat designers. Unpublished Master of Science thesis. Lansing, MI: Michigan State University, Department of Metallurgy, Mechanics, and Material Science.

Branton, P. (1969). Behaviour, body mechanics and discomfort. Ergonomics, 12(2), 316-327.

Chaffin, D. B., and Andersson, G. B. J. (1991). Guidelines for seated work. Chapter 9 in Occupational Biomechanics, Second Edition, (pp. 335-375). New York: John Wiley and Sons, Inc.

Chow, W. W., and Odell, E. I. (1978). Deformations and stresses in soft body tissues of a sitting person. Journal of Biomechanical Engineering, 100, 79-87.

Cleaver, G. E. (1954). Driving seats: An appraisal of the mechanical basis of comfort. Automobile Engineer, 44, 237-241.

Date, K. (1988). An examination of body support and fatigue in automobile seats. Proceedings of the 32nd Annual Meeting of the Human Factors Society: Riding the Wave of Innovation, Volume I, (pp. 593-597). Santa Monica, CA: Human Factors Society.

Diebschlag, W., and Müller-Limmroth, W. (1980). Physiological requirements on car seats: Some results of experimental studies. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 223-230). New York: Academic Press.

Diebschlag, W., Heidinger, F., Kurz, B., and Heiberger, R. (1988). Recommendation for ergonomic and climatic physiological vehicle seat design. SAE Technical Paper 880055. Warrendale, PA: Society of Automotive Engineers, Inc.

Drummond, D. S., Narechania, R. G., Rosenthal, A. N., Breed, A. L., Lange, T. A., and Drummond, D. K. (1982). A study of pressure distributions measured during balanced and unbalanced sitting. The Journal of Bone and Joint Surgery, 1964A(7), 1034-1039.

Floyd, W. F., and Roberts, D. F. (1958). Anatomical physiological and anthropometric principles in the design of office chairs and tables (B.S. 3044: 1958). London, England: British Standards Institution.

Geoffrey, S.P. (1961) A 2-D mannikin--The inside story. X-rays used to determine a new standard for a bsic design tool. SAE Technical Paper 267A. New York, NY: Society of Automotive Engineers, Inc.

Glassford, E. J., and Shvartz, E. (1979). Metabolic heat retention and the vehicle operator. SAE Technical Paper 770248. Warrendale, PA: Society of Automotive Engineers, Inc.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., and Walker, R. A. (1989). 1988 anthropometric survey of U.S. Army personnel: Methods and summary statistics. Final report (NATICK/TR-89/027). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Grandjean, E. (1980). Sitting posture of car drivers from the point of view of ergonomics. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 205-213). New York: Academic Press.

Grandjean, E., Hünting, W., and Pidermann, M. (1983). VDT workstation design: Preferred settings and their effects. Human Factors, 25(2), 161-175.

Haas, W. A. (1989). Geometric model and spinal motions of the average male in seated postures. Unpublished Master's thesis. East Lansing, MI: Michigan State University.

Hertzberg, H. T. E. (1972). The human buttocks in sitting: Pressures, patterns, and palliatives. SAE Technical Paper 720005. New York, NY: Society of Automotive Engineers, Inc.

Hobson, D. A. (1992). Comparative effects of posture on pressure and shear at the body-seat interface. Journal of Rehabilitation Research and Development, 29(4), 21-31.

Hosea, T. M., Simon, S. R., Delatizky, J., Wong, M. A., and Hsieh, C-C. (1986). Myoelectric analysis of the paraspinal musculature in relation to automobile driving. Spine, 11(9), 928-936.

Hubbard, R.P., and Reynolds, H.M. (1984). Anatomical geometry and seating. SAE Technical Paper 840506. Warrendale, PA: Society of Automotive Engineers, Inc.

Hubbard, R. P., Haas, W. A., Boughner, R. L., Conole, R. A., and Bush, N. J. (1993). New biomechanical models for automobile seat design. SAE Technical Paper 930110. Warrendale, PA: Society of Automotive Engineers, Inc.

Husain, T. (1953). An experimental study of some pressure effects on tissues, with reference to the bed-sore problem. Journal of Pathology and Bacteriology, 66, 347-358.

Kamijo, K., Tsujimura, H., Obara, H., and Katsumata, M. (1982). Evaluation of seating comfort. SAE Technical Paper 820761. Warrendale, PA: Society of Automotive Engineers, Inc.

Keegan, J. J. (1953). Alterations of the lumbar curve related to posture and seating. Journal of Bone and Joint Surgery, 35-A(3), 589-603.

Keegan, J. J. (1964). The medical problem of lumbar spine flattening in automobile seats. SAE Technical Paper 838A. New York, NY: Society of Automotive Engineers, Inc.

Kelsey, J.L., and Hardy, R.J. (1975) Driving motor vehicles as a risk factor for acute herniated lumbar intevertebral discs. American Journal of Epidemiol, 102, 63-73.

Kosiak, M. (1961). Etiology of decubitus ulcers. Archives of Physical Medicine and Rehabilitation, 19-29.

Lay, W. E., and Fisher, L. C. (1940). Riding comfort and cushions. SAE Journal, 47(5), 482-496.

Lee, J., and Ferraiuolo, P. (1993). Seat comfort. Seat System Comfort and Safety, (pp. 1-5). Warrendale, PA: Society of Automotive Engineers, Inc.

Maertens, D. (1993). Automotive Seating Comfort Criteria, 4th Edition. Warren, MI: Comfort Criteria Task Force, General Motors Corporation.

Manary, M.A., Schneider, L.W., Flannagan, C.C., and Eby, B.H. (1994) Evaluation of the SAE J826 3-D manikin measures of driver positioning and posture. SAE Technical Paper 941048. Warrendale, PA: Society of Automotive Engineers, Inc.

Nyquist, G. W., and Patrick, L. M. (1976). Lumbar and pelvic orientations of the vehicle seated volunteer. Proceedings of the 20th Stapp Car Crash Conference, (pp. 665-696). Warrendale, PA: Society of Automotive Engineers, Inc.

Podoloff, R. M. (1993). Automotive seating analysis using thin, flexible tactile sensor arrays. SAE Technical Paper 930112. Warrendale, PA: Society of Automotive Engineers, Inc.

Porter, J. M., and Norris, B. J. (1987). The effects of posture and seat design on lumbar lordosis. In E.D. Megaw (ed.), Contemporary Ergonomics, (pp. 191-196). New York: Taylor and Francis.

Rebiffé, R. (1969). The driving seat. Its adaptation to functional and anthropometric requirements. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture. London: Taylor and Francis, Ltd.

Reed, M. P., Saito, M., Kakishima, Y., Lee, N. S., and Schneider, L. W. (1991a). An investigation of driver discomfort and related seat design factors in extended-duration driving. SAE Technical Paper 910117. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M. P., Schneider, L. W., Saito, M., Kakishima, Y., and Lee, N. S. (1991b). An investigation of automotive seating discomfort and seat design factors. Final report (UMTRI-91-11). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Reswick, J. B. (1961). Devices for measuring contact pressures exerted on the human body. Progress report I. Cleveland, OH: Case Institute of Technology.

Reynolds, H. M. (1993). Automotive seat design for sitting comfort. Chapter 5 in B. Peacock and W. Karwowski (eds.), Automotive Ergnomics, (pp. 99-116). Washington, D.C.: Taylor and Francis.

Robbins, D. H. (1986). Study of seatback contours for optimum seat design. Final report (UMTRI-86-39). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Rosemeyer, B., and Pförringer, W. (1979). Measuring pressure forces in sitting. Archives of Orthopaedic and Traumatic Surgery, 95, 167-171.

Sacks, A. H., O'Neill, H., and Perkash, I. (1985). Skin blood flow changes and tissue deformations produced by cylindrical indentors. Journal of Rehabilitation Research, 22(3), 1-6.

Schneider, L.W. and Manary, M.A. (1991). An Investigation of Preferred Steering Wheel Locations and Driver Positioning in Late-Model Vehicles. (UMTRI-91-29). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Schneider, L. W., Robbins, D. H., Pflüg, M. A., and Snyder, R. G. (1985). Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, Volume 1. Final report (DOT-HS-806-715). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Schultz, A.G., Haderspeck-Grib, K., Sinkora, G., and Warwick, D.N. (1985). Quantitative studies of the flexion-relaxation phenomenon in the back muscles. Journal of Orthopedic Research, 3(2), 189-197.

Shields, R. K., and Cook, T. M. (1992). Lumbar support thickness: Effect on seated buttock pressure in individuals with and without spinal cord injury. Physical Therapy, 72(3), 218-26.

Snyder, R. G., Chaffin, D. B., and Schutz, R. K. (1972). Link system of the human torso (AMRL-TR-71-88). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Stokes, I. A. F., and Abery, J. M. (1980). Influence of the hamstring muscles on lumbar spine curvature in sitting. Spine, 5(6), 525-528.

Temming, J. (1993). A new method to assess the summer suitability of car seats. SAE Technical Paper 930106. Warrendale, PA: Society of Automotive Engineers, Inc.

Thier, R. H. (1963). Measurement of seat comfort. Automobile Engineer, 53(2), 64-66.

Treaster, D. E., and Marras, W. S. (1989). Seat pressure: Measurement and analysis. SAE Technical Paper 890849. Warrendale, PA: Society of Automotive Engineers, Inc.

Troup, J. D. G. (1978). Driver's back pain and its prevention: A review of the postural, vibratory and muscular factors, together with the problem of transmitted road-shock. Applied Ergonomics, 9(4), 207-214.

U.S. Office of the Federal Register (1993) Code of Federal Regulations, Title 49, Part 571.202. Washington, D.C.: Government Printing Office.

Ward, E., and Southall, D. (1993). A technique for measuring vehicle seat interface pressure. SAE Technical Paper 930116. Warrendale, PA: Society of Automotive Engineers, Inc.

APPENDIX

BIBLIOGRAPHY OF SEATING ERGONOMICS

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The following bibliography contains references relating to many aspects of seating ergonomics and seat design. The emphasis is on literature related to auto seating, but a wide range of articles on seating issues from rehabilitation and office-chair research are included.

Aaras, A., Westgaard, R. H., and Stranden, E. (1988). Postural angles as an indicator of postural load and muscular injury in occupational work situations. Ergonomics, 31(6), 915-933.

Abraham, S., Johnson, C. L., and Najjar, M. F. (1979, September). Weight by height and age for adults 18-74 years: United States, 1971-74, Vital and health statistics, Series 11, No. 208 (DHEW Publication No. 79-1656). Hyattsville, MD: U.S. Department of Health, Education, and Welfare.

Adam, G. (1988). The application of ergonomics to the design and manufacture of automotive products. (A special publication for delegates to the 10th Congress of the International Ergonomics Association, Sydney, August 1-5, 1988). Chatswood NSW, Australia: Volvo.

Adams, M. A., Dolan, P., Marx, C., and Hutton, W. C. (1986). An electronic inclinometer technique for measuring lumbar curvature. Clinical Biomechanics, 1, 130-134.

Adams, M. A., and Hutton, W. C. (1985, August). The effect of posture on the lumbar spine. Journal of Bone and Joint Surgery, 67-B(4), 625-629.

Adams, M. A., Hutton, W. C., and Stott, J. R. R. (1980, May). The resistance to flexion of the lumbar intervertebral joint. Spine, 5(3), 245-253.

Adams, T., Steinmetz, M. A., Helsey, S. R., Holmes, K., and Greenman, P. E. (1982, February). Physiologic basis for skin properties in palpatory physical diagnosis. Journal of the American Osteopathic Association, 81(6), 366-377.

Adomeit, D. (1979). Seat design--A significant factor for safety belt effectiveness. Proceedings of the 23rd Stapp Car Crash Conference, (pp. 39-68). Warrendale, PA: Society of Automotive Engineers, Inc.

Adomeit, D., and Appel, H. (1979). Influence of seat design on the kinematics and loadings of the belted dummy. In J.P. Cotte and A. Charpenne (eds.), Proceedings of the 4th International Conference on the Biomechanics of Trauma, (pp. 292-304). Bron, France: IRCOBI.

Åkerblom, B. (1969). Anatomische und physiologische gundlagen zur gestaltung von sitzen. In E. Grandjean (ed.), Sitting Posture, (pp. 6-17). London: Taylor.

Åkerblom, B. (1969, March). [Anatomic and physiologic basis for the construction of seats]. Ergonomics, 12(2), 120-31.

Åkerblom, B. (1954). Chairs and sitting. In W.F. Floyd and A.T. Welford (eds.), Symposium on Human Factors in Equipment Design, (pp. 29-35). London: H.K. Lewis and Co., Ltd.

Åkerblom, B. (1948, December). Standing and sitting posture with special reference to the construction of chairs. Doctoral Dissertation. A.B. Nordiska Bokhandeln, Stockholm: Karolinska Institutet.

Aldman, B., and Lewin, T. (1977). Anthropometric measurement of sitting adults. Gothenburg, Sweden: Chalmers University of Technology and the University of Gothenburg.

Althoff, I., Brinckmann, P., Frobin, W., Sandover, J., and Burton, K. (1992, June). An improved method of stature measurement for quantitative determination of spinal loading: Application to sitting postures and whole body vibration. Spine, 17(6), 682-693.

Amstad, H., Bachlin, A., and von, A. N. (1992, May 23). [Ball or chair as seating arrangement in the classroom. A prospective study]. Schweiz Med Wochenschr, 122(21), 811-816.

Anderson, T. E. (1974). The effects of automobile interior design changes on injury risk. Final report (CAL ZQ-5276-V-5/DOT-HS-801-239). Buffalo, NY: Calspan Corporation.

Andersson, G. (1987). Biomechanical aspects of sitting: An application to VDT terminals. Behaviour and Information Technology, 6, 257-269.

Andersson, G. B. J. (1980). The load on the lumbar spine in sitting postures. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 231-239). New York: Academic Press.

Andersson, G. B. J. (1986). Loads on the spine during sitting. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 309-318). Philadelphia, PA: Taylor and Francis.

Andersson, G. B. J. (1976, March 31). [Low backache in working life]. Lakartidningen, 73(14), 1305-7.

Andersson, G. B. J. (1974). On myoelectric back muscle activity and lumbar disc pressure in sitting postures. Unpublished doctoral dissertation, Gotab, University of Gothenburg, Gothenburg, Sweden.

Andersson, G. B. J., Johnson, B., and Örtengren, R. (1974). Myoelectric activity in individual lumbar erector spinae muscles in sitting. A study with surface and wire electrodes. Scandinavian Journal of Rehabilitation Medicine, Suppl. 3, 91-108.

Andersson, G. B. J., Murphy, R. W., Örtengren, R., and Nachemson, A. L. (1979, January). The influence of backrest inclination and lumbar support on lumbar lordosis. Spine, 4(1), 52-58.

Andersson, G. B. J., Örtengren, R., Nachemson, A., and Elfström, G. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. I. Studies on an experimental chair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 104-114.

Andersson, G. B. J., Örtengren, R., and Nachemson, A. M. (1977, November). Intradiskal pressure, intraabdominal pressure and myoelectric back muscle activity related to posture and loading. Clinical Orthopaedics and Related Research, 129, 156-164.

Andersson, G. B. J., Örtengren, R., Nachemson, A., and Elfström, G. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. IV. Studies on a car driver's seat. Scandinavian Journal of Rehabilitation Medicine, 6(3), 128-33.

Andersson, G. B. J., and Örtengren, R. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. II. Studies on an office chair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 115-121.

Andersson, G. B. J., and Örtengren, R. (1974). Lumbar disc pressure and myoelectric back muscle activity during sitting. III. Studies on a wheelchair. Scandinavian Journal of Rehabilitation Medicine, 6(3), 122-127.

Andersson, G. B. J., and Örtengren, R. (1974). Myoelectric back muscle activity during sitting. Scandinavian Journal of Rehabilitation Medicine, Suppl. 3, 73-90.

Andersson, G. B. J., Örtengren, R., Nachemson, A. L., Elfström, G., and Broman, H. (1975, January). The sitting posture: An electromyographic and discometric study. Orthopedic Clinics of North America, 6(1), 105-120.

Andersson, G. B. J., Schultz, A. B., Örtengren, R., and Nachemson, A. L. (1980). Analysis and measurement of the loads of the lumbar spine. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 1-2). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Andronov, M. A., Esenovsky-Lashkov, U. K., Egorov, U. L., and Ugolyev, A. S. (1976). [Theoretical and experimental investigation of some ergonometric properties of the driver's seat.]. Avtomobil'naya Promyshlennost', (5), 24-26.

Anon. (1988). 1990's automotive interiors highlight comfort and convenience. Body Engineering Journal, 16(2), 40, 44-46, 50-51.

Anon. (1963). Seat comfort improved by special measuring device. Automotive Industries, 129(6), 72-73.

Anselm, D. (1975). Verbesserung eines mathematischen Autositz-Modells bezueglich Federkennlinien und Reibung. [Improving a mathematical model of an automobile seat with respect to seat upholstery friction]. ATZ, 180-185.

Aquino, C. F. (1969). A dynamic model of the lumbar spine to aid in the study of injury due to automobile seat belt restraint. Unpublished doctoral dissertation, The University of Michigan, Department of Mechanical Engineering, Ann Arbor, MI.

Aquino, C. F. (1970). A dynamic model of the lumbar spine. Journal of Biomechanics, 3(5), 473-486.

Arborelius, U. P., Wretenberg, P., and Lindberg, F. (1992, November). The effects of armrests and high seat heights on lower-limb joint load and muscular activity during sitting and rising. Ergonomics, 35(11), 1377-1391.

Armstrong, T. J. (1986). Upper-extremity posture: Definition, measurement and control. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 59-73). Philadelphia, PA: Taylor and Francis.

Arnold, A. J., Ferrara, R. A., and Kuechenmeister, T. J. (1985). Driver eyellipses produced by minimum deflection seats and by U.S. adult population changes. In R.W. Swezey, L.B. Strother, T.J. Post, and M.G. Knowles (eds.), Proceedings of the 29th Annual Meeting of the Human Factors Society, Volume I, (pp. 447-451). Santa Monica, CA: Human Factors Society.

Arnold, A. J., Ferrara, R. A., and Kuechenmeister, T. J. (1986). Effect of alternate population mixes on design eye locations in vehicles. Symposium on Visibility for Highway Guidance and Hazard Detection. Washington, D.C.: Transportation Research Board, National Research Council.

Arrowsmith, M. J. (1986). The design and development of the XJ40 seating system. Proceedings of the Institution of Mechanical Engineers. Part D: Transport Engineering Vol. 200, (pp. S79-S85).

Arvikar, R. J., and Seireg, A. (1978, January). Distribution of spinal disc pressures in the seated posture subjected to impact. Aviatiation, Space, and Environmental Medicine, 49(1 Pt. 2), 166-169.

Asano, H., Yanagishima, T., Abe, Y., and Masuda, J. (1989). Analysis of primary equipment factors affecting driving posture. SAE Technical Paper 891240. Warrendale, PA: Society of Automotive Engineers, Inc.

Ashley, C., and Rao, B. K. N. (1974). An equal sensation study of differential vibration between feet and seat. Ergonomics, 17(3), 331-342.

Audu, M. L., and Davy, D. T. (1985, May). The influence of muscle model complexity in musculoskeletal motion modeling. Journal of Biomechanical Engineering, 107, 147-149.

Ayoub, M. M., Deivanayagam, S., and Kennedy, K. W. (1977). Selected design parameters for reclining seats based on engineering anthropometry. Final report (AMRL-TR-77-44). Wright-Patterson AFB, OH: Air Force Systems Command, Aerospace Medical Research Laboratory.

Babbs, F. W. (1979). A design layout method for relating seating to the occupant and vehicle. Ergonomics, 22(2), 227-234.

Babbs, F. W., and Hilton, B. C. (1965). The packaging of car occupants - A British approach to seat design. In Derwyn M. Severy (ed.), Proceedings of the 7th Stapp Car Crash Conference, (pp. 456-464). Springfield, IL: Charles C. Thomas.

Bablich, K., Tettenborn, M., Sochaniwskyj, A. E., and Koheil, R. (1984). Dynamic monitoring and feedback of hyphotic sitting posture for children with cerebral palsy. Proceedings of the 7th Annual Conference on Rehabilitation Engineering, Report No. 05865. Bethesda, MD: Rehabilitation Engineering Society of North America.

Bader, D. L., Barnhill, R. L., and Ryan, T. J. (1986, November). Effect of externally applied skin surface forces on tissue vasculature. Archives of Physical Medicine and Rehabilitation, 67, 807-811.

Barkla, D. M. (1964). Chair angles, duration of sitting, and comfort ratings. Ergonomics, 7, 297-304.

Baty, D., Buckle, P. W., and Stubbs, D. A. (1985). Posture recording by direct observation, questionnaire assessment and instrumentation: A comparison based on a recent field study. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 283-292). Philadelphia, PA: Francis and Taylor.

Beck, A. (1975, May). Proposal for improving ejection seats with respect to sitting comfort and ejection posture. Aviatiation, Space, and Environmental Medicine, 46(5), 736-9.

Bell, A. L., Pedersen, D. R., and Brand, R. A. (1990). A comparison of the accuracy of several hip center location prediction methods. Journal of Biomechanics, 23(6), 617-621.

Belytschko, T. B., Andriacchi, T. P., Schultz, A. B., and Galante, J. O. (1973). Analog studies of forces in the human spine: Computational techniques. Journal of Biomechanics, 6(4), 361-371.

Belytschko, T., Schwer, L., and Privitzer, E. (1978). Theory and application of a three-dimensional model of the human spine. Aviation, 49(1), 158-165.

Bendix, T. (1987, June). Adjustment of the seated workplace with special reference to heights and inclinations of seat and table. Danish Medical Bulletin, 34(3), 125-39.

Bendix, T. (1986). Chair and table adjustments for seated work. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 355-362). Philadelphia, PA: Taylor and Francis.

Bendix, T. A. (1986). Seated trunk posture at various seat inclinations, seat heights and table heights. Human Factors, 26, 695-703.

Bendix, T. (1986). Sitting postures--A review of biomechanic and ergonomic aspects. Manual Medicine, 2, 77-81.

Bendix, T., and Biering-Sorensen, F. (1983). Posture of the trunk when sitting on forward inclining seats. Scandinavian Journal of Rehabilitation Medicine, 15(4), 197-203.

Bendix, T., and Hagberg, M. (1984, August). Trunk posture and load on the trapezius muscle whilst sitting at sloping desks. Ergonomics, 27(8), 873-882.

Bendix, T., Jessen, F., and Krohn, L. (1988, February). Biomechanics of forward-reaching movements while sitting on fixed forward- or backward-inclining or tiltable seats. Spine, 13(2), 193-196.

Bendix, T., Jessen, F. B., and Winkel, J. (1986). An evaluation of a tiltable office chair with respect to seat height, backrest position and task. European Journal of Applied Physiology, 55(1), 30-36.

Bendix, T., Sorensen, S. S., and Klausen, K. (1984). Lumbar curve, trunk muscles, and line of gravity with different heel heights. Spine, 9(2), 223-227.

Bendix, T., Winkel, J., and Jessen, F. (1985). Comparison of office chairs with fixed forwards or backwards inclining, or tiltable seats. European Journal of Applied Physiology, 54(4), 378-385.

Bennett, L., Kavner, D., Lee, B. Y., Trainor, F. S., and Lewis, J. M. (1981, August). Skin blood flow in seated geriatric patients. Archives of Physical Medicine and Rehabilitation, 62(8), 392-398.

Berger, E., and Gilmore, B. J. (1993). Seat dynamic parameters for ride quality. Seat System Comfort and Safety, (pp. 89-102). Warrendale, PA: Society of Automotive Engineers, Inc.

Bergmark, A. (1989). Stability of the lumbar spine. A study in mechanical engineering. Acta Orthopaedica Scandinavica Suppl, 60(230), 1-54.

Berkson, M. H., Nachemson, A., and Schultz, A. B. (1979). Mechanical properties of human lumbar spine motion segments - Part II: Responses in compression and shear; influence of gross morphology. Journal of Biomechanical Engineering, 101(1), 53-57.

Berquet, K. H. (1967, June). [Injuries due to sitting and car seats]. Med Welt, 10(23), 1419-1427.

Berquet, K. H. (1967, November). [Seat wedge or pelvic brim prop]. Med Welt, 4(44), 2642-2645.

Berquist-Ullman, M., and Larsson, U. (1977). Acute low back pain in industry. Acta Orthopaedica Scandinavica, Suppl. 170.

Bertoti, D. B., and Gross, A. L. (1988, July). Evaluation of biofeedback seat insert for improving active sitting posture in children with cerebral palsy. A clinical report. Physical Therapy, 68(7), 1109-1113.

Bhatnager, V., Drury, C. G., and Schiro, S. G. (1985). Posture, postural discomfort, and performance. Human Factors, 27(2), 189-199.

Bhattacharya, A., Knapp, C. F., McCutcheon, E. P., and Evans, J. M. (1979). Cardiac responses of dogs to nonsynchronous and heart synchronous whole-body vibration. J Appl.Physiol: Respirat Environ Exercise Physiol, 46(3), 549-555.

Bhise, V. D., Meldrum, J. F., Jack, D. D., Troell, G. M., Hoffmeister, D. H., and Forbes, L. M. (1981). Driver head movements in left outside mirror viewing. SAE Technical Paper 810761. Warrendale, PA: Society of Automotive Engineers, Inc.

Blaisdell, D. M., Levitt, A. E., and Varat, M. S. (1993). Automotive seat design concepts for occupant protection. Seat System Comfort and Safety, (pp. 109-119). Warrendale, PA: Society of Automotive Engineers, Inc.

Bleise, G., Klee, R. J., and Koerner, W. (1983). Vergleichende Untersuchungen des Sitzklimas von Autositzen. [Comparative investigation of climatic comfort in car seats]. ATZ, (10), 603-607.

Boccafogli, C., Miccoli, G., Bonini, R., and Deboli, R. (1987). Experience with a vibration test stand for seats. SAE Technical Paper 870956. Warrendale, PA: Society of Automotive Engineers.

Bohlin, N., Hallen, A., Runberger, S., and Aasberg, A. (1978). Safety and comfort--Factors in Volvo occupant compartment packaging. SAE Technical Paper 780135. Warrendale, PA: Society of Automotive Engineers, Inc.

Bonelli, C., and Enserink, E. (1977). Vehicle seat back latch systems: Evaluation and testing. Final report (3980-76-62/ DOT-HS-802-186/ MVSS-207). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Bonnardel, G. (1988). Confort vibratoire du siege du conducteur. [Vibration comfort of the driver's seat]. Ingenieurs de l'Automobile, 54-58.

Bonney, R., and Corlett, E. N. (1988). Segmental analysis of oscillatory behaviour of the spinal column. Nottingham: The University of Nottingham, Department of Production Engineering and Production Management.

Boothby, B. (1984, February). Seating by design. Physiotherapy, 70(2), 44-7.

Borkan, S. (1983, May). Want to improve productivity? Take a seat. Dental Laboratory Review, 58(5), 29.

Boughner, R. L. (1991). A model of average adult male human skeletal and leg muscle geometry and hamstring length for automotive seat designers. Unpublished Master of Science thesis. Lansing, MI: Michigan State University, Department of Metallurgy, Mechanics, and Material Science.

Bowker, P., and Davidson, L. M. (1979, October 20). Development of a cushion to prevent ischial pressure sores. British Medical Journal, 2, 958-961.

Branton, P. (1984, June). Backshapes of seated persons--How close can the interface be designed? Applied Ergonomics, 15(2), 105-107.

Branton, P. (1969). Behaviour, body mechanics and discomfort. Ergonomics, 12(2), 316-327.

Branton, P., and Grayson, G. (1967, January). An evaluation of train seats by observation of sitting behaviour. Ergonomics, 10(1), 35-51.

Breen, A., Allen, R., and Morris, A. (1989, January). A digital videofluoroscopic technique for spine kinematics. Journal of Medical Engineering and Technology, 13(1-2), 109-113.

Breen, A. C., Allen, R., and Morris, A. (1989, May). Spine kinematics: A digital videofluoroscopic technique. Journal of Biomedical Engineering, 11(3), 224-218.

Brehaut, W. H., Jr. (1962). Design and testing of passenger seats for crash survival. SAE Technical Paper 517B. New York, NY: Society of Automotive Engineers, Inc.

Bridger, R. S., Von Eisenhart-Rothe, C., and Henneberg, M. (1989, December). Effects of seat slope and hip flexion on spinal angles in sitting. Human Factors, 31(6), 679-688.

Bridger, R. S., Wilkinson, D., and Van Houweninge, T. (1989, April). Hip joint mobility and spinal angles in standing and in different sitting postures. Human Factors, 31(2), 229-241.

Brienza, D. M., Inigo, R. M., Chung, K. C., and Brubaker, C. E. (1993, January). Seat support surface optimization using force feedback. IEEE Transactions on Bimedical Engineering, 40(1), 95-104.

Brigham, F. R. (1975, June). Some quantitative considerations in questionnaire design and analysis. Applied Ergonomics, 6(2), 90-96.

Brinkley, J. W., Hearon, B. F., Raddin, J. H., Jr., McGowan, L. A., and Powers, J. M. (1982). Vertical impact tests of a modified F/FB-111 crew seat to evaluate headrest position and restraint configuration effects (AMRL-TR-82-51). Wright-Patterson AFB, OH: Air Force Systems Command, Aerospace Medical Research Laboratory.

British Standards Institution. (1959). British Standard 30-79: Anthropometric Recommendations for Dimensions of Non-Adjustable Office Chairs, Desks and Tables. London: British Standards Institution.

British Standards Institution. (1965). British Standard 3893: Specifications for Office Desks, Tables and Seating. London: British Standards Institution.

Broman, H., Pope, M. H., Benda, M., Svensson, M., Ottosson, C., and Hansson, T. (1991, January). The impact response of the seated subject. Journal of Orthopaedic Research, 9(1), 150-154.

Bruniquel, G. (1971, November). [Painful postural syndrome of the costal border in pregnant women: revealing sign of the seated pregnant woman]. Bull Fed Soc Gynecol Obstet Lang Fr, 23(5), 657-659.

Bruns, H. J., and Rönitz, R. (1971, March). Optimizing ride comfort. Part one: The basis theoretical approach. Automobile Engineer, 26-28.

Bruns, H. J., and Rönitz, R. (1971, April). Optimizing ride comfort. Part two: the effects of the engine mass, and some results obtained on the simulator. Automobile Engineer, 45-47.

Brunswic, M. (1984, February). Ergonomics of seat design. Physiotherapy, 70(2), 40-43.

Bryan, M. E., Tempest, W., and Williams, D. (1978, September). Vehicle noise and the passenger. Applied Ergonomics, 9(3), 151-154.

Buckle, P. W., Stubbs, D. A., and Baty, D. (1986). Musculo-skeletal disorders (and discomfort) and associated work factors. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 19-30). Philadelphia, PA: Taylor and Francis.

Bukowski, K., and Schoberth, W. (1985). New methods for the production of comfortable car seats. SAE Technical Paper 850486. Warrendale, PA: Society of Automotive Engineers, Inc.

Bulstrode, S., Harrison, R. A., and Clarke, A. K. (1984). Assessment of back rests for use in car seats. Heywood, Lanscaster, England: Health Publications Unit.

Burandt, U. (1969, March). [Radiography of the position of the pelvis and vertebral column while seated on a forward tilted surface]. Ergonomics, 12(2), 356-364.

Burandt, U., and Grandjean, E. (1969, March). [Research concerning the seating behavior of office workers and the effects of various seating profiles]. Ergonomics, 12(2), 338-347.

Burandt, U., and Grandjean, E. (1963). Sitting habits of office employees. Ergonomics, 6, 217-223.

Burns, J. W. (1975, January). Re-evaluation of a tilt-back seat as a means of increasing acceleration tolerance. Aviatiation, Space, and Environmental Medicine, 46(1), 55-63.

Burton, A. K. (1986). Measurement of regional lumbar sagittal mobility and posture by means of a flexible curve. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 92-99). Philadelphia, PA: Taylor and Francis.

Bush, C. A. (1969). Study of pressures on skin under ischial tuberosities and thighs during sitting. Archives of Physical Medicine, 50, 207.

Bush, N. J. (1992). Two-dimensional drafting template and three-dimensional computer model representing the average adult male in automotive seated postures. Thesis for the Master of Science Degree. Lansing, MI: Department of Materials Science and Mechanics, Michigan State University.

Bush-Joseph, C., Schipplein O., and Andersson, G. B. J. (1988). Influence of dynamic factors on the lumbar spine moment in lifting. Ergonomics, 31(2), 211-216.

Cailliet, R. (1964). Neck and arm pain. Philadelphia, PA: F.A. Davis Co.

Caldwell, L. S. (1962). Body stabilization and the strength of arm extension. Human Factors, 125-130.

Cameron, C. (1973). A theory of fatigue. Ergonomics, 16(5), 633-648.

Canole, R. B. (1993). Model of posture, mass distribution, body support forces, and intersegmental forces and moments for the seated average man. Thesis for the Master of Science Degree. Lansing, MI: Department of Biomechanics, Michigan State University.

Cantoni, S., Colombini, D., Occhipinti, E., Grieco, A., and Pedotti. Posture analysis and evaluation at the old and new work place of a telephone company. In E. Grandjean (ed.), Ergonomics and Health in Modern Offices. Proceedings of the International Scientific Conference on Ergonomic and Health Aspects in Modern Offices, (pp. 456-464). Philadelphia, PA: Taylor and Francis.

Carlsoo, S. (1982, December). The effect of vibration on the skeleton, joints and muscles: A review of the literature. Applied Ergonomics, 13(4), 251-258.

Carlsoo, S. (1972). How man moves. London: Heinemann.

Carlsoo, S. (1963). Writing desk, chair and posture of work. Stockholm: Department of Anatomy.

Carr, R. W. (1972). A statistical investigation of crash accelerations effects on a seated occupant. Proceedings Environmental Progress in Science and Education, (pp. 77-81). Mt. Prospect: Institute of Environmental Sciences.

Carter, J. (1972). Hydra-Flex Seat: A new kind of ride for truck drivers. SAE Technical Paper 720914. New York, NY: Society of Automotive Engineers, Inc.

Cartwright, E. O., Jr., Edwards, H. H., Jr., and Held, S. F. (1961). Shock absorbing safety seat (Patent 2,981,317). Dallas, TX: Chance Vought Corporation.

Cavender, K. D. (1993). Real time test for automotive seating foam. SAE Technical Paper 930634. Warrendale, PA: Society of Automotive Engineers, Inc.

Chaffin, D. B. (1973). Localized muscle fatigue-definition and measurement. Journal of Occupational Medicine, 15, 346.

Chaffin, D. B., and Andersson, G. B. J. (1991). Guidelines for seated work. Chapter 9 in Occupational Biomechanics, Second Edition, (pp. 335-375). New York: John Wiley and Sons, Inc.

Chaffin, D. B., Lee, M., and Freivalds, A. (1980). Muscle strength assessment from EMG analysis. Medicine and Science in Sports and Exercise, 12(3), 205-211.

Chandler, R. F., and Trout, E. M. (1978). Evaluation of seating and restraint systems and anthropomorphic dummies conducted during fiscal year 1977 (FAA-AM-78-24). Washington, D.C.: Federal Aviation Administration, office of Aviation Medicine.

Chandler, R. F., and Trout, E. M. (1979). Evaluation of seating and restraint systems conducted during fiscal year 1978. Washington, D.C.: Federal Aviation Administration, Office of Aviation Medicine.

Chao, E. Y., and An, K. N. (1978, August). Graphical interpretation of the solution to the redundant problem in biomechanics. Journal of Biomechanical Engineering, 100, 159-167.

Charlesworth, J. (1993). Spec'ing comfortable seats make sense. Commercial Carrier Journal, 150(2), 50-55.

Chen, S. J. (1973). A mechanical model of the human ligamentous spine and its application to the pilot ejection problem. Iowa City, IA: Iowa University.

Chow, W. W., and Odell, E. I. (1978, May). Deformations and stresses in soft body tissues of a sitting person. Journal of Biomechanical Engineering, 100, 79-87.

Clark, A., and Reinecke. (1991). The BackCycler: Making it easier to sit on the job (Special Report No. 6-01). Burlington, VT: The Vermont Rehabilitation Engineering Center, The University of Vermont.

Clark, A. G., and Ridd, J. E. (1984, June). Restrictions to posture in working environments. Applied Ergonomics, 15(2), 109-110.

Cleaver, G. E. (1954). Driving seats: An appraisal of the mechanical basis of comfort. Automobile Engineer, 44, 237-241.

Clevenson, S. A., Dempsey, T. K., and Leatherwood, J. D. (1978, September). Effect of vibration duration on human discomfort (NASA Technical Paper 1283). Hampton, VA: NASA.

Cochran, G. V. B., and Palmieri, V. (1980, March). Development of test methods for evaluation of wheelchair cushions. Bulletin of Prosthetics Research, 17(1), 9-30.

Cochran, G. V. B., Reddy, N. P., Brunski, J. B., and Palmieri, V. R. (1980). Identification and control of biophysical factors responsible for soft tissue breakdown. Proceedings of the International Conference on Rehabilitation Engineering 1980, (pp. 163-166). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Coermann, R., and Rieck, A. (1964). Eine verfeinerte Methode zur Bestimmung des Komfortgrades von Sitzen. [A refined method of determining the degree of comfort of chairs]. Internationale Zeitschrift fuer angewandte Physiologie einschliesslich Arbeitsphysiologie, 20, 376-397.

Cole, J. H. (1993). Developing a cost effective integrated structural seat. Seat System Comfort and Safety, (pp. 25-34). Warrendale, PA: Society of Automotive Engineers, Inc.

Colombini, D., Occhipinti, E., Frigo, C., Pedotti, A., and Grieco, A. (1986). Biomechanical, electromyographical and radiological study of seated postures. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 331-344). Philadelphia, PA: Francis and Taylor.

Coltman, J. W. (1983). Design and test criteria for increased energy-absorbing seat effectiveness (USAAVRADCOM-TR 82-D-42). Tempe, AZ: Simula Inc.

Cook, J., Branch, T. P., Baranowski, T. J., and Hutton, W. C. (1993, May). The effect of surgical floor mats in prolonged standing: An EMG study of the lumbar paraspinal and anterior tibialis muscles. Journal of Biomedical Engineering, 15(3), 247-250.

Cooper, F. D., and Hall, L. (1966). A sensitive manikin for evaluating seat comfort. Ergonomics and Safety in Motor Car Design, (pp. 3-10). London: Institution of Mechanical Engineers.

Corlett, E. N. (1989). Aspects of the evaluation of industrial seating. Ergonomics, 32(3), 257-269.

Corlett, E. N., and Bishop, R. P. (1976). A technique for assessing postural discomfort. Ergonomics, 19(2), 175-182.

Corlett, E. N., and Eklund, J. A. E. (1986). Change of stature as an indicator of loads on the spine. In N. Corlett, J. Wilson, and I. Manenica, The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 232-242). Philadelphia, PA: Taylor and Francis.

Corlett, E. N., and Eklund, J. A. E. (1984, June). How does a backrest work? Applied Ergonomics, 15(2), 111-114.

Corlett, E. N., and Manenica. (1980). The effects and measurement of working postures. Applied Ergonomics, 11(1), 7-16.

Corlett, N., Wilson, J., and Manenica, I. (1986). The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium. Philadelphia, PA: Taylor and Francis.

Costanzo, A. (1989). Human factor capabilities for avoiding traffic accidents. Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, Volume II, (pp. 876-880). Washington, D.C.: National Highway Traffic Safety Administration.

Cramer, H., Liu, Y. K., and von Rosenberg, D. U. (1973). A distributed parameter model of the inertially loaded human spine. In Y.C. Fung and J.A. Brighton (eds.), Biomechanics Symposium. Properties of Biological Fluids and Solids; Mechanics of Tissues and Organs, (pp. 47-48). New York, NY: ASME.

Culley, S. J., Rudi, A., and Cuchet, D. (1992). The design of a car seat articulation system. FISITA XXIV International Congress Proceedings, Volume I.: Automotive Technology Serving Society. Technical Papers. Engineering for the Customer, (pp. 51-56). London: Institution of Mechanical Engineers.

Cursiter, M. C., and Harding, R. H. (1974, June). Proceedings: Electromyographic recordings of shoulder and neck muscles of seated subjects exposed to vertical vibrations. Journal of Physiology (Lond), 239(2), 117P-118P.

Dais, J. L., and Balachandra, M. (1974). Motion discomfort and transportation guideway form. Transportation Research, 8, 523-531.

Damberg, E., and Müller, G. (1978). Messtechnische und rechnerische Schwingungsuntersuchungen zur Optimierung von Fahrerhausaufhaengungen an Lastkraftwagen. [Measurement and analytical techniques of oscillation investigations to optimize driving compartment suspension of lorries]. FISITA XVII International Congress Proceedings, Volume II, (pp. 685-698). Budapest: OMKDK Technoinform.

Danese, G. (1975). A research study for an energy absorbing sliding seat. Proceedings of the 5th International Technical Conference on Experimental Safety Vehicles, (pp. 699-702). Washington, D.C.: Government Printing Office.

Dannhaus, D. M., Bittner, A. C., Ayoub, M. M., and Halcomb, C. G. (1977). Seating, console, and workplace design: Integration of literature and accommodation model. In A.S. Neal and R.F. Palasek (eds.), Proceedings of the Human Factors Society 21st Annual Meeting: Gateways to the Future, (pp. 88-91). Santa Monica, CA: Human Factors Society.

Danskin, N. (1975). Safety regulations for public service vehicles. Vehicle Safety Legislation - Its Engineering and Social Implications. Discussion Volume, (pp. 45-52). London: Mechanical Engineering Publications, Ltd.

Darcus, H. D., and Weddell, A. G. M. (1947). Some anatomical and physiological principles concerned in the design of seats for naval war-weapons. British Medical Bulletin, 5, 31-37.

Date, K. (1988). An examination of body support and fatigue in automobile seats. Proceedings of the 32nd Annual Meeting of the Human Factors Society: Riding the Wave of Innovation, Volume I, (pp. 593-597). Santa Monica, CA: Human Factors Society.

Davenport, W. G., Brooker, G., and Munro, N. (1971, December). Factors in social perception: Seating position. Perceptual and Motor Skills, 33(3), 747-752.

Davis, P. R. (1980). Engineering aspects of the spine. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 33-36). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Day, D. R. (1988). The dynamic performance of a variety of seat cushion materials under vertical impact loads (DCIEM-88-TR-53). Downsview, Ontario, Canada: Defence and Civil Institute of Environmental Medicine.

De Ree, J. J. (1989, October). The use of graphs in the ergonomic evaluation of tall pilot's sitting posture. Aviation, Space, and Environmental Medicine, 60, 1011-5.

DeHaven, H. (1952). Current safety considerations in the design of passenger seats for transport aircraft. New York, NY: Cornell University Medical College.

Demic, M. (1991). A contribution to optimization of vehicle seats. International Journal of Vehicle Design, 12(5-6), 618-629.

Dempsey, T. K. (1974, December). A model and predictive scale of passenger ride discomfort (NASA TM X-72623/TM X-72623). Hampton, VA: NASA, Langley Research Center.

Dempster, W. T. (1961). Free-body diagrams as an approach to the mechanics of human posture and motion. Chapter 5 in Evans et al. (eds.), Biomechanical Studies of the Musculo-Skeletal System, (pp. 81-135). Springfield, IL: Charles C. Thomas.

Dempster, W. T. (1955, July). Space requirements of the seated operator: Geometrical, kinematic, and mechanical aspects of the body with special reference to the limbs (WADC Technical Report 55-159). Wright-Patterson AFB, OH: Wright Air Development Center.

Dempster, W. T., Sherr, L. A., and Priest, J. G. (1964, September). Conversion scales for estimating humeral and femoral lengths and the lengths of functional segments in the limbs of American Caucasoid male. Human Biology, 36(3), 246-262.

Desjardins, S. P., and Harrison, H. D. (1972). The design, fabrication, and testing of an integrally armored crashworthy crew seat. Final report (USAAMRDL TR 71-5). Fort Eustis, VA: Army Air Mobility Research and Development Laboratory.

Desjardins, S. P., and Laananen, D. H. (1980). Aircraft crash survival design guide. Volume IV: Aircraft seats, restraints, litters, and padding. Final report (TR-7822/ USARTL TR 79-22D). Fort Eustis, VA: Army Air Mobility Research and Development Laboratory.

Devlin, W. A., and Roe, R. W. (1968). The eyellipse and considerations in the driver's forward field of view. SAE Technical Paper 680105. New York, NY: Society of Automotive Engineers, Inc.

Diebschlag, W., Heidinger, F., Kurz, B., and Heiberger, R. (1988). Recommendation for ergonomic and climatic physiological vehicle seat design. SAE Technical Paper 880055. Warrendale, PA: Society of Automotive Engineers, Inc.

Diebschlag, W., and Hormann, M. (1987, November). [Improving seating comfort in wheelchairs for the prevention of pressure sores]. Rehabilitation (Stuttgart), 26(4), 153-183.

Diebschlag, W., and Müller-Limmroth, W. (1980). Physiological requirements on car seats: some results of experimental studies. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 223-230). New York: Academic Press.

Diffrient, N., Tilley, A. R., and Bardagiy, J. C. (1974). Human scale 1/2/3. Cambridge, MA: MIT Press.

Dillard, J., Trafimow, J., Andersson, G. B., and Cronin, K. (1991, March). Motion of the lumbar spine. Reliability of two measurement techniques. Spine, 16(3), 321-324.

Dillon, J. (1981). The role of ergonomics in the development of performance tests for furniture. Applied Ergonomics, 12(3), 169-175.

Dimnet, J. (1980). The improvement in the results of kinematics of in vivo joints. Journal of Biomechanics, 13(8), 653-661.

Dines, J. H., Sutphen, J. H., Roberts, L. B., and Ashe, W. F. (1965, September). Intravascular pressure measurements during vibration. Archives of Environmental Health, 11, 323-326.

Dixon, M. E., Steward, P. B., Mills, F. C., Varvis, C. J., and Bates, D. V. (1961). Respiratory consequences of passive body movement. Journal of Applied Physiology, 16(1), 30-34.

Dolan, M. J., and Oilar, J. F. (1986). How seat design characteristics affect impact injury criteria. SAE Technical Paper 860638. Warrendale, PA: Society of Automotive Engineers, Inc.

Donati, P. M., Boldero, A. G., Whyte, R. T., and Stayner, R. M. (1984). The postural support of seats: A study of driver preferences during simulated tractor operation. Applied Ergonomics, 15(1), 2-10.

DonTigny, R. L. (1989, June). Seat angles and support [letter; comment]. Physical Therapy, 69(6), 510.

Drillis, R., and Contini, R. (1966, September). Body Segment Parameters (PB174 945). University Heights, NY: New York University, School of Engineering and Science.

Drummond, D. S., Narechania, R. G., Rosenthal, A. N., Breed, A. L., Lange, T. A., and Drummond, D. K. (1982). A study of pressure distributions measured during balanced and unbalanced sitting. The Journal of Bone and Joint Surgery, 1964A(7), 1034-1039.

Drury, C. G., and Coury, B. G. (1982, September). A methodology for chair evaluation. Applied Ergonomics, 13(3), 195-202.

Drury, C. G., and Francher, M. (1985, March). Evaluation of a forward-sloping chair. Applied Ergonomics, 16(1), 41-47.

Drury, C. G., and Searle, J. A. (1965). A study of the seating and control positions in commercial vehicle cabs. Lindley, England: The Motor Industry Research Association.

Drury, C. G., and Smith, C. R. (n.d.). Development of a vehicle seat deflector. Lindley, England: The Motor Industry Research Association.

Dul, J. (1986). Muscular coordination in working posture. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 115-125). Philadelphia, PA: Taylor and Francis.

Dunsker, S. B., Colley, D. P., and Mayfield, F. H. (1978). Kinematics of the cervical spine. Congress of Neurological Surgeons Proceedings Vol. 25, (pp. 174-183).

Dupuis, H., and Hartung, E. (1968, November). [Driver-space design of standard buses for one-man operations.] Untersuchung ueber die Fahrerplatzgestaltung fuer den "Standard-Linien" Bus im Einmannbetrieb. ATZ, 70(11), 389-394.

Dupuis, H., and Zerlett, G. (1986). The effects of whole-body vibration. New York: Springer-Verlag.

Dvorak, J., Panjabi, M. M., Novotny, J. E., Chang, D. G., and Grob, D. (1991, August). Clinical validation of functional flexion-extension roentgenograms of the lumbar spine. Spine, 16(8), 943-950.

Dvorak, J., Panjabi, M. M., Chang, D. G., Theiler, R., and Grob, D. (1991, May). Functional radiographic diagnosis of the lumbar spine. Flexion-extension and lateral bending. Spine, 16(5), 562-571.

Edwards, R. G., McCutcheon, E. P., and Knapp, C. F. (1972). Cardiovascular changes produced by brief whole-body vibration of animals. Journal of Applied Physiology, 32(3), 386-390.

Eklund, J. A. E., and Corlett, E. N. (1987). Evaluation of spinal loads and chair design in seated work tasks. Clinical Biomechanics, 2, 27-33.

Eklund, J. A. E., and Corlett, E. N. (1986). Experimental and biomechanical analysis of seating. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 319-330). Philadelphia, PA: Taylor and Francis.

Eklund, J. A. E., Corlett, E. N., and Johnson, F. (1983). A method for measuring the load imposed on the back of a sitting person. Ergonomics, 26(11), 1063-1076.

Eklund, J. A. E., and Corlett, E. N. (1984). Shrinkage as a measure of the effect of load on the spine. Spine, 9(2), 189-194.

Ellis, M. I., Seedhom, B. B., and Wright, V. (1984, April). Forces in the knee joint whilst rising from a seated position. Journal of Biomedical Engineering, 6(2), 113-120.

Elton, B., and Hubbard, R. (1993). Using anthropometric data to improve seat back comfort in current and future passenger car seats. Seat System Comfort and Safety, (pp. 43-57). Warrendale, PA: Society of Automotive Engineers, Inc.

Engdahl, S. (1974). Anthropometric measurements of adults (Report No. 29). Stockholm: Swedish Furniture Research Institute.

Engdahl, S. (1971). School-chairs (Report No. 24). Stockholm: Swedish Furniture Research Institute.

Engdahl, S. (1978). Specification for office furniture. In B. Jonsson (ed.), Sitting Work Postures, No. 12 (pp. 97-135). Sweden: National Board of Occupational Safety and Health.

Engdahl, S. (1977). Workchairs for dentists (Report No. 10). Stockholm: SPRI.

Engin, A. E., and Chen, S.-M. (1988). On the biomechanics of human hip complex in vivo--I. Kinematics for determination of the maximal voluntary hip complex sinus. Journal of Biomechanics, 21(10), 785-795.

Engin, A. E., Peindl, R. D., Berme, N., and Kaleps, I. (1984). Kinematic and force data collection in biomechancis by means of sonic emitters--I: Kinematic data collection methodology. Journal of Biomechanical Engineering, 106, 204-211.

Evans, B. E. (1986). Dual hardness seating cushions from a single head. Cellular Polymers, 5(1), 1-11.

Evans, F. G., Lissner, H. R., and Patrick, L. M. (1962). Acceleration-induced strains in the intact vertebral column. Journal of Applied Physiology, 17(3), 405-409.

Evans, F. G., and Lissner, H. R. (1959). Biomechanical studies on the lumbar spine and pelvis. Journal of Bone and Joint Surgery, 41-A(2), 278-290.

Evans, F. G., and Lissner, H. R. (1965). Studies on the energy absorbing capacity of human lumbar intervertebral discs. In D.M. Severy (ed.), Proceedings of the 7th Stapp Car Crash Conference, (pp. 386-402). Springfield, IL: Charles C. Thomas.

Evans, R. (1954). The relative crash protective qualities and deficiencies of passenger seat MIL-S-7877 (Aer) in forward and aft facing positions (TED No. NAM-AE-6303). Philadelphia, PA: Naval Air Material Center, Aeronautical Medical Equipment Laboratory.

Ewing, C. L., King, A. I., and Prasad, P. (1973). Structural considerations of the human vertebral column under +Gz impact acceleration. Journal of Aircraft, 9(1), 84-90.

Fairbanks, J. C. T., and O'Brien, J. P. (1980). The abdominal cavity and thoraco-lumbar fascia as stabilisers of the lumbar spine in patients with low back pain. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 83–88). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Fairley, T. E., and Griffin, M. J. (1989). The apparent mass of the seated human body: Vertical vibration. Journal of Biomechanics, 22(2), 81-94.

Fairley, T. E., and Griffin, M. J. (1986, February). A test method for the prediction of seat transmissibility. Passenger Comfort, Convenience and Safety: Test Tools and Procedures, (pp. 1-9). Warrendale, PA: Society of Automotive Engineers, Inc.

Faust, E., and Mozelt, K. (1989). [The seats of the 124 Mercedes-Benz car range]. ATZ, 91, 510-516.

Ferguson, A. C., Keating, J. F., Delargy, M. A., and Andrews, B. J. (1992, July). Reduction of seating pressure using FES in patients with spinal cord injury: A preliminary report. Paraplegia, 30(7), 474-478.

Ferguson-Pell, M. W. (1990). Seat cushion selection. Journal of Rehabilitation Research and Development Clinical Supplement, (2), 49-73.

Ferguson-Pell, M., Barbenel, J. C., and Evans, J. H. (1980). The pressure distributing properties of hospital mattresses and their covers. Proceedings of the International Conference on Rehabilitation Engineering 1980, (pp. 178-182). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Ferguson-Pell, M., Wilkie, I. C., and Barbenel, J. C. (1980). Pressure sore prevention for the wheelchair user. Proceedings of International Conference on Rehabilitation Engineering 1980, (pp. 167-171). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Fine, L., Silverstein, B., Armstrong, T., Joseph, B., and Buchholz, B. (1986). A pilot study of postural characteristics of jobs associated with an elevated risk of rotor cuff tendinitis. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 39-43). Philadelphia, PA: Taylor and Francis.

Firooznia, H., Rafii, M., Golimbu, C., and Sokolow, J. (1983). Computed tomography of pressure sores. Journal of Computed Tomography, 7, 367-373.

Fitch, J. (1962). Driver-vehicle fit. Passenger Car Design and Highway Safety, (p. 75). Association for the Aid of Crippled Children.

Fitzgerald, J. G. (1973). The IAM type aircrew lumbar support: Fitting, manufacture and use (304/IAM-AIRCREW-EQUIP-GP-REP-304). Farnborough, England: Great Britain Royal Air Force, Institute of Aviation Medicine.

Floyd, W. F. (1967, October). Postural factors in the design of motor car seats. Proceedings of the Royal Society of Medicine, 60(10), 953-955.

Floyd, W. F., and Roberts, D. F. (1958). Anatomical physiological and anthropometric principles in the design of office chairs and tables (B.S. 3044: 1958). London, England: British Standards Institution.

Floyd, W. F., and Roberts, D. F. (1958). Anatomical and physiological principles in chair and table design. Ergonomics, 2, 1-16.

Floyd, W. F., and Silver, P. H. S. (1955). The function of the erectores spinae muscles in certain movements and postures in man. Journal of Physiology, 129, 184-203.

Floyd, W. F., and Ward, J. S. (1969, March). Anthropometric and physiological considerations in school, office and factory seating. Ergonomics, 12(2), 132-139.

Foley, D. E., and Allemang, R. J. (1988). Vibration considerations concerning vehicular seating systems. Experimental Techniques, 12(7), 19-21.

Forbes, M. J., Holte, R. N., Paul, I. T., and von Kampen, E. (1980). A comparison of three custom seating techniques. Proceedings of International Conference on Rehabilitation Engineering 1980, (pp. 147-152). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Foulke, J. A., Goldstein, S. A., and Armstrong, T. J. (1981). An EMG preamplifier system for biomechanical studies. Journal of Biomechanics, 14(6), 437-438.

Frisch, P. H. (1993). Development of a new manikin prototype featuring an articulated/flexible spine and integrated data acquisition and storage system. Human Surrogates: Design, Development and Side Impact Protection, (pp. 59-68) SAE Technical Paper 930101. Warrendale, PA: Society of Automotive Engineers, Inc.

Frobin, W., and Hierzholzer, E. (1980). Rasterstereographic measurement of the body surface. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 43-44). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Fryer, D. I. (1958). Aircraft passenger-seat design and crash survival (FPRC 1055). Farnborough, England: Great Britain Royal Air Force, Institute of Aviation Medicine.

Futami, T., Umetsu, Y., Osawa, S., Hirai, K., Okubo, S., and Obara, H. (1989). [Development of automatic driving position system]. Nissan Technical Review, 161-167.

Gamba, E., and Sala, G. (1989, November). [A ergonomic chair on an oscillating pivot with an electrical motor for the prevention of occupational lumbar pathology due to the seated posture]. Giornale Italiano di Medicina del Lavoro, 11(6), 289-291.

Gamet, D., and Maton, B. (1989). The fatigability of two antagonistic muscles in human isometric voluntary submaximal contraction: An EMG study. European Journal of Applied Physiology, 58, 361-368.

Garfin, S. R., and Katz, M. M. (1985). The vertebral column: Clinical aspects. In A.M. Nahum and J.W. Melvin (eds.), The Biomechanics of Trauma, (pp. 301-340). Norwalk, CT: Appleton-Century-Crofts.

Geoffrey, S. P. (1961). A 2-D mannikin--The inside story. X-rays used to determine a new standard for a basic design tool. SAE Technical Paper 267A. New York, NY: Society of Automotive Engineers, Inc.

Ghista, D. N. (. (1982). Human body dynamics: Impact, occupational, and athletic aspects. New York, NY: Oxford University Press.

Glaister, D. H. (1961). Properties of polyurethane foams in relation to their use as ejection seat cushion materials. Farnborough, England: Great Britain Royal Air Force, Institute of Aviation Medicine.

Glance, P. (1988). Computer-aided engineering of seat structures. SAE Technical Paper 861394. Warrendale, PA: Society of Automotive Engineers, Inc.

Glassford, E. J. (1977). The relationship of hemodynamics to seating comfort. SAE Technical Paper 790289. Warrendale, PA: Society of Automotive Engineers, Inc.

Glassford, E. J., and Shvartz, E. (1979). Metabolic heat retention and the vehicle operator. SAE Technical Paper 770248. Warrendale, PA: Society of Automotive Engineers, Inc.

Goel, V. K., Goyal, S., Clark, C., Nishiyama, K., and Nye, T. (1985). Kinematics of the whole lumbar spine: Effect of discectomy. Spine, 10(6), 543-554.

Gola, M. M. (1980). Mechanical design, contructional details and calibration of a new force plate. Journal of Biomechanics, 13, 113-128.

Golich, H., and Weigelt, H. (1985). Improvements of the drivers comfort and safety by various means of vibration reduction. In I.D. Brown, R. Goldsmith, K. Coombes, and M.A. Sinclair (eds.), Ergonomics International 85, (pp. 220-222). Philadelphia, PA: Taylor and Francis.

Gomez, T., Beach, G., Cooke, C., Hrudley, W., and Goyert, P. (1991). Normative database for trunk range of motion, strength, velocity, and endurance with the Isostation B-200 lumbar dynamometer. Spine, 16(1), 15-21.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., and Walker, R. A. (1989). 1988 anthropometric survey of U.S. Army personnel: Methods and summary statistics. Final report (NATICK/TR-89/027). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Goswami, A., Ganguli, S., and Chatterjee, B. B. (1987). Anthropometric characteristics of disabled and normal Indian men. Ergonomics, 30(5), 817-823.

Gouw, G. J., Rakheja, S., Sankar, S., and Afework, Y. (1990). Increased comfort and safety of drivers of off-highway vehicles using optimal seat suspension. SAE Technical Paper 901646. Warrendale, PA: Society of Automotive Engineers, Inc.

Gracovetsky, S., Kary, M., Levy, S., Ben, S. R., Pitchen, I., and Helie, J. (1990, December). Analysis of spinal and muscular activity during flexion/extension and free lifts. Spine, 15(12), 1333-1339.

Graf, M., Guggenbühl, U., and Krueger, H. (1993). Investigations on the effects of seat shape and slope on posture, comfort and back muscle activity. International Journal of Industrial Ergonomics, 12, 91-103.

Grandjean, E. (1984). Ergonomics and Health in Modern Offices. Proceedings of the International Scientific Conference on Ergonomic and Health Aspects in Modern Offices. Philadelphia, PA: Taylor and Francis.

Grandjean, E. (1980). Fitting the task to the man. New York: International Publications Service.

Grandjean, E. (1984). Postural problems at office machine work stations (introductory paper). In E. Grandjean (ed.), Ergonomics and Health in Modern Offices. Proceedings of the International Scientific Conference on Ergonomic and Health Aspects in Modern Offices, (pp. 445-455). Philadelphia, PA: Taylor and Francis.

Grandjean, E. (1980). Sitting posture of car drivers from the point of view of ergonomics. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 205-213). New York: Academic Press.

Grandjean, E., Boni, A., and Kretzschmar, H. (1969). The development of a rest chair for healthy and notalgic people. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture, (pp. 193-202). London: Taylor and Francis, Ltd.

Grandjean, E., Hünting, W., Wotzka, G., and Schaerer, R. (1973). An ergonomic investigation of multipurpose chairs. Human Factors, 15(3), 247-255.

Grandjean, E., Hünting, W., and Pidermann, M. (1983). VDT workstation design: preferred settings and their effects. Human Factors, 25(2), 161-175.

Grandjean, W., Hunting, W., and Nishiyama, K. (1984, June). Preferred VDT workstation settings, body posture and physical impairments. Applied Ergonomics, 15(2), 99-104.

Grieco, A. (1986). Sitting posture: An old problem and a new one. Ergonomics, 29(3), 345-362.

Grieco, A., Occhipinti, E., Colombini, D., Menoni, O., Bulgheroni, M., Frigo, C., and Boccardi, S. (1989). Muscular effort and musculo-skeletal disorders in piano students: Electromyographic, clinical and preventive aspects. Ergonomics, 32(7), 697-716.

Griffing, J. P. (1960). The occupational back. Chapter 2 in Modern Occupational Medicine, (pp. 219-227). Philadelphia, PA: Lea and Febiger.

Griffin, M. J. (1978). The evaluation of vehicle vibration and seats. Applied Ergonomics, 9(1), 15-21.

Griffin, M. J. (1986). Evaluation of vibration with respect to human response. SAE Technical Paper 860047. Warrendale, PA: Society of Automotive Engineers, Inc.

Griffin, M. J. (1975, March). Vertical vibration of seated subjects: Effects of posture, vibration level, and frequency. Aviation, Space, and Environmental Medicine, 46(3), 269-276.

Griffin, M. J., Whitham, E. M., and Parsons, K. C. (1982, July). Vibration and comfort. I. Translational seat vibration. Ergonomics, 25(7), 603-630.

Grigg, A. O. (1978). A review of techniques for scaling subjective judgements (TRRL Supplemental Report 379). Crowthorne, Berkshire, England: Transport and Road Research Laboratory.

Grubbs, T. (1975). Standards enforcement test requirements for FMVSS 207, "Seating Systems." Laboratory procedures for FMVSS 207, Seating Systems (TP-207-07/MVSS 207). Washington, D.C.: National Highway Traffic Safety Administration, Office of Standards Enforcement.

Gryp, D., and Foster, D. (1989). A truck seat with advanced features. SAE Technical Report 892522. Warrendale, PA: Society of Automotive Engineers, Inc.

Gusev, L. P. (1989, December). [Hygienic substantiation of the rational construction of a machine operator's seat]. Gigiena I Sanitariia, 12, 95-96.

Gusev, L. P. (1988, May). [Physiological and hygienic requirements for the rational construction of a tractor operator's seat]. Gigiena Truda I Professionalnye Zabolevaniia, 5, 38-41.

Haas, W. A. (1989). Geometric model and spinal motions of the average male in seated postures. Unpublished Master's thesis. East Lansing, MI: Michigan State University.

Hablitzel, H., and Hildebrandt, C. (1975). Wohlbefinden im Fahrzeug am Beispiel des VW-Golf. [Comfort in a motor vehicle exemplified by the VW-Golf]. ATZ, 250-254.

Habsburg, S., and Middendorf, L. (1980). Calibrating comfort: Systematic studies of human responses to seating. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 214-222). New York: Academic Press.

Habsburg, S., and Middendorf, L. (1977). What really connects in seating comfort?--Studies of correlates of static seat comfort. SAE Technical Paper 770247. Warrendale, PA: Society of Automotive Engineers, Inc.

Hagberg, C., and Hagberg, M. (1989). Surface EMG amplitude and frequency dependence on exerted force for the upper trapezius muscle: A comparison between right and left sides. European Journal of Applied Physiology, 58, 641-645.

Hagberg, M. (1979). The amplitude distribution of surface EMG in static and intermittent static muscular performance. European Journal of Applied Physiology, 40, 265-272.

Hagberg, M. (1986). Optimizing occupational muscular stress of the neck and shoulder. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 109-114). Philadelphia, PA: Taylor and Francis.

Haggerty, T. I., Katz, J. J., Lockwood, R. J., and Watts, A. (1985). All-MDI flexible foams in automotive applications. SAE Technical Paper 850485. Warrendale, PA: Society of Automotive Engineers, Inc.

Hagner, W., and Szymkowiak, E. (1982). Zespoly przeciazeniowe kregoslupa ledzwiowego u kierowcow samochodowych. [Syndromes of lumbar spine overloading in automobile drivers]. Medycyna Pracy, 33(5-6), 339-342.

Hakim, N. S., and King, A. I. (1976). An experimentally validated three-dimensional finite element model of a vertebra. In R.E. Mates and C.R. Smith (eds.), Advances in Bioengineering, (pp. 11-12). New York, NY: ASME.

Haldenwanger, H. G. (1982). Entwicklung und Erprobung von Sitzen fuer Personenkraftwagen. [Development and testing of passenger car seats]. ATZ, (9), 437-442, 445.

Haley, J. L.(1972). Crashworthy troop seat designs. U.S. Army Aviation Digest, 18(4), 52-58.

Hall, E. C. (1983). Seating for transportation. Proceedings of the 20th Annual Conference of the Ergonomics Society of Australia and New Zealand. Theme: Economics in the Community, (pp. 191-211). Australia: Ergonomics Society of Australia and New Zealand.

Hall, G. O. (1969). Providing ride comfort for the operator of off-highway vehicles. SAE Technical Paper 690567. New York, NY: Society of Automotive Engineers.

Hall, M. A. W. (1972). Back pain and car-seat comfort. Applied Ergonomics, 3(2), 82-91.

Hallen, A. (1977). Comfortable hand control reach of passenger car drivers. SAE Technical Paper 770245. Warrendale, PA: Society of Automotive Engineers, Inc.

Hammond, D. C., and Roe, R. W. (1972). Driver head and eye positions. SAE Technical paper 720200. New York, NY: Society of Automotive Engineers, Inc.

Hamon, J., and Mauron, G. (1969). Le siege de choc Peugeot a absorption d'energie. [Peugeot shock-seat]. Technical Aspects of Road Safety, (36), 5.1-5.15.

Hanai, T., and Nagashima, H. (1988). Car seat system of the future as seen in "ARC-X". Proceedings of the 32nd Annual Meeting of the Human Factors Society. Riding the Wave of Innovation, Volume I, (pp. 588-592). Santa Monica, CA: Human Factors Society.

Harder, A. (1972). Airdraulic seat system. Elk Grove Village, IL: Coach and Car Equipment Corporation.

Hardy, W. G., Lissner, H. R., Webster, J. E., and Gurdjian, E. S. (1959). Repeated loading tests of the lumbar spine: A preliminary report. American College of Surgeons Surgical Forum, 9, 690-695.

Harris, G. F., Coad, J. E., Pudlowski, R., Abraham, E. A., and Millar, E. A. (1987, December). Thoracic suspension: Quantitative effects upon seating pressure and posture. Paraplegia, 25(6), 446-53.

Harris, G. F., Knox, T. A., Larson, S. J., Sances, A., and Millar, E. A. (1982). A method for the display of balance platform center of pressure data. Journal of Biomechanics, 15(10), 741-745.

Harris, G. F., Salamon, N. J., and Weber, R. C. (1981). Effects of subject position on balance platform measurements. Journal of Biomechanical Engineering, 103, 213-216.

Harvey, G. R. (1980). The engineering aspects of the human trunk. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 97-102). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Haslegrave, C. M. (1980). Anthropometric profile of the British car driver. Ergonomics, 23(5), 437-467.

Haslegrave, C. M. (494). Measurement of the Eye Heights of British Car Drivers Above the Road Surface. Crowthorne, England: Transport and Road Research Laboratory.

Haslegrave, C. M., Wilson, J. R., Corlett, E. N., and Manenica, I. (1990). Work Design in Practice. Proceedings of the Third International Occupational Ergonomics Symposium. London: Taylor and Francis.

Hauck, C., Lenz, W., Meiller, H., and Tietz, J. (1988). Entwicklung einer Fahrersitzrueckenlehne aus Ultramid fuer Nutzfahrzeuge. [Development of a driver's seat backrest made of Ultramid for commercial vehicles]. ATZ, (12), 689-692, 694-695.

Hawkins, F. (1974, February). Ergonomic aspects of crew seats in transport aircraft. Aerospace Medicine, 45(2), 196-203.

Hearon, B. F., and Brinkley, J. W. (1986). Effect of seat cushions on human response to +Gz impact. Aviation, 57(2), 113-121.

Heidinger, H., Kurz, B., and Diebschlag, W. (1988). [Car seats under physiological and biomechanical aspects]. ATZ, 90, 545-548.

Heinsalmi, P. (1986). Method to measure working posture loads at working sites. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 100-104). Philadelphia, PA: Taylor and Francis.

Helander, M. (1976). Vehicle control and driving experience: A psychophysical approach. Proceedings of the 6th Congress of the International Ergonomics Association, (pp. 335-339). Santa Monica, CA: Human Factors Society.

Helbig, K. (1978, March). [Distribution of the seating pressure on unupholstered chairs]. Anthropologischer Anzeiger, 36(3), 194-202.

Heliovarra, M. (1987). Occupation and risk of herniated lumbar intervertebral disc or sciatica leading to hospitalization. Journal of Chronic Disease, 40(3), 259-264.

Hendler, E., and Evans, R. G. (1954). Evaluation of collapsible type ditching seat (TED No. NAM AE-6316). Philadelphia, PA: Naval Air Material Center, Aeronautical Medical Equipment Laboratory.

Hendrix, R. W., Calenoff, L., Lederman, R. B., and Neiman, H. L. (1981). Radiology of pressure sores. Radiology, 138, 351-356.

Henning, H. (1988). [Twenty years of John Andrews R&D Center]. ATZ, 90, 626-628.

Herider, E. A., and LeFevre, W. F. (1967). The truck seating art - Its state and future. SAE Technical Paper 670043. New York, NY: Society of Automotive Engineers, Inc.

Herszkowicz, I., Smith, D., Garber, S., Swarts, A., Krouskop, T. A., Biddy, R., Sheffer, D., and Zuniga, E. (1980). Pressure distribution under the seated disabled worker performing maximal reach. Proceedings of International Conference on Rehabilitation Engineering 1980, (pp. 175-177). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Hertzberg, H. T. E. (1972). The human buttocks in sitting: Pressures, patterns, and palliatives. SAE Technical Paper 720005. New York, NY: Society of Automotive Engineers, Inc.

Hertzberg, H. T. E. (1955). Some contributions of applied physical anthropology to human engineering. Annals New York Academy of Sciences, 63, 616-629.

Highway Safety Research Institute. (1967). Bibliography of integrated seat and occupant restraint design. Appendix B. Volume III of IV. Final report (7A/RFP-142). Ann Arbor, MI: The University of Michigan, Highway Safety Research Institute.

Hill, D. W., Cureton, K. J., and Collings, M. A. (1989). Circadian specificity in exercise training. Ergonomics, 32(1), 79-92.

Hilton, B. C. (1966). Design of low cost seating for effective packaging of vehicle occupants. Proceedings of the 10th Stapp Car Crash Conference, (pp. 207-218). New York, NY: Society of Automotive Engineers, Inc.

Hilton, B. C. (1966). Development of safety seating. Vehicle Crash and Injury Prevention Conference Proceedings, (pp. 105-107). England: Society of Motor Manufacturers and Traders, Ltd.

Hirsch, C. (1955). The reaction of intervertebral discs to compression forces. Journal of Bone and Joint Surgery, 37-A(6), 1188-1196.

Hirsch, C., and Nachemson, A. (1954). New observations on the mechanical behavior of lumbar discs. Acta Orthopaedica Scandinavica, 23, 254-283.

Hobson, D. A. (1992, September). Comparative effects of posture on pressure and shear at the body-seat interface. Journal of Rehabilitation Research and Development, 29(4), 21-31.

Hobson, D. A., Heinrich, M. J., and Hanks, S. F. (1983). Bead seat insert seating system. In B.R. Bowman (ed.), Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 209-211). Bethesda, MD: Rehabilitation Engineering Society of North America.

Hobson, D. A., and Tooms, R. E. (1992, March). Seated lumbar/pelvic alignment. A comparison between spinal cord- injured and noninjured groups. Spine, 17(3), 293-298.

Hodgson, V. R., Lissner, H. R., and Patrick, L. M. (1963). The effect of jerk on the human spine (ASME 63-WA-316). Detroit, MI: Wayne State University, Biomechanics Research Center.

Hodgson, V. I., Lissner, H. R., and Patrick, L. M. (1963). Response of the seated human cadaver to acceleration and jerk with and without seat cushions. Human Factors, 5(5), 505-523.

Hoffman, E. R. (1977). An evaluation of wearing comfort of seat belt installations complying with Australian design rules 4B, 4C, and 5B. Seat Belt Seminar, (pp. 87-109). Canberra, Australia: Australian Government Publishing Service.

Holte, R. N. (1983). The simple wheelchair insert: A wheelchair-based seating system for mildly involved cerebral palsied children. In B.R. Bowman (ed.), Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 200-202). Bethesda, MD: Rehabilitation Engineering Society of North America.

Hontschik, H. (1974). Eine schwingungstechnische und arbeitsphysiologische Untersuchungsmethode fuer Kraftfahrzeuge. [A test method of motor-vehicles from the point of view of vibrations and work physiology]. Technical Aspects of Road Safety, 3.1-3.63.

Hontschik, H., Kinkel, H. J., Rasch, W., and Schmid, I. (1974). Schwingungstechnische und arbeitsphysiologische Untersuchung von Fahrzeugsitzen verschiedener Bauart. [Investigations relative to vibrations and ergonomic conditions of vehicle seats of various design]. ATZ, 216-222.

Hontschik, H., and Schmid, I. (1972). Der Sitz als Verbindungselement von Mensch und Kraftfahrzeug. [The function of the seat as a link between man and motor vehicle]. ATZ, 155-161.

Hood, W. B., and Higgins, L. S. (1965). Circulatory and respiratory effects of whole-body vibration in anaesthetized dogs. Journal of Applied Physiology, 20(6), 1157-1162.

Hoover, G. N., and Ashe, W. F. (1962). Respiratory response to whole body vertical vibration. Aerospace Medicine, 33, 980-984.

Hoover, G. N., Asher, W. F., Dines, J. H., and Fraser, T. M. (1961). Vibration studies. III: Blood pressure responses to whole-body vibration in anaethetized dogs. Archives of Environmental Health, 3, 426-432.

Hosea, T. M., Simon, S. R., Delatizky, J., Wong, M. A., and Hsieh, C.-C. (1986). Myoelectric analysis of the paraspinal musculature in relation to automobile driving. Spine, 11(9), 928-936.

Hubbard, R. P., Haas, W. A., Boughner, R. L., Conole, R. A., and Bush, N. J. (1993). New biomechanical models for automobile seat design. SAE Technical Paper 930110. Warrendale, PA: Society of Automotive Engineers, Inc.

Hubbard, R. P., and Reynolds, H. M. (1984). Anatomical geometry and seating. SAE Technical Paper 840506. Warrendale, PA: Society of Automotive Engineers, Inc.

Hult, L. (1954). Cervical, dorsal and lumbar spinal syndromes. Acta Orthopaedica Scandinavica Suppl. 17.

Hult, L. (1954). The Munkfors investigation. Acta Orthopaedica Scandinavica Suppl, 16.

Hunting, W., and Grandjean, E. (1972). [Effects of various seat surface inclinations on sitting posture and comfort]. Int Z Angew Physiol, 31(1), 1-9.

Husain, T. (1953, October). An experimental study of some pressure effects on tissues with reference to the bed-sore problem. Journal of Pathology and Bacteriology, 66, 347-358.

Hutchinson, T. P., and Haslegrave, C. M. (1980). Determination of patterns of human body measurements by use fof partial correlations. Ergonomics, 23(5), 475-483.

Iizuka, H., Yanagishima, T., Kataoka, T., and Seno, T. (1985). The development of drowsiness warning devices. Proceedings of the 10th International Technical Conference on Experimental Safety Vehicles, (pp. 282-288). Washington, D.C.: National Highway Traffic Safety Administration.

Ikeda, T., and Kimura, H. (1988, October). Present and future aspects of automobile interior materials. JSAE Journal, 9(4), 78-85.

Institution of Mechanical Engineers. (1980). Engineering aspects of the spine, I Mech E Conference Publications 1980-2/ SAE-MEP-119. London: Mechanical Engineering Publications Ltd. for The Instituion of Mechanical Engineers.

Institute for Consumer Ergonomics. (1981, November). Seated anthropometry: The problems involved in a large scale survey of disabled and elderly people. Ergonomics, 24(11), 831-845.

Iwasaki, S., Matsuoka, Y., and Yamanoi, T. (1988). [Objective evaluation of seating comfort]. Jidosha-Gijutsu, 42(11), 1403-1408.

Jacob, R. J. K., Egeth, H. E., and Bevan, W. (1976). The face as a data display. Human Factors, 18(2), 189-200.

Jacobson, I. D., Richards, L. G., and Kuhlthau, A. R. (1978). Models of human reaction to vehicle environments. Applied Ergonomics, 9(3), 169-172.

Jaeger, M., and Luttman, A. (1986). Biomechanical model calculations of spinal stress for different working postures in various workload situations. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 144-154). Philadelphia, PA: Taylor and Francis.

Jaeger, M., and Luttmann, A. (1989). Biomechanical analysis and assessment of lumbar stress during load lifting using a dynamic 19-segment human model. Ergonomics, 32(1), 93-112.

Jaeger, M., and Luttmann, A. (1987). Determination of spinal stress by biomechanical model calculations and comparisons with spinal mechanical strength. In G. Bergmann, R. Kolbell, and A. Rohlmann (eds.), Biomechanics: Basic and Applied Research, (pp. 473-478). Martinus Nijhoff: Dordrecht.

Janeway, R. N. (1975). Human vibration tolerance criteria and applications to ride evaluation. SAE Technical Paper 750166. Warrendale, PA: Society of Automotive Engineers, Inc.

Jayson, M. I. V. (1980). Structure and function of the human spine. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 9-10). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Jeffrey, R. S., and Cook, P. L. (1991). Seat belts and reclining seats. Injury, 22(5), 416-417.

Jensen, R. H. (1975). An investigation of muscle lines of action about the hip: A centroid line approach vs the straight line approach. Journal of Biomechanics, 8, 103-110.

Jindo, T., Yanagishima, T., and Shimizu, Y. (1990). An evaluation structure of automobile interiors using multivariate analysis. FISITA XXIII International Congress Proceedings, Volume II. The Promise of New Technology in the Automotive Industry. Technical Papers, (pp. 635-641) SAE Technical Paper 905202. Warrendale, PA: Society of Automotive Engineers, Inc.

Johnson, D. A., Samin, J. C., and Neve, M. (1989, August). A new design of vehicle seat intended to alleviate lower back pain. Journal of Biomechanical Engineering, 111(3), 261-262.

Jones, J. C. (1969, March). Methods and results of seating research. Ergonomics, 12(2), 171-181.

Jonsson, B. (1970). The functions of individual muscles in the lumbar part of the erector spinae muscle. Electromyography, 10, 5.

Jonsson, B. a. A. (1978). Functional anatomical and biomechanical aspects on sitting. In B. Jonsson (ed.), Sitting Work Postures, No. 12 (pp. 6-17). Sweden: National Board of Occupational Safety and Health.

Jorgensen, K., Fallentin, N., Krogh-Lund, C., and Jensen, B. (1988). Electromyography and fatigue during prolonged low-level static contractions. European Journal of Applied Physiology, 57, 316-321.

Joyce, J., and Dunn, W. H. (1992). Evaluation of seat design parameters for improved occupant ride. FISITA XXIV International Congress Proceedings, Volume I. Automotive Technology Serving Society. Technical Papers. Engineering for the Customer, (pp. 43-50). London: Institution of Mechanical Engineers.

Judic, J. M., Cooper, J. A., Truchot, P., Effenterre, P. V., and Duchamp, R. (1993). More objective tools for the integration of postural comfort in automotive seat design. SAE Technical Paper 930113. Warrendale, PA: Society of Automotive Engineers, Inc.

Jurgens, H. W. (1980). Body movements of the driver in relation to sitting conditions in the car: A methodological study. In D.J. Oborne and J.A. Levis (ed.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 249-256). New York: Academic Press.

Kabada, M. P., Ferguson-Pell, M. W., Palmieri, V. R., and Cochran, G. V. B. (1984). Ultrasound mapping of the buttock-cushion interface contour. Archives of Physical Medicine and Rehabilitation, 65, 467-469.

Kahn, J. F., and Monod, H. (1989). Fatigue induced by static work. Ergonomics, 32(7), 839-846.

Kaigle, A. M., Pope, M. H., Fleming, B. C., and Hansson, T. (1992, April). A method for the intravital measurement of interspinous kinematics. Journal of Biomechanics, 25(4), 451-456.

Kaleps, I., Clauser, C. E., Young, J. W., Chandler, R. F., Zehner, G. F., and McConville, J. T. (1984, December). Investigation into the mass distribution properties of the human body and its segments. Ergonomics, 27(12), 1225-1237.

Kamijo, K., Tsujimura, H., Obara, H., and Katsumata, M. (1982). Evaluation of seating comfort. SAE Technical Paper 820761. Warrendale, PA: Society of Automotive Engineers, Inc.

Kantowitz, B. H. (1992). Selecting measures for human factors research. Human Factors, 34(4), 387-398.

Katsuraki, M., and Nagashima, H. (1992). [Analysis of optimum seat figure with sitting posture to realize seat comfort]. Japan: Japan Automobile Research Institute.

Kaulbars, U. (1990). Schwingungseinwirkung an Arbeitsplaetzen von Kraftfahrern auf schweren Lastkraftwagen. [Vibrations acting on heavy-truck driver] (BIA-Report 2/90). Germany: Berufsgenossenschaftliches Institut fuer Arbeitssicherheit.

Kauss, W., and Goehlich, H. (1982). Aktive Schwingungsisolierung des Fahrerplatzes ungefederter Fahrzeuge. [Active insulation of the driver's seat against vibration in unsprung vehicles]. ATZ, (9), 425-428, 431-432, 434.

Keegan, J. J. (1953). Alterations of the lumbar curve related to posture and seating. Journal of Bone and Joint Surgery, 35-A(3), 589-603.

Keegan, J. J. (1966, October 1). Choosing seating for hospital patients. Hospitals, 40(19), 72-73.

Keegan, J. J. (1962). Evaluation and improvement of seats. Industrial Medicine and Surgery, 137-148.

Keegan, J. J. (1964). The medical problem of lumbar spine flattening in automobile seats. SAE Technical Paper 838A. New York, NY: Society of Automotive Engineers, Inc.

Keegan, J. J., and Radke, A. O. (1964). Designing vehicle seats for greater comfort. SAE Journal, 72(9), 50-55.

Keesen, W., During, J., Beeker, T. W., Goudfrooij, H., and Crowe, A. (1984). Recordings of the movement at the intervertebral segment L5-S1: A technique for the determination of the movement in the L5-S1 spinal segment by using three specified postural positions. Spine, 9(1), 83-90.

Kelsey, J. L. (1975). An epidemiological study of acute herniated lumbar intervertebral discs. Rheumatol, Rehabil, 14, 144-156.

Kelsey, J. L. (1975). An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral discs. International Journal of Epidemiology, 4, 197-204.

Kelsey, J. L., Githens, P. B., O'Conner, T., Weil, U., Calogero, J. A., Holford, T. R., White, A. A., Walter, S. D., Ostfeld, A. M., and Southwick, W. O. (1984). Acute prolapsed lumbar intervertebral disc: An epidemiological study with special reference to driving automobiles and cigarette smoking. Spine, 9(6), 608-613.

Kelsey, J. L., and Hardy, R. J. (1975). Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral discs. American Journal of Epidemiology, 102, 63-73.

Kember, P. A. (1976). The Benesh movement notation used to study sitting behavior. Applied Ergonomics, 7(3), 133-136.

Kendall, P. H. (1967). Car seats and back-ache. Proceedings of the Royal Society of Medicine, 60(10), 958-959.

Keown, I. (1993). The search for the perfect airline seat. Frequent Flyer, (January), 34-39.

Keyserling, W. M. (1986). Postural analysis of the trunk and shoulders in simulated real time. Ergonomics, 29(4), 569-583.

Keyserling, W. M., and Armstrong, T. J. (1990). Job evaluation procedures to identify ergonomic stress. Chapter 14 in Work Design in Practice. The Proceedings of the Third International Occupational Ergonomics Symposium, (pp. 103-109). New York: Taylor and Francis.

Keyserling, W. M., Stetson, D. S., Silverstein, B. A., and Brouwer, M. L. (1993). A checklist for evaluating ergonomic risk factors associated with upper extremity cumulative trauma disorders. Ergonomics, 36(7), 807-831.

Kilbom, A., Persson, J., and Jonsson, B. (1986). Risk factors for work-related disorders of the neck and shoulder--with special emphasis on working postures and movements. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 55-54). Philadelphia, PA: Taylor and Francis.

King, A. I. (1984). The spine -- Its anatomy, kinematics, injury mechanisms, and tolerance to impact. In B. Aldman and A. Chapon (eds.), The Biomechanics of Impact Trauma, (pp. 191-225). Amsterdam: Elsevier Science Publishers B.V.

Kinkel, H. J., Maxion, H., and Hontschik, H. (1971). Arbeitsphysiologische Untersuchungen an Kraftfahrzeugsitzen. [Occupational physiological studies on motor vehicle seats]. Arbeitsmedizin, 6(11), 298-303.

Kippers, V., and Parker, A. W. (1984). Posture related to myoelectric silence of erectores spinae during trunk flexion. Spine, 9(7), 740-745.

Kippers, V., and Parker, A. W. (1989). Validation of single-segment and three-segment spinal models used to represent lumbar flexion. Journal of Biomechanics, 22(1), 67-75.

Kirk, N. S., Ward, J. S., Asprey, E., Baker, E., and Peacock, B. (1969, May). Discrimination of chair seat heights. Ergonomics, 12(3), 403-413.

Kishe, A., and Hata, S. (1991). The concept of future man-machine system and the evaluation method of vigilance. SAE Technical Paper 910114. Warrendale, PA: Society of Automotive Engineers, Inc.

Kleeman, W. B. (1982). Air traffic controllers' chairs evaluated for the Federal Aviation Administration. Human Factors Society Bulletin, 25(12), 5-7.

Kleeman, W. B. (1986). AMP seats offer working comfort. Wood and Wood Products, 91(11), 34-38.

Klein, A. B., Snyder-Mackler, L., Roy, S. H., and DeLuca, C. J. (1991, June). Comparison of spinal mobility and isometric trunk extensor forces with electromyographic spectral analysis in identifying low back pain. Physical Therapy, 71(6), 445-454.

Kleinhanss, G., and Piekarski, C. (1982, April). [The assessment of whole-body vibrations (oscillations) with respect to their effect on seated or standing subjects (author's transl)]. Biomedizinische Technik (Berlin), 27(4), 87-95.

Knutsson, B., Lindh, K., and Telhag, H. (1966). Sitting--An electromyographic and mechanical study. Acta Orthopaedica Scandinavica, 37, 415.

Kohara, J., and Sugi, T. (1972). Development of biomechanical manikins for measuring seat comfort. SAE Technical paper 720006. New York, NY: Society of Automotive Engineers, Inc.

Koller, M., Stidl, H. G., Kundi, M., and Haider, M. (1982). [The influence of different materials for furniture fabrics on heat regulation and comfort]. Zbl Bakt Hyg, Abr. Orig. B, 176, 291-304.

Koogle, T. A., Piziali, R., Nagel, D. A., and Perkash, I. (1976). A motion transducer for use in the intact in vitro human lumbar spine. In R.E. Mates and C.R. Smith (eds.), Advances in Bioengineering, (pp. 33-34). New York, NY: ASME.

Koogle, T. A., Piziali, R. L., Nagel, D. A., and Perkash, I. (1977). A motion transducer for use in the intact in-vitro human lumbar spine. Journal of Biomechanical Engineering, 99(3), 160-165.

Kosiak, M. (1961, January). Etiology and decubitus ulcers. Archives of Physical Medicine and Rehabilitation, 19-29.

Kozawa, Y., Sugimoto, G., and Suzuki, Y. (1986). A new ride comfort meter. SAE Technical Paper 860430. Warrendale, PA: Society of Automotive Engineers, Inc.

Kozlowski, E. (1988). Comfort and convenience in automotive seating. Body Engineering Journal, 16(2), 62-64.

Kramer, J., Lenz, G., Klein, W., Laturnus, H., Kramer, H., and Steinhaus, M. (1979, February 16). [Improved seating posture in automobile driving]. Med Welt, 30(7), 238-241.

Krause, H. E., and Shirazi, M. (1970). Research on a distributed parameter mathematical model of the human body in dynamic mechanical environments (AMRL-TR-70-113). Wright-Patterson AFB, OH: Air Force Systems Command, Aerospace Medical Research Laboratory.

Kriukova, D. N. (1977, April). [Electomyographic analysis of the degree of fatigue of the postural muscles in man depending on the shape of the work seat]. Gigiena Truda I Professionalnye Zabolevaniia, 4, 12-16.

Kroemer, K. H. (1989). Engineering anthropometry. Ergonomics, 32(7), 767-784.

Kroemer, K. H. (1971, October). Seating in plant and office. American Industrial Hygiene Association Journal, 32(10), 633-652.

Kroemer, K. H., and Robinette, J. C. (1969, April). Ergonomics in the design of office furniture. Industrial Medicine and Surgery, 38(4), 115-125.

Krogman, W. M., and Johnston, F. E. (1963). Human mechanics - Four monographs abridged (AMRL-TDR-63-123). Wright-Patterson AFB, OH: Air Force Systems Command, Aerospace Medical Research Laboratory.

Krouskop, T. A. (1983). A synthesis of the factors that contribute to pressure sore formation. Medical Hypotheses, 11, 255-267.

Krouskop, T. A., Garber, S. L., Trono, R., and Bushong, C. (1980). Effects of cushion modification on pressure distribution. Proceedings of the International Conference on Rehabilitation Engineering 1980, (pp. 172-174). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

Kubokawa, C. C. (1974). Integral aircraft passenger seat. Technical support package. The NASA Ames integral aircraft passenger seat concept - A human engineering approach (NASA TB 73-10495/ ARC 10799). Moffett Field, CA: National Aeronautics and Space Administration, Ames Research Center.

Lackner, J. R., and Teixeira, R. A. (1977). Optokinetic motion sickness: Continuous head movements attenuate the visual induction of apparent self-rotation and symptoms of motion sickness. Aviation, Space, and Environmental Medicine, 48(3), 248-253.

Lamb, T. W., Falchuk, K. H., Mithoefer, J. C., and Tenney, S. M. (1966). Mechanical and chemical ventilatory stimulus interaction at low and high altitudes. Journal of Applied Physiology, 21(2), 399-403.

Lamb, T. W., and Tenney, S. M. (1966). Nature of vibration hyperventilation. Journal of Applied Physiology, 21(2), 404-410.

Lander, C., Korbon, G. A., DeGood, D. E., and Rowlingson, J. C. (1987, April). The Balans chair and its semi-kneeling position: An ergonomic comparison with the conventional sitting position. Spine, 12(3), 269-272.

Lange, W. (1974). [Subjective response to combined vibrations, acting on man via the seat (author's translation)]. European Journal of Applied Physiology, 33(2), 151-170.

Langeron, P., and Leman, S. (1970, January). [Lumbar sympathectomy in atherosclerosis of lower limbs. Determination of the results as function of the seat of predominant lesions.] 106 cases. Angeiologie, 22(1), 41-49.

Lawrence, J. L. (1955). Rheumatism in coal miners, Part III. Occupational factors. British Journal of Industrial Medicine, 12, 249-261.

Lay, W. E., and Fisher, L. C. (1940). Riding comfort and cushions. SAE Journal, 47(5), 482-496.

Le, K. M., Madsen, B. L., Barth, P. W., Ksander, G. A., Angell, J. B., and Vistnes, L. M. (1984). An in-depth look at pressure sores using monolithic silicon pressure sensors. Plastic and Reconstructive Surgery, 74(6), 745-756.

Le Carpentier, E. F. (1969). Easy chair dimensions for comfort -- A subjective approach. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture, (pp. 214-223). London: Taylor and Francis Ltd.

Leatherwood, J. D. (1975). Vibrations transmitted to human subjects through passenger seats and considerations of passenger comfort (NASA TN D-7929). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.

Leatherwood, J. D., Dempsey, T. K., and Clevenson, S. A. (1980). A design tool for estimating passenger ride comfort within complex ride environments. Human Factors, 22(3), 291-312.

Leatherwood, J. D., and Dempsey, T. K. (1976). A model for prediction of ride quality in a multifactor environment (NASA TM X-72842). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.

Leatherwood, J. D., and Dempsy, T. K. (1976). Psychophysical relationships characterizing human response to whole-body sinusoidal vertical vibrations. Technical note (L-10496/ NASA TN D-8188). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.

Lee, J., and Ferraiuolo, P. (1993). Seat comfort. Seat System Comfort and Safety, (pp. 1-5). Warrendale, PA: Society of Automotive Engineers, Inc.

Lee, N. S., and Schneider, L. W. (1988, November). A preliminary investigation of driver lean in late model vehicles with bench and bucket seats. Final report (UMTRI-88-49). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Lee, N. S., Schneider, L. W., and Ricci, L. L. (1990). Review of selected literature related to seating discomfort (UMTRI-90-12). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Lee, S. D. (1978). A study of the differences and characteristics between the nations, in the measured values of the human body and the working area. International Journal of Production Research, 16(4), 335-347.

Lepoutre, F. X., and Malvache, N. (1977). Process of measures representing spine curvatures in a sagittal plane for a seated subject, submitted to acceleration in a horizontal plane. Proceedings of the 3rd International Conference on Impact Trauma, (pp. 367-378). Bron, France: IRCOBI.

Lepoutre, F. X., Roger, D., and Loslever, P. (1986). Experimental analysis of a visuo-postural system in an office workstation. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 363-372). Philadelphia, PA: Francis and Taylor.

Levine, S. P., Kett, R. L., Cederna, P. S., Bowers, L. D., and Brooks, S. V. (1989, September). Electrical muscle stimulation for pressure variation at the seating interface. Journal of Rehabilitation Research and Development, 26(4), 1-8.

Levis, J. A. (1978). The seated bus passenger -- A review. Applied Ergonomics, 9(3), 143-150.

Lewin, T. (1969). Anthropometric studies on Swedish industrial workers when standing and sitting. Ergonomics, 12(6), 883-902.

Libertiny, G. Z. (1984). Passenger car seating loads: A human factors engineering problem. SAE Technical Paper 840509. Warrendale, PA: Society of Automotive Engineers, Inc.

Liedtke, K. A., and Schmid, P. G. (1969). Effect of vibration on total vasular resistance in the forelimb of the dog. Journal of Applied Physiology, 26(1), 95-100.

Life, M. A., and Pheasant, S. T. (1984). An integrated approach to the study of posture in keyboard operation. Applied Ergonomics, 15(2), 83-90.

Liu, Y. K. (1968). The human body under time-dependent boundary conditions. Progress report (Office of Research Administration Report No. 01279-1-P). Ann Arbor, MI: The University of Michigan.

Lloyd, N. M. (1960). Comfort criteria for seat design. Automotive Industries, 123(9), 44-48.

Loczi, J. (1993). Ergonomic assessment of exiting automobiles. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. Designing for Diversity, Volume 1, (pp. 401-405). Santa Monica, CA: Human Factors and Ergonomics Society.

Lovsund, P., Nilson, G., Thorngren, L., Haland, Y., and Svensson, S. E. A test-rig for parametric studies of the car seat. SAE Technical Paper 930347. Warrendale, PA: Society of Automotive Engineers, Inc.

Lowry, M. (1989, December). Are you sitting comfortably? Good seating requirements in a patient care setting. Professional Nurse, 5(3), 162-164.

Lowry, M. (1992). Hospital seating and pressure areas. Nursing Standard, 6(34), 10-11.

Lueder, R. K. (1983, December). Seat comfort: A review of the construct in the office environment. Human Factors, 25(6), 701-711.

Lundervold, A. J. S. (1951). Electromyographic investigations of position and manner of working in typewriting. Acta Orthopaedica Scandinavica, Suppl. 84.

Lundervold, A. J. S. (1951). Electromyographic investigations during sedentary work, especially typewriting. British Journal of Physical Medicine, 14, 31.

Lundervold, A. J. S. (1958). Electromyographic investigation during typewriting. Ergonomics, 1, 226.

Maertens, D. (1993). Automotive Seating Comfort Criteria, 4th Edition. Warren, MI: Comfort Criteria Task Force, General Motors Corporation.

Magora, A. (1972). Investigation of the relation between low back pain and occupation. 3. Physical requirements: Sitting, standing and weight lifting. Industrial Medicine and Surgery, 415.

Mahanty, S. D., and Roemer, R. B. (1979). Thermal response of skin to application of localized pressure. Archives of Physical Medicine and Rehabilitation, 60, 584-590.

Mahanty, S. D., and Roemer, R. B. (1980). Thermal and circulatory response of tissue to localized pressure application: A mathematical model. Archives of Physical Medicine and Rehabilitation, 61, 335-340.

Mairiaux, P., Davis, P. R., Stubbs, D. A., and Baty, D. (1984, August). Relation between intra-abdominal pressure and lumbar moments when lifting weights in the erect posture. Ergonomics, 27(8), 883-94.

Mairiaux, P., and Malchaire, J. (1988). Relation between intra-abdominal pressure and lumbar stress: Effect of trunk posture. Ergonomics, 31(9), 1331-1342.

Mallikarjunarao, C., Padgaonkar, A. J., Levine, R. S., Gurdjian, E. S., and King, A. I. (1977). Kinesiology of the human spine under static loading. In R. Skalak and A.B. Schultz (eds.), Biomechanics Symposium, (pp. 99-102). New York, NY: ASME.

Manary, M. A., Schneider, L. W., Flannagan, C. C., and Eby, B. H. (1994). Evaluation of the SAE J826 3-D manikin measures of driver positioning and posture. SAE Technical Paper 941048. Warrendale, PA: Society of Automotive Engineers, Inc.

Mandal, A. C. (1986). Investigation of the lumbar flexion of office workers. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 345-354). Philadelphia, PA: Taylor and Francis.

Mandal, A. C. (1981, March). The seated man (Homo Sedens). The seated work position. Theory and practice. Applied Ergonomics, 12(1), 19-26.

Mandal, A. C. (1984). What is the correct height of furniture. In E. Grandjean (ed.), Ergonomics and Health in Modern Offices. Proceedings of the International Scientific Conference on Ergonomic and Health Aspects in Modern Offices, (pp. 471-476). Philadelphia, PA: Taylor and Francis.

Mandal, A. C. (1970, September 3). [Work chair with a tipping seat]. Ugeskr Laeger, 132(36), 1699-1703.

Mandal, A. C. (1976, March). Work-chair with tilting seat. Ergonomics, 19(2), 157-164.

Mandal, A. C. (1974, May 1). [Working stool with movable seat]. Sygeplejersken, 74(17), 48-51.

Mandel, A. C. (1975, March 15). Letter: Work-chair with tilting seat. Lancet, 1(7907), 642-643.

Manenica, I. (1986). A technique for postural load assessment. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 270-277). Philadelphia, PA: Taylor and Francis.

Manenica, I., and Corlett, E. N. (1973). A model of vehicle comfort and a method for its assessment. Ergonomics, 16(6), 849-854.

Marek, T., and Noworol, C. (1986). The influence of under- and overstimulation on sitting posture. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 168-178). Philadelphia, PA: Taylor and Francis.

Marks, L. E. (1988). Magnitude estimation and sensory matching. Perception and Psychophysics, 43(6), 511-525.

Marks, L. E. (1987). On cross-modal similarity: Auditory-visual interactions in speeded discrimination. Journal of Experimental Psychology, 13(3), 384-394.

Marks, L. E., Szczesiul, R., and Ohlott, P. (1986). On the cross-modal perception of intensity. Journal of Experimental Psychology, 12(4), 517-534.

Martin, B. J., Roll, J. P., and Gauthier, G. M. (1984, January). Spinal reflex alterations as a function of intensity and frequency of vibration applied to the feet of seated subjects. Aviation, Space, and Environmental Medicine, 55(1), 8-12.

Maton, B., and Gamet, D. (1989). The fatigability of two agonistic muscles in human isometric voluntary submaximal contraction: An EMG study. European Journal of Applied Physiology, 58, 369-374.

Matsuhashi, K. (1991). Improvement of seating comfort. Proceedings of the 6th International Pacific Conference on Automotive Engineering, Volume 1, (pp. 625-633). Seoul, Korea: Korea Society of Automotive Engineers.

Matsuoka, Y., and Hanai, T. (1988). Study of comfortable sitting posture. SAE Technical Paper 880054. Warrendale, PA: Society of Automotive Engineers, Inc.

May, D., Fincke, R., Bretz, J. C., Cancelliere, L., and Gallo, S. (1980). Individually customized postural support system. Proceedings of the International Conference on Rehabilitation Engineering 1980, (pp. 144-146). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

McCloskey, D. I., Matthews, P. B. C., and Mitchell, J. H. (1972). Absence of appreciable cardiovascular and respiratory responses to muscle vibration. Journal of Applied Physiology, 33(5), 623-626.

McConville, J. T., Churchill, T. D., Kaleps, I., Clauser, C. E., and Cuzzi, K. (1980). Anthropometric relationships of body and body segment moments of inertia (AMRL-TR-80-119). Wright Patterson Air Force Base, OH: Aerospace Medical Research Laboratories.

McEnvoy, J. T., and Spiegelhoff, S. P. (1985). Multimodular foam -- A unique process in multifirmness high resiliency polyurethane foam. Journal of Cellular Plastics, 21(3), 192-197.

McFarland, R. A., Damon, A., Stoudt, H. W., Moseley, A. L., Dunlap, J. W., and Hall, W. A. (1953). Human body size and capabilities in the design and operation of vehicular equipment. Boston, MA: Harvard School of Public Health.

McGill, S. M., and Norman, R. W. (1987). Reassessment of the role of intra-abdominal pressure in spinal compression. Ergonomics, 30(11), 1565-1588.

Meldrum, J. F. (1965). Automobile driver eye position. SAE Technical Paper 650464. New York, NY: Society of Automotive Engineers, Inc.

Meldrum, J. F. (1965). Driver Eye Position (Technical Report No. S-65-3). Dearborn, MI: Engineering and Research Staff, Ford Motor Company.

Mellin, G., Kiiski, R., and Weckstrom, A. (1991, September). Effects of subject position on measurements of flexion, extension, and lateral flexion of the spine. Spine, 16(9), 1108-1110.

Melvin, J. (1988). Using biomechanical impact response data. AATD System Technical Characteristics, Design Concepts, and Trauma Assessment Criteria. (Phase 1 Task E-F Final Report in DOT-HS-807-224). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Messenger, A. J., and Griffin, M. J. (1989). Effects of anthropometric and postural variables on the transmission of whole-body vertical vibration from seat-to-head. Technical report (Report No. 172). England: Southampton University, Institute of Sound and Vibration Research.

Miles, J. (1978). Is your car killing you? Or rather, are its seats? Autocar, 149(4268), 23-28.

Miller, J. M., and Gatchell, S. M. (1975). A research design to collect data for a second generation eyellipse. SAE Technical Paper 750362. Warrendale, PA: Society of Automotive Engineers, Inc.

Miller, J. A. A., and Skogland, L. B. (1980). A comparison of the mechanical behavior of adolescent and adult spinal motion segments. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 117). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Miller, S. A., Mayer, T., Cox, R., and Gatchel, R. J. (1992, March). Reliability problems associated with the modified Schober technique for true lumbar flexion measurement. Spine, 17(3), 345-348.

Milne, J. S., and Lauder, I. J. (1974). Age effects in kyphosis and lordosis in adults. Annals of Human Biology, 1, 327-337.

Milner, N. P., Corlett, E. N., and O'Brien, C. (1986). A model to predict recovery from maximal and submaximal isometric exercise. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 126-135). Philadelphia, PA: Taylor and Francis.

Montgomery, L. D., and Glassford, E. J. (1978). A pulsating cushion that improves lower body hemodynamics of seated individuals. SAE Technical Paper 780421. Warrendale, PA: Society of Automotive Engineers.

Montreuil, S., and Laville. (1986). Cooperation between ergonomists and workers in the study of posture in order to modify work conditions. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 293-304). Philadelphia, PA: Taylor and Francis.

Moore, S., Bergman, J. S., Edwards, G., Cowsar, D., Echols, S. D., and Forbes, J. (1982). The DESEMO customized seating support -- Custom-molded seating for severely disabled persons. Physical Therapy, 62(4), 460-463.

Moore, S., and Brunt, D. (1991, August). Effects of trunk support and target distance on postural adjustments prior to a rapid reaching task by seated subjects. Archives of Physical Medicine and Rehabilitation, 72(9), 638-641.

Moore, S., Brunt, D., Nesbitt, M. L., and Juarez, T. (1992, May). Investigation of evidence for anticipatory postural adjustments in seated subjects who performed a reaching task. Physical Therapy, 72(5), 335-343.

Moraal, J., Van Eig, A. J., and Riersma, J. B. J. (1977). Comfort evaluation of passenger cars--The development of a simplified test procedure. SAE Technical Paper 770251. Warrendale, PA: Society of Automotive Engineers, Inc.

Morris, J. M., Lucas, D. B., and Bresler, B. (1961). Role of the trunk in stability of the spine. Journal of Bone and Joint Surgery, 43-A(3), 327-351.

Morrison, D. W. (1980). Interior cab dimensions of heavy duty motor vehicles. Washington, D.C.: Federal Highway Administration, Bureau of Motor Carrier Safety.

Moscarini, F. (1968, September 26). [Collaboration between engineering and medicine for the purpose of comfort of the driver's seat and habitability of the automobile]. Minerva Medica, 59(77), 4051-4052.

Mourant, R. R., Pak, T. -., and Moussa-Hamouda, E. (1978). Dynamic eye positions by vehicle type. Final report of the Second Generation Eyellipse Project. Detroit, MI: Wayne State University, Department of Industrial Engineering and Operations Research.

Muksian, R., and Nash, C. J. (1974, May). A model for the response of seated humans to sinusoidal displacements of the seat. Journal of Biomechanics, 7(3), 209-215.

Munton, J. S. (1982, July). An overview of research on seating. Engineering in Medicine, 11(3), 107-110.

Nachemson, A. (1966). Electromyographyic studies on the vertebral portion of the psoas muscle. Acta Orthopaedica Scandinavica, 37, 177-190.

Nachemson, A. (1960). Lumbar intradiscal pressure. Experimental studies on post-mortem material. Acta Orthopaedica Scandinavica Suppl, 43, 7-104.

Nachemson, A. (1959). Measurement of intradiscal pressure. Acta Orthopaedia Scandinavia, 28, 269-289.

Nachemson, A. (1968). The possible importance of the psoas muscle for stabilization of the lumbar spine. Acta Orthopaedia Scandinavia, 39, 47-57.

Nachemson, A., and Elfstrom, G. (1970). Intravital dynamic pressure measurements in lumbar discs. Scandinavian Journal of Rehabilitation Medicine, Suppl. 1, 3-40.

Nachemson, A., and Morris, J. M. (1964). In vivo measurements of intradiscal pressure. Journal of Bone and Joint Surgery, 46-A(5), 1077-1092.

Nachemson, A. L., Schultz, A. B., and Berkson, M. H. (1979). Mechanical properties of human lumbar spine motion segments - Influences of age, sex, disc level, and degeneration. Spine, 4(1), 1-8.

Nag, P. K. (1986). Influence of posture on muscle contraction behaviour in arm and leg ergometry. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 155-167). Philadelphia, PA: Taylor and Francis.

Najjar, M. F., and Rowland, M. (1987). Anthropometric reference data and prevalence of overweight, United States, 1976-80 (Series 11, No. 238). Washington, D.C.: U.S. Department of Health and Human Services, Public Health Service, National Center for Health Statistics.

Nakamichi, H., Ueno, K., and Kamiya, K. (1991). [Improvement of seat characteristics for reduction of driver's physical stress]. Jidosha-Gijutsu, 45(1), 102-105.

Nakaya, H., and Okiyama, H. (1993). A development of statistical human back contour model for backrest comfort evaluation. Seat System Comfort and Safety, (pp. 77-87). Warrendale, PA: Society of Automotive Engineers, Inc.

Nelham, R. L. (1975, October). The manufacture of moulded supportive seating for the handicapped. Biomedical Engineering, 10(10), 379-381.

Nelham, R. L. (1984, February). Principles and practice in the manufacture of seating for the handicapped. Physiotherapy, 70(2), 54-58.

Nemeth, G., and Ohlsen, H. (1985). In vivo moment arm lengths for hip extensor muscles at different angles of hip flexion. Journal of Biomechanics, 18(2), 129-140.

Neveu, A. J., Koppelman, F. S., and Stopher, P. R. (1979). Perceptions of comfort, convenience, and reliability for the work trip. Transportation Research Record, 723, 59-63.

Newstead, S. E., Pollard, P., and Riezebos, D. (1987). The effect of set size on the interpretation of quantifiers used in rating scales. Applied Ergonomics, 18(3), 178-182.

Nicholson, A. N., and Stone, B. M. (1987, July). Influence of back angle on the quality of sleep in seats. Ergonomics, 30(7), 1033-1041.

Nicolaidis, G. C. (1975). Quantification of the comfort variable. Transportation Research, 9, 55-66.

Niederer, P., Birchler, B., Mesqui, F., and Lehareinger, Y. (1985). Computer assisted single-view photogrammetry for accident scene documentation. SAE Technical Paper 850067. Warrendale, PA: Society of Automotive Engineers, Inc.

Nilson, G., Lovsund, P., Thorngren, L., Haland, Y., and Svensson, S. (1993). The potential injury-reducing benefits of a well designed car seat. Proceedings of the International Conference on the Biomechanics of Impacts, (pp. 421-431). Bron, France: IRCOBI.

Nishikiori, T., and Matsuhashi, K. (1984). [Comfort of seat]. Mazda Technical Journal, (2), 32-38.

Nordin, M., Hultman, G., Philipsson, R., Ortelius, A., and Andersson, G. B. J. (1986). Dynamic measurements of trunk movements during work tasks. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 74-81). Philadelphia, PA: Taylor and Francis.

Nyquist, G. W. (1977). Height, weight, and sex of injured automobile occupants (Enviromental Activites Publication No. A-3459). Warren, MI: General Motors Corporation.

Nyquist, G. W., and Murton, C. J. (1975). Static bending response of the human lower torso. Proceedings of the 19th Stapp Car Crash Conference, (pp. 513-541). Warrendale, PA: Society of Automotive Engineers, Inc.

Nyquist, G. W., and Patrick, L. M. (1976). Lumbar and pelvic orientations of the vehicle seated volunteer. Proceedings of the 20th Stapp Car Crash Conference, (pp. 665-696). Warrendale, PA: Society of Automotive Engineers, Inc.

Oborne, D. J. (1978). Passenger comfort -- An overview. Applied Ergonomics, 9(3), 131-136.

Oborne, D. J. (1978). Techniques available for the assessment of passenger comfort. Applied Ergonomics, 9(1), 45-49.

Oborne, D. J. (1977). Vibration and passenger comfort. Applied Ergonomics, 8(2), 97-101.

Oborne, D. J. (1978). Vibration and passenger comfort: Can data from subjects be used to predict passenger comfort? Applied Ergonomics, 9(3), 155-161.

Oborne, D. J. (1983). Whole-body vibration and international standard ISO 2631: A critique. Human Factors, 25(1), 55-69.

Oborne, D. J., and Boarer, P. A. (1982). Subjective response to whole-body vibration: The effects of posture. Ergonomics, 25(7), 673-681.

Oborne, D. J., and Clarke, M. J. (1975). Questionnaire surveys of passsenger comfort. Applied Ergonomics, 6(2), 97-103.

Oborne, D. J., and Levis, J. A. (eds.) (1980). Human factors in transport research. Volume 2 - User factors: Comfort, the environment and behaviour. New York: Academic Press.

O'Connor, P. D., Robinson, M. E., Shirley, F. R., and Millan, M. M. (1993, July). The effect of marker placement deviations on spinal range of motion determined by video motion analysis. Physical Therapy, 73(7), 478-483.

Oestroem, C. A. (1981). Bussfoerares arbetsmiljoe: Stol. [Working environment of professional bus drivers: Seat] (229). Linkoeping, Sweden: Statens Vaeg- och Trafikinstitut.

Okushima, H. (1970). Study on hydrodynamic pressure of lumbar intevertebral disc. Arch Jap Chir, 39, 45.

Oliver, R. J. (1970). A study of the comfort characteristics of production car seats (MIRA 1970/12). Lindley, England: Motor Industry Research Association.

Oliveri, M. (1988, June 21). [Correct sitting posture--An important element in the therapy and prevention of chronic back complaints. Ergonomic requirements for correct furniture for sitting]. Schweizerische Rundschau fur Medizin Praxis, 77(25), 706-711.

Olsen, F. G. (1965). Comfort packages for diverse passenger car objectives. SAE Technical paper 650463. New York, NY: Society of Automotive Engineers, Inc.

O'Neill, H., Politi-Meeks, D., and Perkash, I. (1983). Commercialization process for a research and development wheelchair cushion. In B.R. Bowman (ed.), Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 197-199). Bethesda, MD: Rehabilitation Engineering Society of North America.

Oomens, C. W. J., van Campen, D. H., and Grootenboer, H. J. (1987). In vitro compression of a soft tissue layer on a rigid foundation. Journal of Biomechanics, 20(10), 923-935.

O'Reagan, J. R., and Law, D. F. (1980). Reusable casting technique for customized total contact seating. Proceedings of the International Conference on Rehabilitation Engineering 1980, (pp. 153-155). Ottawa, Canada: Canadian Medical and Biological Engineering Society.

O'Rourke, D. A. (1983). Webbed elastic for postural seating in cases of severe deformity. In B.R. Bowman (ed.), Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 206-208). Bethesda, MD: Rehabilitation Engineering Society of North America.

Osvalder, A. -., Neumann, P., Loevsund, P., and Nordwall, A. (1993). Dynamic load response of the in vitro lumbar spine in flexion. Proceedings of the International Conference on the Biomechanics of Impacts, (pp. 239-251). Bron, France: IRCOBI.

Osvalder, A. -., Neuman, P., Aldman, B., Loevsund, P., and Nordwall, A. (1987). Methods for studying effects on the spine under different loads. Proceedings of the International Conference on the Biomechanics of Impacts, (pp. 239-249). Bron, France: IRCOBI.

Oxford, H. W. (1969). Anthropometric data for educational chairs. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture, (pp. 26-47). London: Taylor and Francis, Ltd.

Oxland, T. R., Crisco, J. J., Panjabi, M. M., and Yamamoto, I. (1992). The effect of injury on rotational coupling at the lumbosacral joint. Spine, 17(1), 74-80.

Oxland, T. R., Lin, R. M., and Panjabi, M. M. (1992, July). Three-dimensional mechanical properties of the thoracolumbar junction. Journal of Orthopaedic Research, 10(4), 573-580.

Paddan, G. S., and Griffin, M. J. (1988). The transmission of translational seat vibration to the head--II. Horizontal seat vibration. Journal of Biomechanics, 21(3), 199-206.

Paddan, G. S., and Griffin, M. J. (1988). The transmission of translational seat vibration to the head-I. Vertical seat vibration. Journal of Biomechanics, 21(3), 191-197.

Paddan, G. S., and Griffin, M. J. (1992). The transmission of translational seat vibration to the head: The effect of measurement position at the head. Proceedings of the Institution of Mechanical Engineers. Part H, Journal of Engineering in Medicine, 206(3), 159-168.

Palanichamy, M. S., Patil, M. K., and Ghista, D. N. (1978, June). Minimization of the vertical vibrations sustained by a tractor operator, by provision of a standard-type tractor seat suspension. Annals of Biomedical Engineering, 6(2), 138-153.

Panjabi, M. M. (1973). Three-dimensional mathematical model of the human spine structure. Journal of Biomechanics, 6(6), 671-680.

Panjabi, M. M., Brand, R. A., and White, A. A. III,. (1976). Three-dimensional flexibility and stiffness properties of the human thoracic spine. Journal of Biomechanics, 9(4), 185-192.

Panjabi, M., Chang, D., and Dvorak, J. (1992, February). An analysis of errors in kinematic parameters associated with in vivo functional radiographs. Spine, 17(2), 200-205.

Panjabi, M. M., Takata, K., and Goel, V. K. (1983, May). Kinematics of lumbar intervertebral foramen. Spine, 8(4), 348-357.

Panjabi, M. M., and White, A. A. III,. (1980). Basic biomechanics of the spine. Neurosurgery, 7(1), 76-93.

Panjabi, M., and White, A. A. III,. (1971). A mathematical approach for three-dimensional analysis of the mechanics of the spine. Journal of Biomechanics, 4(3), 203-211.

Paquet, N., Malouin, F., Richards, C. L., Dionne, J. P., and Comeau, F. (1991, May). Validity and reliability of a new electrogoniometer for the measurement of sagittal dorsolumbar movements. Spine, 16(5), 516-519.

Park, W. H., and Wambold, J. C. (1976). Correlation of objective and subjective bus-ride ratings. Transportation Research Record, 584, 55-63.

Parsons, K. C., and Griffin, M. J. (1978, August). The effect of rotational vibration in roll and pitch axes on the discomfort of seated subjects. Ergonomics, 21(8), 615-625.

Parsons, K. C., and Griffin, M. J. (1983). Methods for predicting passenger vibration discomfort. SAE Technical Paper 831029. Warrendale, PA: Society of Automotive Engineers, Inc.

Parsons, K. C., and Griffin, M. J. (1980). Predicting the vibration discomfort of seated passengers. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 114-122). New York: Academic Press.

Parsons, K. C., and Griffin, M. J. (1982, July). Vibration and comfort. II. Rotational seat vibration. Ergonomics, 25(7), 631-644.

Patil, K. M. (1988). Tractor-occupant vibration response and its minimization by a new seat suspension. Mechanics Research Communications, 15(6), 341-352.

Patil, K. M., Palanichamy, M. S., and Ghista, D. N. (1977). Dynamic response of human body seated on a tractor and effectiveness of suspension systems. SAE Technical Paper 770932. Warrendale, PA: Society of Automotive Engineers, Inc.

Patil, M. K., Palanichamy, M. S., and Ghista, D. N. (1978). Man-tractor system dynamics: Towards a better suspension system for human ride comfort. Journal of Biomechanics, 11(8-9), 397-406.

Patil, M. K., Palanichamy, M. S., and Ghista, D. N. (1980). Response of human body to tractor vibrations and its minimisation by provision of relaxation suspensions to both wheels and seat at the plane of centre of gravity. Medical and Biological Engineering and Computing, 18(5), 554-562.

Paton, C. R., Pickard, E. C., and Hoehn, V. (1940). Seat cushions and the ride problem. SAE Journal, 47, 273-283.

Patridge, R. E., and Anderson, J. A. (1969). Back pain in industrial workers. In Proceedings of the International Rheumatology Congress.

Patterson, R. P., and Fisher, S. V. (1980). Pressure and temperature patterns under the ischial tuberosities. Bulletin of Prosthetics Research, 17(2), 5-11.

Pearcy, M. J. (1985). Stereo radiography of lumbar spine motion. Acta Orthopedaedica Scandinavica, 56(212), 1-45.

Pearcy, M., Porteck, I., and Shepherd, J. (1984). Three-dimensional x-ray analysis of normal movement in the lumbar spine. Spine, 9(3), 294-297.

Pepermans, R. G., and Corlett, E. N. (1983). Cross-modality matching as a subjective assessment technique. Applied Ergonomics, 14(3), 169-176.

Peteroy, F. E. (1981, September). Anatomy of non-task seating: How to determine seated comfort for the body at rest. Contract, 23(9), 106-110.

Petrofsky, J. S., Glaser, R. M., Phillips, C. A., Lind, A. R., and Williams, C. (1982). Evaluation of the amplitude and frequency components of the surface EMG as an index of muscle fatigue. Ergonomics, 25(3), 213-223.

Pheasant, S. (1986). Bodyspace: Anthropometry, Ergonomics and Design. Philadelphia, PA: Taylor and Francis.

Pheasant, S. T. (1982). A technique for estimating anthropometric data from the parameters of the distribution of stature. Ergonomics, 25(11), 981-992.

Philippart, N. L., Kuechenmeister, T. J., Ferrara, R. A., and Arnold, A. J.. (1985). The effects of the steering wheel to pedal relationship on driver-selected seat position. SAE Technical Paper 850311. Warrendale, PA: Society of Automotive Engineers.

Philippart, N. L., Kuechenmeister, T. J., and Stanick, J. M. (1986). Truck driver selected seat position model. SAE Technical Paper 861131. Warrendale, PA: Society of Automotive Engineers, Inc.

Philippart, N., Stanick, J., and Kuechenmeister, T. (1985). Describing truck driver eye, head, stomach, knee and seat locations in heavy truck space. In R.W. Swezey, L.B. Strother, T.J. Post, and M.G. Knowles (eds.), Proceedings of the 29th Annual Meeting of the Human Factors Society, Volume I, (pp. 443-446). Santa Monica, CA: Human Factors Society.

Phillipart, N. L., Roe, R. W., Arnold, A. J., and Kuechenmeister, T. J. (1984). Driver selected seat position model. SAE Technical Paper 840508. Warrendale, PA: Society of Automotive Engineers, Inc.

Picard, F., and Wisner, A. (1961). How can the physiologist contribute to the improvement of automobile seats. Billancourt, France: Regie Nationale des Usines Renault.

Pietsch, H. (1984). The automatic leveling air suspension seat for industrial vehicles. SAE Technical Paper 840507. Warrendale, PA: Society of Automotive Engineers, Inc.

Podoloff, R. M. (1993). Automotive seating analysis using thin, flexible tactile sensor arrays. SAE Technical Paper 930112. Warrendale, PA: Society of Automotive Engineers, Inc.

Pope, M. H., Broman, H., and Hansson, T. (1989, October). The dynamic response of a subject seated on various cushions. Ergonomics, 32(10), 1155-1166.

Pope, M. H., Broman, H., and Hansson, T. (1990, June). Factors affecting the dynamic response of the seated subject. Journal of Spinal Disorders, 3(2), 135-42.

Pope, M. H., Wilder, D. G., Buturla, E., Matteri, R., Frymoyer, W. W., and Frymoyer, J. W. (1977). Radiographic and biomechanical studies of the human spine. Final report (AFOSR-TR-0063). Washington, D.C.: Air Force Office of Scientific Research, Bolling Air Force Base.

Pope, M. H., Wilder, D. G., Jorneus, L., Broman, H., Svensson, M., and Andersson, G. (1987, November). The response of the seated human to sinusoidal vibration and impact. Journal of Biomechanical Engineering, 109(4), 279-284.

Pope, M. H., Wilder, D. G., and Frymoyer, J. W. (1980). Vibration as an aetiologic factor in low back pain. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 11-17). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Popplow, J. R., and Bossi, L. L. M. (1988). Canadian forces flight trial of individually molded fibreglass lumbar supports (DCIEM 88-RR-12). Downsview, Ontario, Canada: Defence and Civil Institute of environmental Medicine.

Porter, J. M., and Norris, B. J. (1987). The effects of posture and seat design on lumbar lordosis. In E.D. Megaw (ed.), Contemporary Ergonomics, (pp. 191-196). New York: Taylor and Francis.

Porter, J. M., and Sharp, J. C. (1984). The influence of age, sex, and musculoskeletal health upon the subjective evaluation of vehicle seating. Contemporary Ergonomics, 148-154.

Poulton, E. C. (1982). Biases in quantitative judgements. Applied Ergonomics, 13(1), 31-42.

Prasad, P., and King, A. I. (1974). An experimentally validated dynamic model of the spine. Journal of Applied Mechanics, 41(3), 546-550.

Preuschen, G., and Dupuis, H. (1969, March). [Body position and seat construction for motor vehicle drivers]. Ergonomics, 12(2), 234-245.

Purcell, W. F. H. (1980). The human factor in farm and industrial equipment design. No. 6 in the ASAE Distinguished Lecture Series, Winter Meeting of the ASAE, (pp. 1-30). St. Joseph, MI: American Society of Agricultural Engineers.

Pywell, J. F. (1993). Automotive seat design affecting comfort and safety. Seat System Comfort and Safety, (pp. 13-24). Warrendale, PA: Society of Automotive Engineers, Inc.

Pywell, J. F. (1993). Measuring seat comfort. Automotive Engineering, 101(7), 25-29.

Rachel, T. L. (1992). Split frame seating. Materials for Automobile Interiors, (pp. 41-52). Warrendale, PA: Society of Automotive Engineers, Inc.

Radke, A. O. (1956). The application of human engineering data to vehicular seat design (Report No. 117). Milwaukee, WI: Bostrom Research Laboratories.

Radke, A. O. (1964). The importance of seating in driver comfort and performance. SAE Technical Paper 838B. New York, NY: Society of Automotive Engineers, Inc.

Rakheja, S., and Sankar, S. (1984). Suspension designs to improve tractor ride: I--Passive seat suspension. SAE Technical Paper 841107. Warrendale, PA: Society of Automotive Engineers, Inc.

Reason, J. (1978). Motion sickness: Some theoretical and practical considerations. Applied Ergonomics, 9(3), 163-167.

Rebiffé, R. (1966). An ergonomic study of the arrangement of the driving position in motor cars. Paper 3 in Ergonomics and Safety in Motor Car Design, (pp. 26-33). London: The Institution of Mechanical Engineers.

Rebiffé, R. (1980). General reflections on the postural comfort of the driver and passengers: Consequences on seat design. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, the Environment and Behaviour, (pp. 240-248). New York: Academic Press.

Rebiffé, R. (1969, March). [Seat of the driver: It's adaptation to functional and anthropometric requirements]. Ergonomics, 12(2), 246-261.

Rebiffé, R. (1969). [The driving seat. Its adaptation to functional and anthropometric requirements.] Le siege du conducteur: Son adaptation aux exigences fonctionnelles et anthropometriques. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture, (pp. 132-147). London: Taylor and Francis, Ltd.

Reddy, N. P., Patel, H., Cochran, G. V., and Brunski, J. B. (1982). Model experiments to study the stress distributions in a seated buttock. Journal of Biomechanics, 15(7), 493-504.

Reed, M. P., and Grant, C. (1993, November 22). Development of a measurement protocol and analysis techniques for assessment of body pressure distributions on office chairs. Technical Report. Ann Arbor, MI: The University of Michigan, Center of Ergonomics.

Reed, M. P., Saito, M., Kakishima, Y., Lee, N. S., and Schneider, L. W. (1991). An investigation of driver discomfort and related seat design factors in extended-duration driving. SAE Technical Paper 910117. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M. P., Schneider, L. W., Saito, M., Kakishima, Y., and Lee, N. S. (1991). An investigation of automotive seating discomfort and seat design factors. Final report (UMTRI-91-11). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Reid, D. T., and Sochaniwskyj, A. Effects of anterior-tipped seating on respiratory function of normal children and children with cerebral palsy.

Reinecke, S. M., Hazard, R. G., Coleman, K., and Pope, M. H. (1992). A continuous passive lumbar motion device to relieve back pain in prolonged sitting. In S. Kumar (ed.), Advances in Industrial Ergonomics and Safety IV, (pp. 971-976). Philadelphia, PA: Taylor and Francis.

Reinecke, S. M., and Hazard, R. G. (1994). Continuous passive lumbar motion in seating. In K. Noro (ed.), Hard Facts About Soft Machines: The Ergonomics of Seating, (pp. 141-148). Philadelphia, PA: Taylor and Francis.

Reinecke, S. M., Weisman, G., Clark, A. A., Fenwick, J., and Pope, M. H. (n.d.). Relationship between unsupported sitting postures and low back pain. Burlington, VT: The University of Vermont, The Vermont Rehabilitation Engineering Center, Department of Orthopaedics and Rehabilitation.

Rensselaer Research Corporation. (1970). Bus design: Concepts and evaluation (NY-MTD-18). Troy, NY: Rensselaer Research Corporation.

Reswick, J. B. (1961). Devices for measuring contact pressures exerted on the human body. Progress report I. Cleveland, OH: Case Institute of Technology.

Reynolds, H. M. (1993). Automotive seat design for sitting comfort. Chapter 5 in B. Peacock and W. Karwowski (eds.), Automotive Ergonomics, (pp. 99-116). Washington, D.C.: Taylor and Francis.

Reynolds, H. M., and Hubbard, R. P. (1986). Old problems and new approaches in seating biomechanics. Passenger Comfort, Convenience and Safety: Test Tools and Procedures, (pp. 35-40). Warrendale, PA: Society of Automotive Engineers, Inc.

Reynolds, H. M., and Robbins, D. H. (1976). Torso linkage modeling. A discussion. Proceedings of the 6th Congress of the International Ergonomics Association, (pp. 456-459). Santa Monica, CA: Human Factors Society.

Reynolds, H. M., Snow, C. C., and Young, J. W. (1981). Spatial Geometry of the Human Pelvis (Memorandum Report AAC-119-81-5). Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute.

Richards, L. G. (1980). On the psychology of passenger comfort. In D.J. Oborne and J.A. Levis (eds.), Human Factors in Transport Research. Volume 2 - User Factors: Comfort, The Environment and Behaviour, (pp. 15-23). New York: Academic Press.

Richards, L. G., Jacobsen, I. D., and Kuhlthau, A. R. (1978). What the passenger contributes to passenger comfort. Applied Ergonomics, 9(3), 137-142.

Rieck, A. (1969). Uber die messung des sitzkomforts von atuositzen. In E. Grandjean (ed.), Sitting Posture, (pp. 92-97). London: Taylor.

Riessner, F. E. (1972, April). The dynamic seated position. Quintessence Int, 3(4), 73-80.

Rizzi, M. (1969, March). [Development of an adjustable backrest for auto and quiet sitting]. Ergonomics, 12(2), 226-233.

Robbins, D. H. (1985). Anthropometric specifications for mid-sized male dummy, Volume 2. Final report (DOT-HS-806-716). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Robbins, D. H. (1985). Anthropometric specifications for small female and large male dummies, Volume 3. Final report (DOT-HS-806-717). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Robbins, D. H. (1986). Study of seatback contours for optimum seat design. Final report (UMTRI-86-39). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Robbins, D. H., and Reynolds, H. M. (1975). Position and mobility of skeletal landmarks of the 50th percentile male in an automotive seating posture. Final report (UM-HSRI-BI-74-4/Vehicle Research Institute Report VRI 7.1). Ann Arbor, MI: Highway Safety Research Institute, The University of Michigan.

Robinette, K. M., and McConville, J. T. (1981). An alternative to percentile models. SAE Technical Paper 810217. Warrendale, PA: Society of Automotive Engineers, Inc.

Rockwell-Standard Corporation. (1955). Bibliography of vehicular seating. Birmingham, MI: Rockwell-Standard Corporation, Research and Development.

Roe, R. W. (1975). Describing the driver's work space: Eye, head, knee, and seat positions. SAE Technical Paper 750356. Warrendale, PA: Society of Automotive Engineers, Inc.

Roe, R. W., and Kyropoulos, P. (1970). The application of anthropometry to automotive design. SAE Technical Paper 700553. New York, NY: Society of Automotive Engineers, Inc.

Rogers, S. B., and Wierwille, W. W. (1988). The occurrence of accelerator and brake pedal actuation errors during simulated driving. Human Factors, 30(1), 71-81.

Rohmert, W., and Mainzer, J. (1986). Influence parameters and assessment methods for evaluating body postures. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 183-217). Philadelphia, PA: Taylor and Francis.

Rondinelli, R., Murphy, J., Esler, A., Marciano, T., and Cholmakjian, C. (1992, August). Estimation of normal lumbar flexion with surface inclinometry. A comparison of three methods. American Journal of Physical Medicine and Rehabilitation, 71(4), 219-224.

Rosemeyer, B. (1971). [Electromyographic studies of back and shoulder muscles in standing and seating postions with reference to the position of the automobile driver]. Arch Orthop Unfallchir, 71(1), 59-70.

Rosemeyer, B., and Pförringer, W. (1979). Measuring pressure forces in sitting. Archives of Orthopaedic and Traumatic Surgery, 95, 167-171.

Rosemeyer, R. (1975, August). [Damage to the locomotion apparatus due to faulty posture in the car seat.] Schadigung des Bewegungsapparates durch falsche Haltung im Autositz. Zeitschrift fuer Orthopadie und ihre Grenzgebiete, 113(4), 653-655.

Rosenburg, R., and Seidel, H. (1989). Electromyography of lumbar erector spinae muscles -- Influence of posture, interelectrode distance, strength, and fatigue. European Journal of Applied Physiology, 59, 104-114.

Roth, J. T., Ayoub, M. M., and Halcomb, C. G. (1977). Seating, console and workplace design: seated operator reach profiles. In A.S. Neal and R.F. Palasek (eds.), Proceedings of the 21st Annual Meeting of the Human Factors Society, Gateways to the Future, (pp. 83-87). Santa Monica, CA: Human Factors Society.

Russell, P., Pearcy, M. J., and Unsworth, A. (1993, June). Measurement of the range and coupled movements observed in the lumbar spine. British Journal of Rheumatology, 32(Suppl 6), 490-497.

Sacks, A. H., O'Neill, H., and Perkash, I. (1985). Skin blood flow changes and tissue deformations produced by cylindrical indentors. Journal of Rehabilitation Research, 22(3), 1-6.

Sandover, J. (1981). Chronic low back pain in professional drivers: Summary and conclusions. England: Loughborough University of Technology.

Sandover, J. (1978). Modelling human responses to vibration. Aviation, Space, and Environmental Medicine, 49(1), 335-339.

Sato, T. (1987). Effects of seat belts and injuries resulting from improper use. Journal of Trauma, 27(7), 754-758.

Sato, T., and Johansen, D. W. (1989). Comfort design using molded seat foam techniques. SAE Technical Paper 890846. Warrendale, PA: Society of Automotive Engineers, Inc.

Satow, A., and Taniguchi, S. (1989). The development of a motor performance method for the measurement of pain. Ergonomics, 32(3), 307-316.

Schneider, L. W., Anderson, C. K., and Olson, P. L. (1979). Driver anthropometry and vehicle design characteristics related to seat positions selected under driving and non-driving conditions. SAE Technical Paper 790384. Warrendale, PA: Society of Automotive Engineers, Inc.

Schneider, L. W., Olson, P. L., Anderson, C. K., and Post, D. V. (1979). Identification of variables affecting driver seated position (UM-HSRI-79-47). Ann Arbor, MI: The University of Michigan, Highway Safety Research Institute.

Schneider, L. W., and Ricci, L. L. (1989). Survey of driver seating discomfort and related factors (UMTRI-89-23). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Schneider, L. W., Robbins, D. H., Pflüg, M. A., and Snyder, R. G. (1985). Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, Volume 1. Final report (DOT-HS-806-715). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Scholey, M., and Hair, M. (1989). Back pain in physiotheriapists involved in back care education. Ergonomics, 32(2), 179-190.

Schram, S. B., and Hosek, R. S. (1982, March). Error limitations in X-ray kinematics of the spine. Journal of Manipulative and Physiological Therapeutics, 5(1), 5-10.

Schultz, A. B., Andersson, G. B. J., Haderspek, K., Ortengren, R., Nordin, M., and Bjork, R. (1982). Analysis and measurement of lumbar trunk loads in tasks involving bends and twists. Journal of Biomechanics, 15(9), 669-675.

Schultz, A. B., Belytschko, T. B., Andriacchi, T. P., and Galante, J. O. (1973). Analog studies of forces in the human spine: Mechanical properties and motion segment behavior. Journal of Biomechanics, 6(4), 373-383.

Schultz, A. B., and Galante, J. O. (1970). A mathematical model for the study of the mechanics of the human vertebral column. Journal of Biomechanics, 3(4), 405-416.

Schultz, A. B., Haderspeck-Grib, K., Sinkora, G., and Warwick, D. N. (1985). Quantitative studies of the flexion-relaxation phenomenon in the back muscles. Journal of Orthopedic Research, 3(2), 189-197.

Schultz, A. B., Warwick, D. N., Berkson, M. H., and Nachemson, A. L. (1979). Mechanical properties of human lumbar spine motion segments - Part 1: Responses in flexion, extension, lateral bending, and torsion. Journal of Biomechanical Engineering, 101(1), 46-52.

Schwer, L., Belytschko, T., and Schultz, A. (1975). A three dimensional dynamic model of the spine. In R. Skalak and R.M. Nerem (eds.), Biomechanics Symposium, (pp. 139-141). New York, NY: ASME.

Searle, J. A. (1969). The cab mock-up method of determining the layout of commercial vehicle cabs (Report No. 1969/6). Nuneaton, England: The Motor Industry Research Association.

Searle, J. A. (1974). The geometrical basis of seat-belt fit. Ergonomics, 17, 401-416.

Serati, A. (1969, March). [Construction of driver's seats for SBB-locomotives and railcars]. Ergonomics, 12(2), 262-8.

Setright, L. J. K. (1978). The agony and the ecstasy of driving position. Car and Driver, 23(12), 87-92.

Shackel, B., Chidsey, K. D., and Shipley, P. (1969). The assessment of chair comfort. In E. Grandjean (ed.), Proceedings of the Symposium on Sitting Posture, (pp. 155-192). London: Taylor and Francis, Ltd.

Shanks, A., and Lewis, M. (1975). Are you sitting comfortably? Autocar, 143(4110), 23-26.

Shanku, G. (1989). Development, design and application of seat heating systems for passenger cars. SAE Technical Paper 890848. Warrendale, PA: Society of Automotive Engineers, Inc.

Shao, W., and Zhou, Y. (1990). Design principles of wheeled-tractor driver-seat static comfort. Ergonomics, 33(7), 959-965.

Shen, W., and Galer, I. A. R. (1993). Development of a pressure related assessment model of seating discomfort. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. Designing for Diversity, Volume 2, (pp. 831-835). Santa Monica, CA: Human Factors and Ergonomics Society.

Sheppard, D. J. (1985). Development of a computer program to design seat belt layouts giving the greatest comfort, safety and convenience. Part 1: Program enhancements and optimisation of static comfort (K52012/1). Nuneaton, Warwickshire, England: Motor Industry Research Association.

Sheridan, T. B., Meyer, J. E., Roy, S. H., Decker, K. S., Yanagishima, T., and Kishi, Y. (1991). Physiological and psychological evaluations of driver fatigue during long term driving. SAE Technical Paper 910116. Warrendale, PA: Society of Automotive Engineers, Inc.

Shields, R. K., and Cook, T. M. (1988, November). Effect of seat angle and lumbar support on seated buttock pressure [see comments]. Physical Therapy, 68(11), 1682-1686.

Shields, R. K., and Cook, T. M. (1992, March). Lumbar support thickness: Effect on seated buttock pressure in individuals with and without spinal cord injury. Physical Therapy, 72(3), 218-226.

Shirazi-Adl, A. (1991, May). Finite-element evaluation of contact loads on facets of an L2-L3 lumbar segment in complex loads. Spine, 16(5), 533-541.

Shvartz, E., Gaume, J. G., Reibold, R. C., Glassford, E. J., and White, R. T. (1982, August). Effect of the circutone seat on hemodynamic, subjective, and thermal responses to prolonged sitting. Aviation, Space, and Environmental Medicine, 53(8), 795-802.

Siekman, A. R., and Flanagan, K. (1983). The anti-thrust seat: A wheelchair insert for individuals with abnormal reflex pattern or other specialized problems. In B.R. Bowman (ed.), Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 203-205). Bethesda, MD: Rehabilitation Engineering Society of North America.

Sihvonen, T., Partanen, J., and Hänninen, O. (1988). Averaged (rms) surface EMG in testing back function. Electromyography in Clinical Neurophysiology, 28, 335-339.

Silverstein, B., Fine, L., Armstrong, T., Joseph, B., Buchholz, B., and Robertson, M. (1986). Cumulative trauma disorders of the hand and wrist in industry. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 31-38). Philadelphia, PA: London and Francis.

Simmonds, G. R. W. (1966). The effect of cab layout on the performance of a commercial vehicle. A preliminary study (A.P. Report 8). Lindley, England: Motor Industry Research Association.

Sippo, A. C., and Belyavin, A. J. (1991, January). Determining aircrew helmet size design requirements using statistical analysis of anthropometric data. Aviation, Space, and Environmental Medicine, 62, 67-74.

Sjogaard, G. (1986). Intramuscular changes during long-term contraction. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 136-143). Philadelphia, PA: Taylor and Francis.

Slechta, R. F., Forrest, J., Carter, W. K., and Wade, E. A. (1959). Comfort evaluation of the C-124A pilot seat (Weber) (WADC Technical Report 58-314). Wright-Patterson AFB, OH: Air Research and Development Command, Wright Air Development Center.

Smeathers, J. E., and Biggs, W. D. (1980). Mechanics of the spinal column. Engineering Aspects of the Spine, I Mech E Conference Publications 1980-2 (pp. 103-106). London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers.

Smith, C. C., and Kwak, Y. K. (1978). Identification of the dynamic characteristics of a bench-type automotive seat for the evaluation of ride quality. Journal of Dynamic Systems, 100(1), 42-49.

Smith, H. P. R. (1973). Driver's eye position relative to the 'H' point for trucks and buses. Applied Ergonomics, 4(3), 139-143.

Smith, S. D. (1992, August). Impedance response characteristics of the primate Mucaca mulatta exposed to seated whole-body gz vibration. Journal of Biomechanics, 25(8), 839-847.

Snijders, C. J. (1992). Transfer of lumbosacral load to iliac bones and legs. Part I - Biomechanics of self-bracing of the sacroiliac joints and its significance for treatment and exercise. In A. Vleeming, V. Mooney, C. Snijders, T. Dorman (eds.), First Interdisciplinary World Congress on Low Back Pain and its Relation to the Sacroiliac Joint, (pp. 233-271).

Snyder, R. G., Chaffin, D. B., and Schutz, R. K. (1972). Joint range of motion and mobility of the human torso. Proceedings of the 15th Stapp Car Crash Conference, (pp. 13-41) SAE Technical Paper 710848 . New York, NY: Society of Automotive Engineers, Inc.

Snyder, R. G., Chaffin, D. B., and Schutz, R. (1972). Link system of the human torso (AMRL-TR-71-88). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Society of Automotive Engineers, I. (1954). SAE seating manual. New York, NY: Society of Automotive Engineers, Inc.

Society of Automotive Engineers, I. (1987). U.S. truck driver anthropometric and truck work space: Survey and recommended practices (SAE-SP-712). Warrendale, PA: Society of Automotive Engineers, Inc.

Son, K., Miller, J. A., and Schultz, A. B. (1988, May). The mechanical role of the trunk and lower extremities in a seated weight-moving task in the sagittal plane. Journal of Biomechanical Engineering, 110(2), 97-103.

Spilling, S., Eiterheim, J., and Aaras, A. (1986). Cost-benefit analysis of work environment investment at STK's telephone plant at Kongsvinger. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 380-398). Philadelphia, PA: Taylor and Francis.

St. Hoyme, L. E., and Gindhart, P. S. (1976). Evaluation of 2-D anthropomorphic template ("Oscar") and 3-D anthropomorphic device (H-point machine) in relation to heights and body proportions of American drivers. Final report (DOT-HS-801 946/ DOT-HS-803 773). Washington, D.C.: National Highway Traffic Safety Administration.

States, J. D. (1980). Safety belts and seat design - An insight from racing. Proceedings of the 24th Conference of the American Association for Automotive Medicine, (pp. 437-445). Morton Grove, IL: American Association for Automotive Medicine.

States, J. D., Huelke, D. F., Dance, M., and Green, R. N. (1987). Fatal injuries caused by underarm use of shoulder belts. Journal of Trauma, 27, 740-745.

Stech, E. L. (1977). Design and evaluation methods for optimizing ejection seat cushions for comfort and safety. Final report (AMRL-TR-68-126). Wright-Patterson AFB, OH: Air Force Systems Command, Aerospace Medical Research Laboratory.

Steele, J. (1972). Today's truck seats stress driver comfort. Fleet Owner, 67(6), 55-58.

Stein, G. J., and Ballo, I. (1991). Active vibration control system for the driver's seat for off-road vehicles. Vehicle System Dynamics, 20(2), 57-78.

Stephens, D. G. (1974). Development and application of ride-quality criteria (NASA TM X-72008). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.

Stewart, C. P. (1991, December). Physiological considerations in seating. Prosthetics and Orthotics International, 15(3), 193-198.

St-Georges, M., Valiquette, C., and Drouin, G. (1989, September). Computer-aided design in wheelchair seating. Journal of Rehabilitation Research and Development, 26(4), 23-30.

Stikeleather, L. F., Hall, G. O., and Radke, A. O. (1972). A study of vehicle vibration spectra as related to seating dynamics. SAE Technical paper 720001. New York, NY: Society of Automotive Engineers, Inc.

Stokes, I. A. F., and Abery, J. M. (1980). Influence of the hamstring muscles on lumbar spine curvature in sitting. Spine, 5(6), 525-528.

Stumbaum, F., and Diebschlag, W. (1980, September). Messsystem zur Erfassung der Druckverteilung zwischen Mensch und Sitzmobel. [Device for measurement of pressure distribution between men and seating furniture (author's transl)]. Biomedizinische Technik (Berlin), 25(9), 223-227.

Suggs, C. W., Abrams, C. F., and Stikeleather, L. F. (1969, January). Application of a damped spring-mass human vibration simulator in vibration testing of vehicle seats. Ergonomics, 12(1), 79-90.

Suh, C. H. (1977). Dynamic simulation of the cervical spine with use of the differential displacement matrix. Proceedings of the 3rd International Conference on Impact Trauma, (pp. 355-366). Bron, France: IRCOBI.

Sullivan, A., and McGill, S. M. (1990, December). Changes in spine length during and after seated whole-body vibration. Spine, 15(12), 1257-1260.

Susnik, J., and Gazvoda, T. (1986). Torque of the dorsal erectors and the compressive load on the L5/Si disc at inclined postures and when lifting. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 218-231). Philadelphia, PA: Taylor and Francis.

Svensson, H. O., and Andersson, G. B. J. (1983). Low back pain in 40-47 year old men: Work history and work environment factors. Spine, 8, 272-276.

Svensson, M. Y., Lösvund, P., Haland, Y., and Larsson, S. (1993). Rear-end collisions - A study of the influence of backrest properties on head-neck motion using a new dummy neck. SAE Technical Paper 930343. Warrendale, PA: Society of Automotive Engineers, Inc.

Swart, B. (1974). Seating the tough/fragile driver. Fleet Owner, 69(11), 47-54.

Taksic, V. (1986). Comparison of some indices of postural load assessment. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 278-282). Philadelphia, PA: Francis and Taylor.

Tarrière, C., Rebiffé, R., Hamon, J., and Mauron, G. (1970). Optimum utilization of the vehicle available occupant space to ensure passenger protection. 1970 International Automobile Safety Conference Compendium, (pp. 82-111) SAE Technical Paper 700360. New York, NY: Society of Automotive Engineers.

Temming, J. (1993). A new method to assess the summer suitability of car seats. SAE Technical Paper 930106. Warrendale, PA: Society of Automotive Engineers, Inc.

Thier, R. H. (1963). Measurement of seat comfort. Automobile Engineer, 53(2), 64-66.

Thomson, K. D. (1988). On the bending moment capability of the pressurized abdominal cavity during human lifting activity. Ergonomics, 31(5), 817-828.

Thomson, R. W., Romilly, D. P., Navin, F. P. D., and Macnabb, M. J. (1993). Dynamic requirements of automobile seatbacks. Seat System Comfort and Safety, (pp. 193-198). Warrendale, PA: Society of Automotive Engineers, Inc.

Tichauer, E. R. (1967). The biomechanics of the arm-back aggregate under industrial working conditions. Byars, 153-170.

Tillotson, K. M., and Burton, A. K. (1991, January). Noninvasive measurement of lumbar sagittal mobility. An assessment of the flexicurve technique. Spine, 16(1), 29-33.

Toi, Y., Fukunaga, K., and Morioka, M. (1984). [Comfortable riding space]. Mazda Technical Journal, (2), 4-13.

Trail, I. A., and Galasko, C. S. B. (1990). The Matrix Seating System. Journal of Bone and Joint Surgery, 72(4), 666-669.

Treaster, D. E. (1986). Pressure distribution and myolectric activity as a function of seating parameters. Unpublished Master's thesis. Columbus, OH: The Ohio State University.

Treaster, D. E., and Marras, W. S. (1987). Measurement of seat pressure distributions. Human Factors, 29(5), 563-575.

Treaster, D. E., and Marras, W. S. (1989). Seat pressure: Measurement and analysis. SAE Technical Paper 890849. Warrendale, PA: Society of Automotive Engineers, Inc.

Troup, J. D. G. (1978). Driver's back pain and its prevention: A review of the postural, vibratory and muscular factors, together with the problem of transmitted road-shock. Applied Ergonomics, 9(4), 207-214.

Troup, J. D. G., Hood, C. A., and Chapman, A. E. (1968). Measurements of the sagittal mobility of the lumbar spine and hips. Annals of Physical Medicine, 9, 308-321.

Tzivian, I. L., Rayhinstein, V. H., Motov, V. F., and Ovseychik, F. F. (1971). Results of clinical study of pressure within the intervertebral lumbar discs. Ortopediia Travmatologiia I Protezirovanie, 6, 31.

Umezawa, F. (1971). The study of comfortable sitting postures. J Jap Orthop Assoc, 45, 1015.

Underhill, B., and McCullough, B. (1972). An energy-absorbing seat design for light aircraft. SAE Technical Paper 720322. New York, NY: Society of Automotive Engineers, Inc.

United Nations, E. C. f. (1989). Agreement concerning the adoption of uniform conditions of approval and reciprocal recognition of approval for motor vehicle equipment and parts. Done at Geneva on 20 March 1958. Addendum 79: Regulation no. 80 to be annexed to the agreement: Uniform provisions concerning the approval of seats of large passenger vehicles and of these vehicles with regard to the strength of the seats and their anchorages. (E/ECE/324/Rev.1/Add.79/ E/ECE/TRANS/505/Rev.1/Add.79). New York, NY: United Nations, Economic Commission for Europe.

Vacek, M., and Zaruba, L. (1986). A survey and assessment of physiologically significant properties of automobile seats. FISITA XXI International Congress Proceedings, Volume II, (pp. 2.241-2.246). Yugoslavia: Yugoslav Society of Automotive Engineers.

van Eldick Theime, H. C. A. (1961). Passenger riding comfort criteria and methods of analysing ride and vibration data. SAE Technical Paper 295A. New York, NY: Society of Automotive Engineers, Inc.

Vanharanta, H., Heliovaara, M., Korpi, J., and Troup, J. D. (1987, April). Occupation, work load and the size and shape of lumbar vertebral canals. Scandinavian Journal of Work, Environment and Health, 13(2), 146-149.

Vanwonterghem, K. (1986). A postural load evaluation technique: Based on energy expenditure, heart rate and subjective appreciation. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 256-269). Philadelphia, PA: Taylor and Francis.

Varterasian, J. H. (1981). On measuring automobile seat ride comfort (GMR-3679). Warren, MI: General Motors Research Laboratories.

Varterasian, J. H. (1982). On measuring automobile seat ride comfort. SAE Technical Paper 820309. Warrendale, PA: Society of Automotive Engineers.

Varterasian, J. H., and Thompson, R. R. (1977). The dynamic characteristics of automobile seats with human occupants. SAE Technical Paper 770249. Warrendale, PA: Society of Automotive Engineers, Inc.

Verriest, J. P. (1986). Driving posture and comfort drivers of road vehicles, (passenger cars. Commercial vehicles and heavy lorries) [sic]. Recherche-Transports-Securite, 38-44.

Verriest, J. -. (1988). Le confort postural du conducteur: etude experimentale et modelisation. [Postural comfort of the driver: Experimental study and modelling]. Ingenieurs de l'Automobile, 122-128.

Verriest, J. P., and Alonzo, F. (1986, February). A tool for the assessment of inter-segmental angular relationships defining the postural comfort of a seated operator. Passenger Comfort, Convenience and Safety: Test Tools and Procedures,SAE Technical Paper 860057 (pp. 71-83). Warrendale, PA: Society of Automotive Engineers.

Viano, D. C., and Andrzejak, D. V. (1992). Research issues on the biomechanics of seating discomfort: an overview with focus on issues of the elderly and low-back pain. Analytical Modeling and Occupant Protection Technologies, (pp. 69-81). Warrendale, PA: Society of Automotive Engineers, Inc.

Vogt, H., and Theyson, H. (1990). Seating comfort through electromyography. FISITA XXIII International Congress Proceedings, Volume II. The Promise of New Technology in the Automotive Industry. Technical Papers, (pp. 627-734). Warrendale, PA: Society of Automotive Engineers, Inc.

Vollestad, N. K., and Sejersted, O. M. (1988). Biochemical correlates of fatigue. European Journal of Applied Physiology, 57, 336-347.

Vulcan, A. P., and King, A. I. (1970). Forces and moments sustained by the lower vertebral column of a seated human during seat-to-head acceleration. In N. Perrone (ed.), Dynamic Response of Biomechanical Systems, (pp. 84-100). Bethesda, MD: National Institutes of Health.

Wachsler, R. A., and Learner, D. B. (1960). An analysis of some factors influencing seat comfort. Ergonomics, 3, 315-320.

Wangenheim, M., Wos, H., and Samuelson, B. (1986). ARBAN--A force ergonomic analysis method. In N. Corlett, J. Wilson, and I. Manenica, The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 243-255). Philadelphia, PA: Taylor and Francis.

Ward, E., and Southall, D. (1993). A technique for measuring vehicle seat interface pressure. SAE Technical Paper 930116. Warrendale, PA: Society of Automotive Engineers, Inc.

Weber, A., Sancin, E., and Grandjean, E. (1984). The effects of various keyboard heights on EMG and physical discomfort. In E. Grandjean (ed.), Ergonomics and Health in Modern Offices. Proceedings of the International Scientific Conference on Ergonomic and Health Aspects in Modern Offices, (pp. 477-483). Philadelphia, PA: Taylor and Francis.

Weber, J., van der Star, A., and Snijders, C. J. (1986). Development and evaluation of a new instrument for the measurement of work postures; in particular the inclination of the head and the spinal column. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 82-91). Philadelphia, PA: Taylor and Francis.

Weichenrieder, A., and Haldenwanger, H. G. (1985). The best function for the seat of a passenger car. SAE Technical Paper 850484. Warrendale, PA: Society of Automotive Engineers, Inc.

Weishaupt, W. A. (1987). Improvement of seating comfort due to a new wheelchair seating system. International Journal of Rehabilitation Research, 10(4), 90-99.

Westgaard, R. H. (1988). Measurement and evaluation of postural load in occupational work situations. European Journal of Applied Physiology, 57, 291-304.

Westgaard, R. H., Woersted, M., Jansen, T., and Aaras, A. (1986). Muscle load and illness associated with constrained body postures. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 3-18). Philadelphia, PA: Taylor and Francis.

Westrin, C. G. (1973). Low back sick listing. A nosological and medical insurance investigation. Scandinavian Journal of Social Medicine, Supplement 7.

White, A. A. I., and Panjabi, M. M. (1978, March). The basic kinematics of the human spine: A review of past and current knowledge. Spine, 3(1), 12-20.

White, A. A. I., and Panjabi, M. M. (1990). Clinical biomechanics of the spine, 2nd Edition. Philadelphia, PA: J.B. Lippincott Co.

Whitham, E. M., and Griffin, M. J. (1977). Measuring vibration on soft seats. SAE Technical Paper 770253. Warrendale, PA: Society of Automotive Engineers, Inc.

Whittenberger, R. K. Improved Seat and Back Cushions (WADC Tech. Report 59-376). Wright-Patterson Air Force Base, OH: Aerospace Medical Laboratory.

Whittenberger, R. K. (1959). Improved seat and back cushions (WADC Technical Report 59-376). Wright-Patterson AFB, OH: Air Research and Development Command, Wright Air Development Center.

Wick, J., and Drury, C. G. (1986). Postural change due to adaptations of a sewing workstation. In N. Corlett, J. Wilson, and I. Manenica (eds.), The Ergonomics of Working Postures: Models, Methods and Cases. The Proceedings of the First International Occupational Ergonomics Symposium, (pp. 375-379). Philadelphia, PA: Francis and Taylor.

Wiker, S. F., Chaffin, D. B., and Langolf, G. D. (1989). Shoulder posture and localized fatigue and discomfort. Ergonomics, 32(2), 211-237.

Wilder, D. G., Pope, M. H., and Frymoyer, J. W. (1980). Vibration as an etiological factor in low back pain. Orthopedic Transactions -- Journal of Bone and Joint Surgery, 4(3), 344-345.

Wilder, D. G., Seroussi, R. E., Dimnet, J., and Pope, M. H. (1986). How the lumbar motion segment responds to sustained sitting. Advances in Bioengineering, (pp. 8-9). Rockville, MD: National Institute for Occupational Safety and Health.

Wilder, D. G., Woodworth, B. B., Frymoyer, J. W., and Pope, M. H. (1982). Vibration and the human spine. Spine, 7(3), 243-254.

Williams, R., Binkley, J., Bloch, R., Goldsmith, C. H., and Minuk, T. (1993, January). Reliability of the modified-modified Schober and double inclinometer methods for measuring lumbar flexion and extension. Physical Therapy, 73(1), 33-44.

Williams, R., Krouskop, T., Noble, P., and Brown, J. (1983). The influence of inflation pressure on the effectiveness of air filled wheelchair cushions. Proceedings of the 6th Annual Conference on Rehabilitation Engineering, Volume 3, (pp. 215-217). Bethesda, MD: Rehabilitation Engineering Society of North America.

Wilson, J. R., Corlett, E. N., and Manenica, I. (1987). New Methods in Applied Ergonomics. Proceedings of the Second International Occupational Ergonomics Symposium. London: Taylor and Francis.

Wing, P., Tsang, I., Gagnon, F., Susak, L., and Gagnon, R. (1992, July). Diurnal changes in the profile shape and range of motion of the back. Spine, 17(7), 761-766.

Winkel, J. (1978). Leg problems from longlasting sitting. In B. Jonsson (ed.), Sitting Work Postures, No. 12 (pp. 72-78). Sweden: National Board of Occupational Safety and Health.

Winkel, J. (1981). Swelling of the lower leg in sedentary work -- A pilot study. Journal of Human Ergology, 10, 139-149.

Winkel, J., and Bendix, T. (1986). Muscular performance during seated work elevated by two different EMG methods. European Journal of Applied Physiology, 55(2), 167-173.

Winkel, J., and Gard, G. (1988). An EMG-study of work methods and equipment in crane coupling as a basis for job redesign. Applied Ergonomics, 19(3), 178-184.

Winkel, J., and Jorgensen, K. (1986, February). Evaluation of foot swelling and lower-limb temperatures in relation to leg activity during long-term seated office work. Ergonomics, 29(2), 313-328.

Winkelholz, E. A. (1967). [Measurement of the vibration characteristics of the vehicle-seat/man system.] Messung der Schwingungseigenschaften des Systems Fahrzeugsitz-Mensch. V.D.I.-Berichte, (113).

Wisner, A., Donnadieu, A., and Berthoz, A. (1964). A biomechanical model of man for the study of vehicle seat and suspension. International Journal of Production Research, 3(4), 285-315.

Woodson, W. E. (1971). Motor vehicle driver eye position and control reach anthropometrics (DOT HS-800 619). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Woodson, W. E., and Selby, P. H. (1975). Driver workspace state-of-the-art analysis (DOT HS-801 612). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., and Leonhard, T. (1969, March). Investigations for the development of an auditorium seat. Ergonomics, 12(2), 182-197.

Wretenberg, P., Arborelius, U. P., and Lindberg, F. (1993). The effects of a pneumatic stool and a one-legged stool on lower limb joint load and muscular activity during sitting and rising. Ergonomics, 36(5), 519-535.

Yabuki, K., Usami, A., and Kamiya, K. (1989). Influence of seat support characteristics on driver's eye position. JSAE Review, 10(1), 77-78.

Yamaguchi, Y., Umezawa, F., and Ishinada, Y. (1972). Sitting posture: An electromyographic study on healthy and notalgic people. J Jap Orthop Assoc, 46, 277.

Yamazaki, N. (1992, May). Analysis of sitting comfortability of driver's seat by contact shape. Ergonomics, 35(5-6), 677-692.

Yang, K. H., Khalil, T., Tzeng, C. R., and King, A. I. (1984). Finite element model of a functional spinal unit (GMR-4318). Warren, MI: General Motors Research Laboratories.

Yang, K. H., and King, A. I. (1983). Mechanism of facet load transmission as a hypothesis for low-back pain. Spine, 9(6), 557-565.

Yates, J. W., and Karwowski, W. (1992, July). An electromyographic analysis of seated and standing lifting tasks. Ergonomics, 35(7-8), 889-898.

Young, J. W., Chandler, R. F., Snow, C. C., Robinette, K. M., Zehner, G. F., and Lofberg, M. S. (1983). Anthropometric and mass distribution characteristics of the adult female (FAA-AM-83-16). Washington, D.C.: Office of Aviation Medicine, Federal Aviation Administration.

Yu, C.-Y., Keyserling, W. M., and Chaffin, D. B. (1988). Development of a work seat for industrial sewing operations: Results of a laboratory study. Ergonomics, 31(12), 1765-1786.

Yu, C.-Y., and Keyserling, W. M. (1989). Evaluation of a new work seat for industrial sewing operations. Applied Ergonomics, 20(1), 17-25.

Zechman, F. W., Peck, D., and Luce, E. (1965). Effect of vertical vibration on respiratory airflow and transpulmonary pressure. Journal of Applied Physiology, 20(5), 849-854.

Zimmermann, C. L., Cook, T. M., and Goel, V. K. (1993, June). Effects of seated posture on erector spinae EMG activity during whole body vibration. Ergonomics, 36(6), 667-675.