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**Matthew P. Reed and Lawrence W. Schneider**
University of Michigan Transportation Research Institute

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## ABSTRACT

Prominent, longitudinally convex lumbar supports are frequently recommended for auto seats based on the assumption that such supports will induce sitters to choose postures with substantial lumbar lordosis. Lumbar lordosis has been associated with reduced spine loading as measured by pressure in the intervertebral disks. Data from a laboratory study of the influence of lumbar support on driving posture demonstrate that, on average, lumbar lordosis is not strongly affected by large increases in lumbar support prominence. These findings, and their implications for seat design, are reviewed.

## INTRODUCTION

A lumbar support is a structure that contacts the lower back in the area of the lumbar spine during sitting. In automotive seats, the lumbar support is usually integrated into the backrest. The general purpose of the lumbar support is to stabilize the sitter's torso and thereby improve comfort and postural stability. More specifically, a firm seat structure behind the pelvis and lumbar spine can restrict the rearward rotation of the pelvis that normally accompanies sitting and reduce flexion (forward bending) of the lumbar spine.

When standing, a person's lumbar spine usually has an inward curve, in contrast to the outward curve that is typical in the thoracic spine. An inward spine curvature is referred to as lordosis, while an outward curve of the spine is called kyphosis. When a person sits, the pelvis usually rotates rearward, flexing the lumbar spine. This flexion motion causes the lumbar spine to move from lordosis to flat and then into kyphosis. Sitting slumped in a chair without a backrest typically produces a kyphotic (outward curving) lumbar curve, because the pelvis is allowed to rotate rearward.

A frequently stated objective of lumbar support design is to preserve the sitter's standing lumbar lordosis (1). Lordosis is associated with lower pressure in the lumbar intervertebral discs compared with more flexed (flat or kyphotic) lumbar spine postures (2, 3). Since disc pressure is related to stress in the spine and paraspinal tissues, lordotic postures have been regarded as healthier and more likely to be comfortable than flat or kyphotic lumbar spine postures.

Auto seat designers often try to preserve or induce a lordotic lumbar spine curvature by providing a firm, longitudinally convex lumbar support in the lower part of the seatback. The deflected contour of such a support is intended to mate with the lordosis of the sitter's lower back, providing relatively even contact pressure behind the sitter's pelvis and lumbar spine. If, however, the sitter's back does not assume a lordotic shape, there can be a mismatch between the sitter's back and the seat. This mismatch may produce uncomfortable pressure concentrations and may result in the lower levels of the lumbar spine, where most discomfort is reported, being unsupported (4).

One important question that has not been addressed by previously published research is whether longitudinally convex lumbar supports in auto seats are used by sitters in the way that the designers intend. That is, do prominent lumbar supports result in postures with substantial lumbar lordosis? Reed *et al.* (5) reported preliminary results from a study examining the effects of changes in lumbar support contour on driving posture. In this paper, selected findings from the completed study are discussed along with the implications for seat design.

## METHODS

The laboratory and equipment used in this study have been described in detail elsewhere (5, 6). Only a brief summary is presented here. A seating buck consisting of an instrument panel, steering wheel, accelerator pedal, brake pedal, and test seat was constructed with dimensions based on those of a contemporary minivan, as shown in Figure 1.

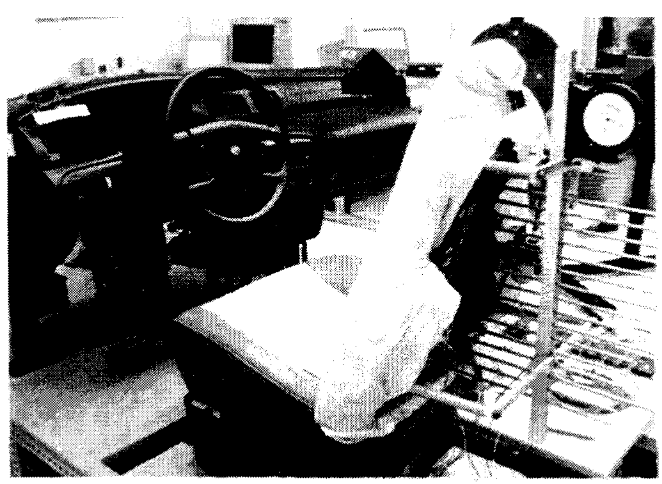

Figure 1. Laboratory seating buck.

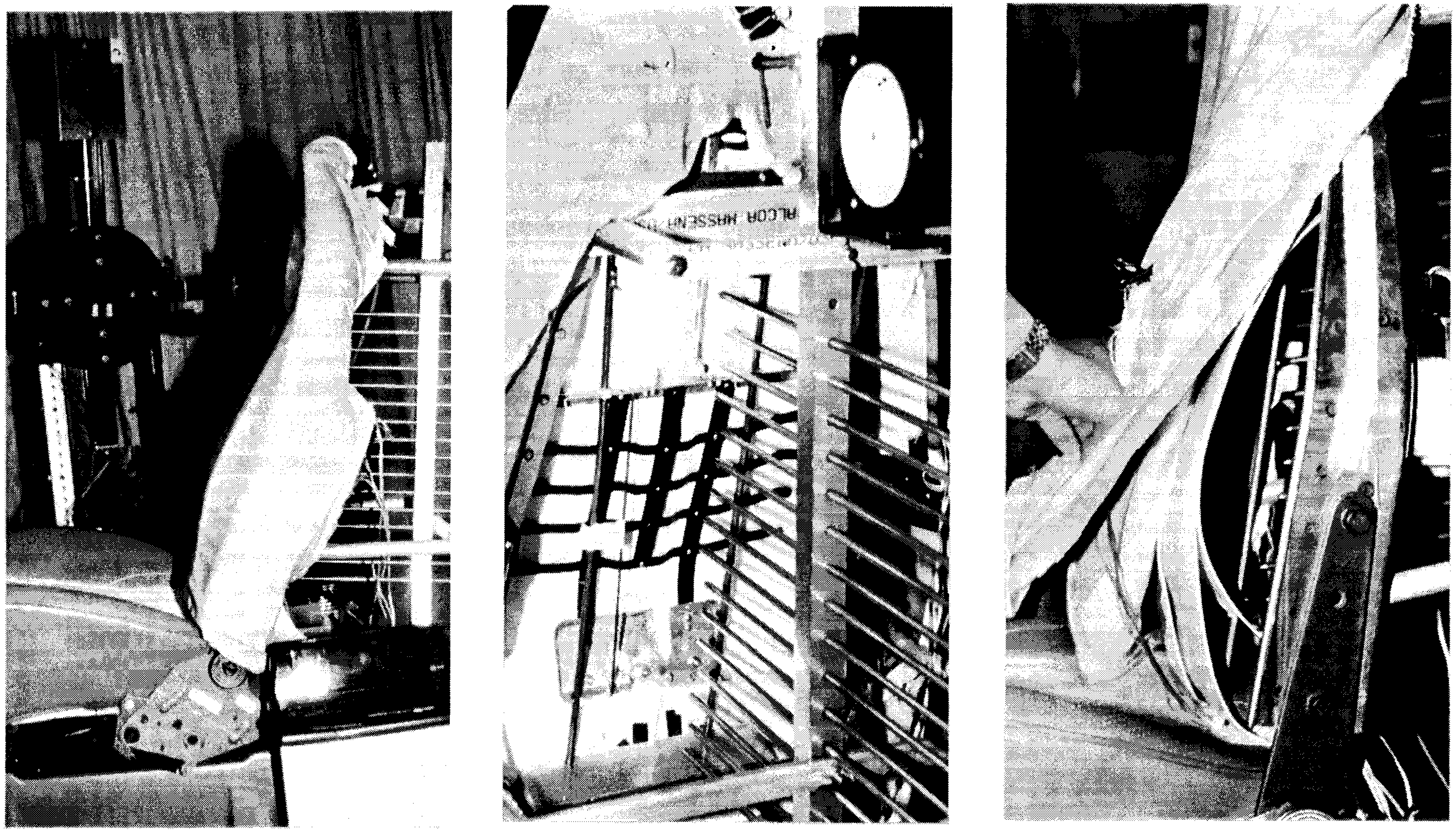

Figure 2. Test seat showing adjustable lumbar support and back contour measurement rods.

The steering wheel and pedals were connected to an interactive driving simulator that projected a road scene on a large screen in front of the buck.

A minivan seat, shown in Figure 2, was extensively modified for use in testing. The upholstery and foam were removed from the seatback and replaced with a thinly padded surface supported by a highly adjustable Schukra lumbar support. The prominence of the support could be adjusted from 0-mm (flat) up to 45-mm of prominence relative to the flat condition. The vertical position of the support could be adjusted over a 120-mm range using a motorized control. The upper part of the seatback was approximately flat and designed to avoid interference with the upper back and shoulders of the sitters at typical seatback recline angles. Steel rods were mounted in a frame perpendicular to the seatback and were pushed forward during measurement to compress the foam padding behind the sitter. The 15-mm-thick padding bottomed out consistently in the areas of contact between the seat and sitter so that the probes recorded the longitudinal back contour. The thinly padded backrest was intended to present nearly the same deflected contour to all subjects. A backrest more thickly padded and more representative of seats intended for on-road use would present substantially different deflected support contours to heavy and light subjects.

The research was conducted in two phases. In Phase 1, forty-eight male and female subjects operated the driving simulator during one-hour sessions using three different lumbar support prominences. Posture was recorded at the start of the session and thereafter at ten-minute intervals using a sonic digitizing apparatus (6). Findings from analyses of data from the first twenty-four Phase-1 subjects were reported previously (5). One of the important observations from Phase-1 testing was that the initial postures chosen by the subjects were very similar to those measured throughout the one-hour driving simulations. In these laboratory conditions, short-term posture measurement produced results representative of postures throughout a one-hour test.

Based on the findings from Phase 1, a second phase of testing was conducted using short-term (five-minute) sitting sessions with a wider range of test conditions. Table 1 shows the conditions. Three types of trials were conducted. In the preferred-posture trials, subjects were allowed to select the driving posture that they preferred, adjusting the seat track position, seatback recline angle, and steering-wheel tilt. In half of these conditions, the subject was also allowed to adjust the vertical position of the lumbar support. In the other half of the preferred-posture trials, the vertical position of the lumbar support was fixed at the mean position selected by subjects in Phase-1 testing (about 156 mm above the H-point).

In the prescribed-posture trials the subjects were required to sit using a specified procedure intended to maximize lumbar lordosis. The seat and steering wheel adjustments were set at the positions previously selected by the subject for preferred-posture trials. The subject sat in the seat while leaning forward from the hips as much as possible, then slid rearward on the seat until firm contact was made between the buttock-sacrum area and the seatback. The subject then leaned back against the backrest to obtain a comfortable driving posture while maintaining his or her pelvis as upright as possible. The objective of these prescribed-posture trials was to determine the maximum lumbar lordosis (minimum spine flexion) that was possible under the test conditions.

Table 1
Phase-2 Test Conditions
(Fixed/Adjustable Vertical Lumbar Support Position)

| Lumbar Support Prominence | Preferred Posture | | Prescribed Posture |
|---|---|---|---|
| A: 0 mm | Adjustable | Fixed | Fixed |
| C: 25 mm | Adjustable | Fixed | Fixed |
| D: 35 mm | Adjustable | Fixed | Fixed |
| E: 45 mm | Adjustable | Fixed | Fixed |

Phase-2 testing was conducted with 32 subjects recruited from the Phase-1 subject pool. Table 2 summarizes their stature and weight. Subjects were licensed drivers selected from four stature-gender groups ranging in stature from small women to large men. Age ranged from 19 to 72 years, with a mean age of 40 years.

The posture measurement procedures were the same as those reported in Reed *et al.* (5). The three-dimensional location of ten body landmarks, along with the longitudinal back contour measured by the backrest probes, was recorded for each test condition. Measures of posture were computed from these landmarks. The three posture variables that are important for the current analysis are defined in Table 3 and illustrated in Figures 3 and 4. Pelvis angle and sternum angle are directly related to the orientation of the top and bottom of the thoracic and lumbar spine. If the sacrum and pelvis are assumed to form a rigid body link, and the ribcage and the thoracic spine another, then the relative values of the pelvis and sternum angles describe the amount of flexion in the thoracic and lumbar spine.

Contour prominence is measured from the back contour probe measurements as described in Figure 4. When the lower back contour curves outward relative to the subject, corresponding to a kyphotic spine posture, the tangent reference line is drawn between the lowest point in the contour and the point in the upper half of the contour that produces the largest angle of the reference line relative to vertical. The resulting contour prominence measurement is negative.

Table 2
Phase-2 Test Subjects

| Group | N | Stature (mm) (min-mean-max) | Stature (%ile by Gender)* (min-mean-max) | Weight (kg) (min-mean-max) |
|---|---|---|---|---|
| Small Female | 8 | 1533–1565–1582 | 6–14–29 | 49–55–64 |
| Midsize Female | 8 | 1595–1621–1640 | 29–40–57 | 51–58–66 |
| Midsize Male | 8 | 1728–1754–1775 | 33–47–61 | 60–78–96 |
| Large Male | 8 | 1776–1835–1866 | 62–88–95 | 75–85–100 |

*Estimates based on distributions in Gordon *et al.* (7).

Table 3
Posture Variables

| Variable | Definition* |
|---|---|
| Pelvis Angle | Angle with respect to vertical of a line from the pubic symphysis landmark to the mean of the left and right anterior-superior iliac spine landmarks. Larger pelvis angles indicate more rearward pelvis rotation. |
| Sternum Angle | Angle with respect to vertical of a line from the bottom sternal landmark to the top sternal landmark. Larger sternum angles indicate more rearward rotation of the ribcage. |
| Contour Prominence | Maximum displacement of the lumbar portion of the longitudinal back contour from a line through the bottom of the contour tangent to the thoracic section of the contour (see Figure 4). |

• All angles measured in sagittal plane.

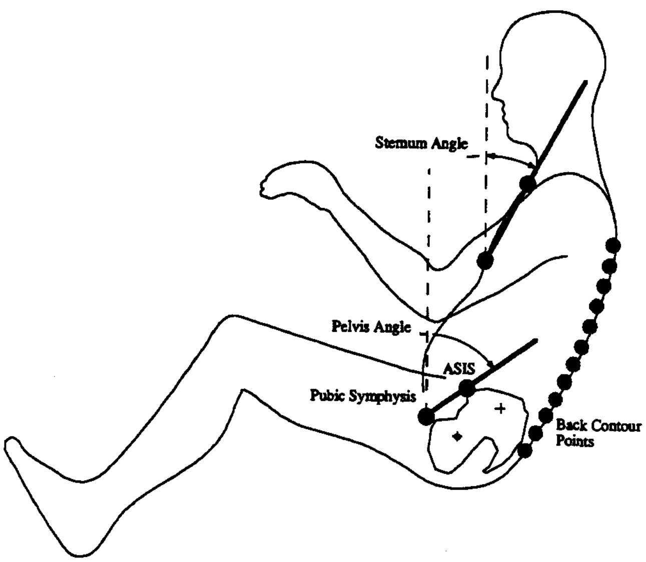


Figure 3. Body landmarks and definition of pelvis angle and sternum angle.

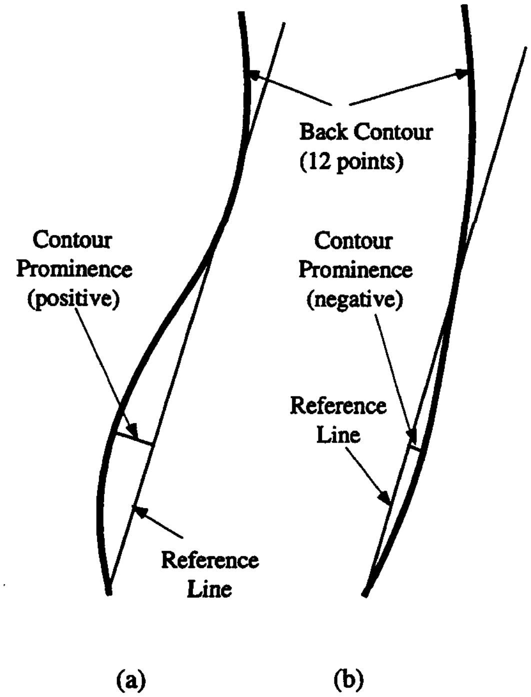


Figure 4. Definition of contour prominence measured on longitudinal back contour for both positive (a) and negative (b) prominences.

## RESULTS

STANDING POSTURE – The comfortable standing posture of all subjects was recorded prior to the sitting trials and provides a useful, standardized reference posture to which seated postures can be compared. Table 4 shows the pelvis angle, sternum angle, and contour prominence measures for the thirty-two Phase-2 subjects obtained with the subjects standing. Subtracting the sternum angle from the pelvis angle gives a measure of the amount of flexion in the thoracic and lumbar spine. Although the absolute values of the pelvis-sternum variable have little meaning, the change in this variable is a measure of the change in orientation between the pelvis and ribcage, and is therefore a useful measure of the change in thoracic and lumbar spine flexion. To simplify comparisons between sitting and standing postures, the standing posture for each subject is defined as zero degrees of spine flexion. Net flexion or extension of the thoracic and lumbar spine relative to the standing posture is obtained by computing the difference between the pelvis and sternum angles and subtracting the standing value.

Table 4
Subjects' Comfortable Standing Posture

| Variable | Mean (Std. Dev.) |
|---|---|
| Pelvis Angle | 0.3 (8.0) |
| Sternum Angle | 16.4 (4.9) |
| Spine Flexion* | 0.0 |
| Contour Prominence (mm)† | 24.4 (6.8) |

*See text for calculation procedure.
†Standing contour measured using skin surface points over spinous processes.

SUBJECTS' PREFERRED DRIVING POSTURES – Table 5 shows the pelvis angle, sternum angle, and contour prominence in the subjects' preferred driving postures for the flat (0-mm) and 45-mm lumbar support conditions. In general, postures were not significantly different with the lumbar support vertically adjustable or with it fixed, so only data from the fixed conditions are reported here. There are also no significant differences between subject groups on these variables, so data from all subjects are pooled. All of the comparisons between postures discussed in this paper are statistically significant with $p<0.001$ using the appropriate within-subject $t$ or $F$ tests.

Table 5 shows the effects of a 45-mm increase in lumbar support prominence on the sitter's posture. On average, the subjects' pelves were 3.7 degrees more upright, and their sternums were 3.7 degrees more reclined, with the 45-mm lumbar support. The net change in spine flexion between the flat and 45-mm lumbar support conditions is a reduction of about 7.4 degrees of flexion. This is accompanied by an increase in contour prominence of about 9.4 mm, as calculated from the back probe data.

Table 5 also shows the seated values for preferred postures after subtracting the standing values for each subject, thus expressing the seated posture in terms of the change in orientation of the body segments relative to the standing posture. On average, subjects' pelves rotated rearward 55.4 degrees relative to the standing posture when sitting with the flat lumbar support, while their sternums reclined only 6.2 degrees. Using the difference between the pelvis and sternum angles as a measure of spine flexion, the subjects flexed their spines an average of 49.2 degrees relative to the standing posture when sitting with a flat lumbar support. The average reduction in the prominence of the back contour from standing to sitting with the flat support is 23.0 mm. Table 5 also shows the change in posture produced by the addition of the 45-mm lumbar support as a percentage of the total change in posture from standing to sitting with a flat lumbar support. The rearward rotation of the pelvis was reduced 6.9 percent by the 45-mm increase in lumbar support prominence. In contrast, sternum angle recline increased by almost 60%, although the absolute change was only 3.7 degrees.

There are two contrasting values in Table 5 for the change in spine shape as a result of increased lumbar support prominence. The flattening of the lumbar spine, as measured by the longitudinal back contour, was reduced 41.3 percent. However, the net spine flexion, as measured by the difference between the pelvis and sternum orientations, decreased by only 15.2 percent. Because of the importance of these measures of lumbar spine posture, additional analysis and simulations were conducted to determine if a 15.2 percent reduction in spine flexion could result in a 41.3 percent reduction in the amount of spine flattening produced by sitting.

Table 5
Subjects' Preferred Driving Postures
(means and standard deviations)

| Variable | 0 mm (flat) | 45 mm | 0 mm (flat) (*re* standing) | 45 mm (*re* standing) | Change (flat to 45 mm)* | Change (flat to 45 mm)** |
|---|---|---|---|---|---|---|
| Pelvis Angle | 55.7 (12.8) | 52.0 (13.0) | 55.4 (14.4) | 51.6 (14.6) | –3.7 (4.9) | –6.9% |
| Sternum Angle | 22.6 (8.3) | 26.3 (8.1) | 6.2 (6.4) | 9.9 (6.3) | 3.7 (4.8) | 59.7% |
| Spine Flexion | -- | -- | 49.2 (14.9) | 41.8 (15.0) | –7.4 (6.5) | –15.2%† |
| Contour Prominence (mm) | 1.5 (5.8) | 10.9 (9.0) | –23.0 (6.4) | –13.5 (8.3) | 9.4 (5.3) | –41.3%† |

Table 6
Prescribed Driving Postures
(means and standard deviations)

| Variable | 0 mm (flat) | 45 mm | 0 mm (flat) (*re* standing) | 45 mm (*re* standing) | Change (flat to 45 mm)* | Change (flat to 45 mm)** |
|---|---|---|---|---|---|---|
| Pelvis Angle | 45.6 (12.4) | 41.7 (12.8) | 45.2 (13.8) | 41.3 (14.2) | –3.9 (4.4) | –8.6% |
| Sternum Angle | 22.7 (7.0) | 25.8 (8.6) | 6.3 (6.2) | 9.4 (7.3) | 3.1 (4.9) | 49.2% |
| Spine Flexion | -- | -- | 39.0 (16.1) | 31.9 (15.6) | –7.0 (6.9) | –17.9%† |
| Contour Prominence (mm) | 9.6 (6.5) | 20.5 (7.5) | –14.8 (7.6) | –4.0 (7.8) | 10.9 (6.2) | –73.6%† |

* Standard deviation of within-subject effect.
** Change between flat and 45-mm lumbar support prominences as a percentage of the total change in the variable from standing to sitting with the flat lumbar support.
† See simulation results below.

PRESCRIBED POSTURES – Table 6 shows the results for the prescribed-posture condition, in which the subjects' sitting procedure was specified to maximize lordosis. Comparing the values to those in Table 5, the primary difference between the preferred- and prescribed-posture conditions is that subjects sat with more upright pelves in the prescribed-posture condition (approximately 10 degrees more upright). This was expected, since the goal of the prescribed sitting procedure was to produce maximally upright pelvis angles, thereby maximizing lumbar lordosis. Surprisingly, the difference in pelvis angle between the preferred- and prescribed-posture conditions is about ten degrees with both the flat and 45-mm lumbar supports. On these variables, the differences between the flat and 45-mm lumbar support conditions in the prescribed-posture trials are about the same as in the preferred-posture trials. The data from the prescribed-posture trials show that the test conditions did not preclude the subjects from sitting with substantially less lumbar spine flexion than was observed when the subjects were allowed to select their postures.

KINEMATIC SPINE MODELING – A planar kinematic model of the human torso was used to visualize the postures measured with subjects. The model development is described in Reed *et al.* (6). The model is based on midsize-male anthropometry and consists of a pelvis and seventeen vertebrae linked by revolute (pin) joints. The model spine can be flexed or extended by distributing the net change in orientation between the top and bottom of the spine among the seventeen intervertebral joints (T1/T2 to L5/S1). For the present illustrations, spine motion is distributed evenly among the six lumbar joints (T12/L1 to L5/S1), following the recommendation of Hubbard *et al.* (8). No thoracic spine mobility is included. In general, more spine motion is expected at the base of the spine (L5/S1) than higher in the spine (9), but the assumption of even distribution of motion in the lumbar spine is made for simplicity and because it results in larger predicted changes in back contour when the net spine flexion is changed. The assumption of a fixed motion distribution in the spine reduces the kinematic degrees of freedom (dof) to four. The spine can be flexed or extended (1 dof), the entire model can be rotated in the plane (1 dof), and the model can be translated on the X and Z axes (2 dof). Figure 5 shows the model moved in five steps from the mean standing posture to the mean sitting posture with the flat lumbar support, demonstrating the articulation of the lumbar spine. The shoulder and hip joint centers are illustrated, along with the flesh-plane line connecting the mean ASIS and pubic symphysis points, which define the pelvis angle.

The model was initially configured to a starting posture corresponding to the typical midsize-male driving posture reported by Schneider *et al.* (10), which includes an approximately flat lumbar spine contour. The model was then adjusted to represent simultaneously the mean values of pelvis angle and sternum angle obtained with the flat and 45-mm lumbar supports, as shown in Figure 6. These mean values can be found in Table 5. A reference line is constructed from the posterior-superior iliac spines at the back of the pelvis tangent to the thoracic spine. Lordosis in the model simulations is measured as the maximum perpendicular deviation of a lumbar spinous process point from the tangent line. Figure 7 shows the method of calculating lordosis with the model.

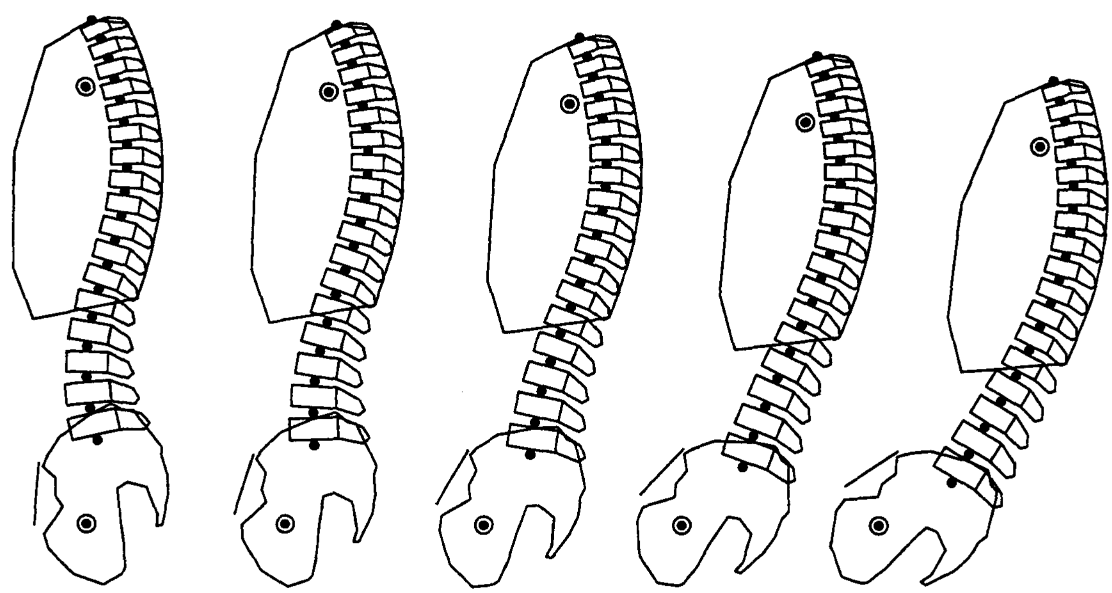

Figure 5. Simulation sequence showing the mean change in posture from standing (left) to sitting (right, mean preferred posture in the flat lumbar support condition), demonstrating the articulation of the model lumbar spine. Shoulder and hip joint centers are shown. Net lumbar spine flexion is 49 degrees.

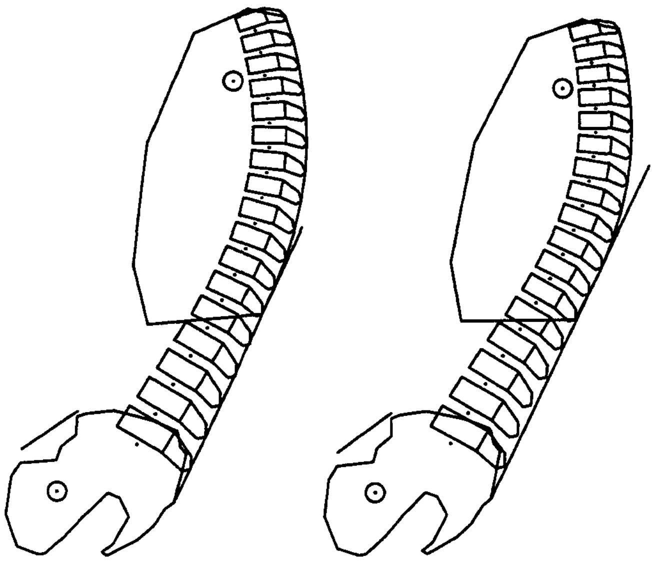


Figure 6. Kinematic simulations of the mean posture change induced by a 45-mm increase in lumbar support prominence, based on the measured changes in orientation of the thorax and pelvis.

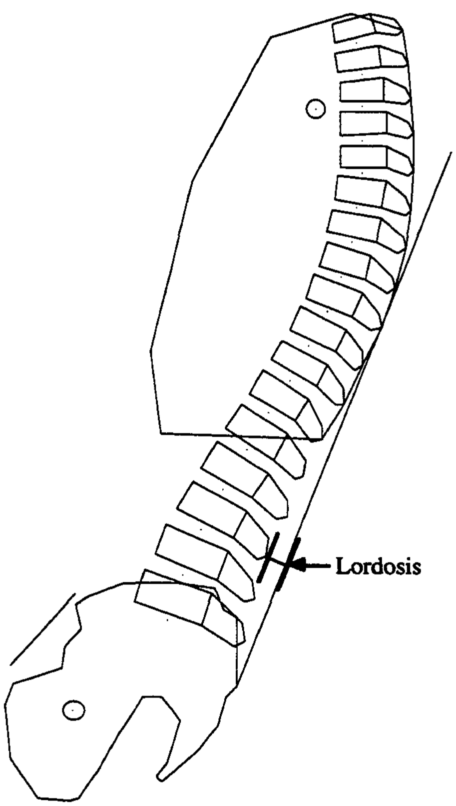


Figure 7. Method of calculating lumbar lordosis with the kinematic model.

There is an approximately linear relationship between spine extension and lumbar lordosis with the kinematic model. Figure 8 shows the results of simulations with the model geometry adjusted to reflect small-female, midsize-male, and large-male anthropometry reported in Schneider *et al.* (10). The slopes of linear fits to the curves in Figure 7 are 0.67, 0.72, and 0.81 mm/degree. The appropriate slopes to use with the current data were computed for each subject group by linear interpolation on mean group stature, producing slopes of 0.68, 0.69, 0.72, and 0.78 mm/degree for the current small-female, midsize-female, midsize-male, and large-male subject groups, respectively. The average slope for simulating the current subject groups is 0.72 mm/degree.

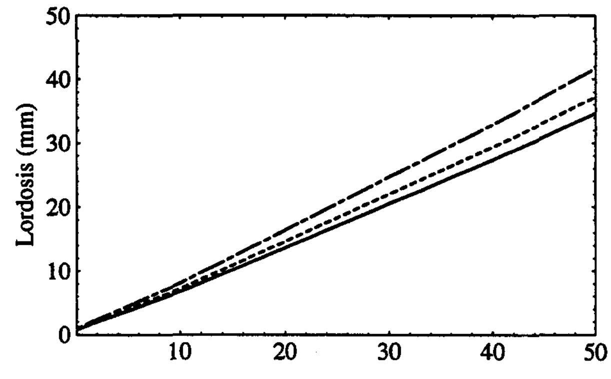


Figure 8. The lordosis produced in the model by extending the lumbar spine from the neutral sitting posture (flat spine profile). Results are shown for simulations with the model adjusted to small female (—), midsize male (– –) and large male (- —) anthropometry. Slopes of linear fits are 0.67, 0.72, and 0.81 mm/degree, respectively.

Using this average value, model lordosis increases by 5.3 mm in response to the 7.4-degree reduction in spine flexion associated with the mean change in posture produced by 45-mm increase in lumbar support prominence. In contrast, the mean increase in longitudinal back contour prominence measured using the contour probes was 9.4 mm (see Table 5).

The difference may be caused by an inconsistent relationship between the back contour measured with the probes and actual spine profile. The contour probes were mounted 25 mm to the right of the seat centerline to avoid a central rib of the lumbar support mechanism. Because the lateral position of the subject was not controlled, the probes would probably seldom be directly behind the spine, even if they were positioned directly on the seat centerline. As a result of this potential variability in alignment, the probe points are not likely to represent the spine profile accurately, although they may more accurately represent the depressed seat surface profile. The greater pressure concentration associated with the 45-mm lumbar support may also have compressed the soft back tissue adjacent to the spine to a greater extent than with flat support, increasing the apparent lordosis more than the actual change in spine curvature.

DISTRIBUTION OF SPINE FLEXION – Although the mean reduction in spine flexion produced by the 45-mm lumbar support is about 7.4 degrees, there is considerable variability among the subjects. Figure 9 shows the distribution of the reduction in spine flexion produced by the change from the flat lumbar support to the 45-mm prominence for the thirty-two subjects. Five of the thirty-two subjects sat with increased spine flexion with the 45-mm lumbar support, compared to the flat-support condition.

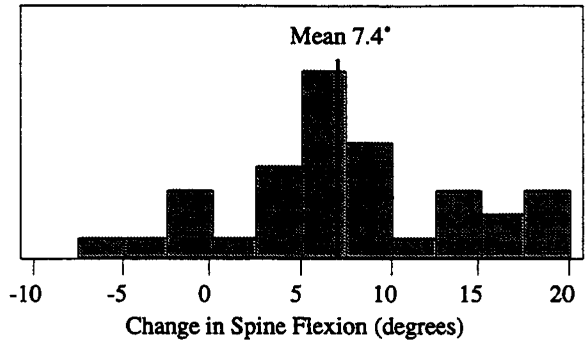


Figure 9. Difference in spine flexion (measured by pelvis angle – sternum angle) between the flat and 45-mm lumbar support conditions (mean = 7.4, std. dev. = 6.5, N = 32).

The change in lordosis associated with the changes in spine flexion shown in Figure 9 can be estimated using the simulation technique described above. Figure 10 shows the distribution of estimates for the change in lumbar lordosis based on pelvis angle and sternum angle. The estimated standard deviation of the change in lordosis produced by the 45-mm lumbar support is 4.5 mm.

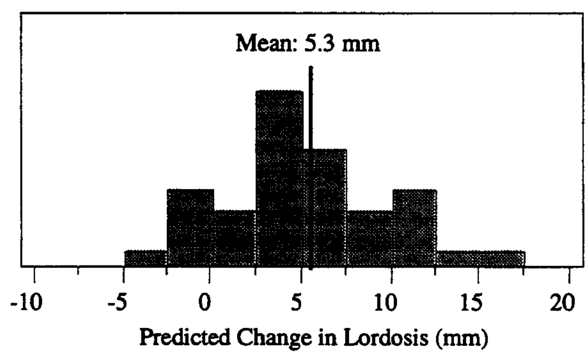


Figure 10. Distribution of the predicted change in lordosis produced by the net changes in spine flexion based on kinematic modeling technique (mean = 5.3, std. dev. = 4.5, N = 32).

## DISCUSSION

SUMMARY OF FINDINGS – The objective of this study was to document the effects of changes in lumbar support prominence on driving posture. The analyses in this paper focused on data from two extreme conditions (flat and 45-mm prominence). The results for other prominences (25 and 35 mm) fall between the postures reported here. A primary conclusion is that, on average, a longitudinally convex lumbar support with a large prominence does not result in a driving posture with a corresponding amount of lordosis. That is, the sitter's back does not usually conform to the support. The results from the prescribed-posture trials show that the test conditions did not preclude the subjects from choosing postures with more lordosis (less spine flexion), but even these postures were considerably flexed relative to the standing spine posture (average of 32 degrees of net spine flexion relative to standing versus 42 degrees in preferred postures with the 45-mm lumbar support).

The prominent lumbar support did, however, result in statistically significant and potentially important reductions in spine flexion relative to the flat lumbar support. Based on the pelvis angle and sternum angle measurements, the net flexion of the thoracolumbar spine relative to the standing posture was reduced about 15 percent, on average, by the addition of the 45-mm lumbar support. However, the net change in lordosis produced by this reduction in flexion is small, estimated at about 5.3 mm, on average, using the model simulation technique.

APPLICABILITY OF RESULTS – The results of this study are limited in that only one vehicle interior package was represented. The seating buck was designed to approximate the interior geometry of a minivan with a relatively high seat height (H30 = 352 mm). High seat heights typically result in more-flexed knee postures (*i.e.*, included knee angles closer to 90 degrees). The average knee angle in the current study was about 114 degrees. Larger (more extended) knee angles would be expected at lower seat heights. Tension in the hamstrings resulting from more-extended knees tends to restrict forward pelvis rotation, further reducing the possibility of substantially lordotic lumbar spine postures. Hence, substantial lumbar lordosis is expected to be less frequently observed at lower seat heights.

These results document only the posture effects associated with changing the lumbar support prominence while maintaining all other seat design factors constant. Other changes in the seat might also affect spine posture. However, the prescribed-posture trials demonstrate that the maximally upright pelvis angle is only about ten degrees more upright, on average, than the preferred orientation. An analysis of hip-flexibility data (6, 11, 12) suggests that the prescribed-posture condition represents a hamstring-limited pelvis orientation, so changes in seat pan or backrest design are not likely to reduce rearward pelvis rotation beyond the level attained in those trials. Further, the seatback was designed specifically to reduce the possibility of upper-seatback interference with the shoulders and thorax precluding more lordotic postures. Data from pressure sensors located on the seatback suggest that pressure behind the upper back and shoulders did not substantially restricted rearward thorax rotation. Further, since subjects were permitted to adjust the seatback recliner, a desire for additional rearward thorax rotation could have been readily accommodated by a change in seatback angle.

The flat lumbar support condition used in this study probably represents more lumbar support, as measured on the deflected seat contour, than many production seats. The seatback used in this study was thinly padded so that all sitters would bottom out the foam in the lumbar area, assuring that both heavy and light sitters would experience approximately the same deflected seatback contour. Most production auto seats are more thickly padded in the lumbar area, so that the depressed contour is more strongly dependent on body weight. A large number of production driver seats have approximately flat undepressed contours in the lumbar area. Unless the support structure underlying the foam has a pronounced convexity, the depressed contour of the lumbar area of these seats will almost certainly be concave, resulting in a negative effective lumbar support prominence as defined in this study. Heavier sitters, in particular, who deflect the padding in the lumbar area to a greater extent than light sitters, are likely to experience deflected seatback contours with negative lumbar support values.

Modifying a seat so that the depressed backrest contour changes from a negative to positive lumbar support prominence, as defined in this study, may produce a much larger mean change in posture than would a change from flat to 45-mm of prominence, because hamstring extensibility would probably restrict pelvis orientation for fewer subjects at negative values of lumbar support. Therefore, it should not be concluded that, in general, a 45-mm increase in lumbar support prominence will produce only a 15% reduction in spine flexion. These results are applicable only for the change from flat to a 45-mm prominence, and for knee and hip angles in the range studied.

Although these results are probably widely applicable to driving postures, they may not apply to passengers. The vision and hand location requirements of driving impose substantial constraints on torso posture that are not typically experienced by passengers. The lack of these constraints may allow passengers to respond differently to changes in lumbar support contour.

IMPLICATIONS FOR COMFORT – Although the difference in spine flexion between the 45-mm and flat lumbar supports is fairly small, such a difference may nonetheless be very important for the comfort of the sitter. The passive tension in the paraspinal tissues increases in a nonlinear manner as the lumbar spine is flexed. Even small reductions in flexion may produce large reductions in tissue stress and may reduce discomfort. However, the postures recorded in this study with the 45-mm lumbar support may not be attainable in a production seat because of the need to maintain pressure concentrations in the lumbar area at an acceptable level. That is, a highly prominent, firm support may produce more discomfort as a result of pressure concentration than it eliminates by reductions in spine flexion.

RECOMMENDATION FOR LUMBAR SUPPORT ASSESSMENT – Because of the small amount of change in back contour resulting from a large change in lumbar support prominence, and the difficulty in establishing a consistent reference line with a seated subject, lumbar lordosis, and back contour in general, may not be good measures of the effectiveness of lumbar support. Measuring the relative orientation of the pelvis and thorax is probably a more appropriate means of evaluating the extent to which a seat design minimizes lumbar spine flexion.

## CONCLUSIONS

Automobile seatbacks should be designed for drivers' preferred postures rather than for postures with a large degree of lordosis. A prominent, convex support did not induce drivers to sit with corresponding lordosis, although increasing the lumbar support prominence reduced spine flexion relative to standing by about 15%. The results of this study suggest an upper bound on the reduction in spine flexion that is possible using a longitudinally convex lumbar support. In this study, drivers flexed their spines relative to the standing orientation by an average of 42 degrees when sitting with a lumbar support that was more prominent than all of the subjects' standing lordoses. This means that the average seated lumbar lordosis for drivers is unlikely to approach the average standing lordosis, even with a well-designed lumbar support.

Within a reasonable range, seatback design may have only a small effect on back contour, particularly relative to intersubject variability. The change in back contour produced by adding a 45-mm prominence to the lumbar support was only 9.4 mm, on average, compared with an estimated population standard deviation of 6 to 8 mm. For more-thickly padded seats, the population variance in seated back contour would probably be larger due to differing levels of padding deflection. When designing seats, it may be practical to assume that an individual's back contour is relatively unaffected by changes in seatback geometry. However, this may not apply to relatively poor seatback designs, *e.g.*, those with negative lumbar support as measured on the deflected seat contour. Improving such designs may result in substantial changes in posture.

In this study, drivers' backs generally did not conform to the seatback contour, suggesting that seatbacks should be designed to provide support for a range of seated back contours, rather than for a specific contour. Given the apparent physiological advantages of reducing lumbar spine flexion, the seat design should provide support when people sit with the minimum amount of lumbar spine flexion with which they are comfortable, even though that posture may involve only a small degree of lordosis.

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