

Reclined Postures in Vehicle Seats: Preferred Seatback Contours and Head Support Locations

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by

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ABSTRACT

Published recommendations for longitudinal seat back contour in automotive seats are difficult to apply to seat design. Most studies describe sitter preferences in terms of the vertical position of the lumbar support apex location and an associated prominence, but the reference plane for the prominence is not well defined, the contour in areas adjacent to the apex is not described, and the contour that the sitter experiences is mediated by the seat padding and bolstering. Moreover, most studies of sitter preferences for seat back contours have focused on driving postures with an unsupported head and have not considered highly reclined postures with head support. Studies that have considered reclined postures have used production seats with seat back pivot locations that result in large changes in the lumbar support location with respect to the sitter's torso with changes in recline angle.

To address these gaps, a laboratory study was conducted with specially constructed seat with a seat back pivot coincident with the seat H-point. The seat back longitudinal contour was specified using a Bézier curve and produced by six linear actuators under computer control. A convenience sample of thirty men (N=16) and women (N=14) with a wide range of body size and age used a touchscreen interface to choose their preferred contours at seat back recline angles of 25, 30, 35, 40, 45, and 50 degrees. Three different starting contours were presented at each of the randomly presented back angles. In each trial, the investigator interactively adjusted a planar, padded head support to help the participant achieve a supported head position that would be comfortable for resting.

The participants' selected seat back contours were strongly influenced by the starting contour but were unrelated to seat back angle and to participant characteristics. The distribution of the Bézier parameters were used to estimate the range of contours that would be needed to accommodate the preferences of a large percentage of sitters. Fore-aft head support locations relative to the seat back line were not affected by recline angle for this seat with an H-point pivot. The vertical position of the head location along the seat back line was strongly associated with stature but minimally related to seat back angle.

INTRODUCTION

Automobile seats are expected to embrace a wider range of functionality due to increasing vehicle automation. Reclined postures that provide an opportunity to sit or rest with a supported head may become more common as vehicle operators spend less time engaged in the driving task. Although most front-row seats in current vehicles are equipped with recliner mechanisms capable of producing a wide range of seat back angles, vehicle manufacturers generally prohibit use of reclined postures while the vehicle is in motion due to safety concerns. Specifically, crash protection systems, including seat belts and airbags, are optimized for normally seated occupants and may not provide good protection for reclined occupants.

Moreover, most seats are not designed to provide good support for the back or head in reclined postures, due to two primary design issues. First, the seat back pivot is generally well to the rear and below the sitter's pelvis. When the seat back is reclined, the critical lumbar support area in the lower portion of the seat back moves upward relative to the sitter's anatomy. Second, the head restraint is designed primarily for protection of the neck in rear impacts and not as a comfortable head rest (Reed et al. 2019a, 2019b).

Addressing these issues is challenging due to the lack of quantitative information on both sitter's preferred seat back contours and preferred head support locations across a wide range of seat back angles. Several technical issues also arise. Although many studies have addressed preferences and requirements for lumbar support (e.g., Reed et al. 1995, 1996; Reed 2000; Kolich 2009; De Carvalho and Callaghan 2015; Buchman-Pearle et al. 2021), the resulting recommendations typically lack sufficient specificity to be directly useful in design. For example, preferred lumbar support contours are typically presented in terms of the height and prominence of the apex relative to the seat H-point, but the associated contour is not described. Moreover, interpreting lumbar support results from a study for vehicle seat design can be confounded by a lack of data concerning the compliance of the seat back. The ASPECT program introduced a new H-point manikin that provided the first standardized way of measuring lumbar support prominence in automotive seats (Reed et al. 1999), but the manikin, described in SAE J4002, does not measure the location of the prominence (Kolich 2009).

Head restraint location is governed by regulations, including the U.S. Federal Motor Vehicle Safety Standard 202a, which mandates minimum height and backset requirements. Studies have quantified driver head locations relative to the seat back and head restraint, but only in nominal driver and passenger postures with an unsupported head (Park et al. 2018). Sitter-preferred head and neck postures in reclined conditions have been quantified, but in seats that have not been optimized for reclined postures (Reed et al. 2019b).

To address these gaps, the current study aimed to quantify sitter preferences for longitudinal seat back contours and head support locations across a wide range of recline angles. A highly adjustable seat mockup was created that created a near-neutral recline trajectory by placing the seat back pivot near the seat H-point. Six motorized linear actuators linked to a computerized control system provided fine-grain adjustment of the

back contour. Data were gathered from an anthropometrically diverse population in short duration sitting sessions and analyzed in a manner that allows generalization to a broader population.

METHODS

Test Seat

Figure 1 shows several views of the test seat. The seat cushion was obtained from a production front passenger seat and was selected to be minimally featured, e.g., minimal bolsters. The seat cushion was mounted on an adjustable-height riser. The adjustable height floor (i.e., heel rest surface) was set to achieve a seat height (floor to H-point) of 270 mm, typical of a midsize sedan.

The seat back developed for the current study includes an adjustable pivot location (see holes on the side of the fixture in Figure 1b). During pilot testing, a range of different pivot locations were tested to find a position that would enable the seat back to remain in approximately the same location relative to the torso throughout a wide range of recline. Although individuals differed in the ideal location, a single pivot at the seat H-point location was used for the current study.

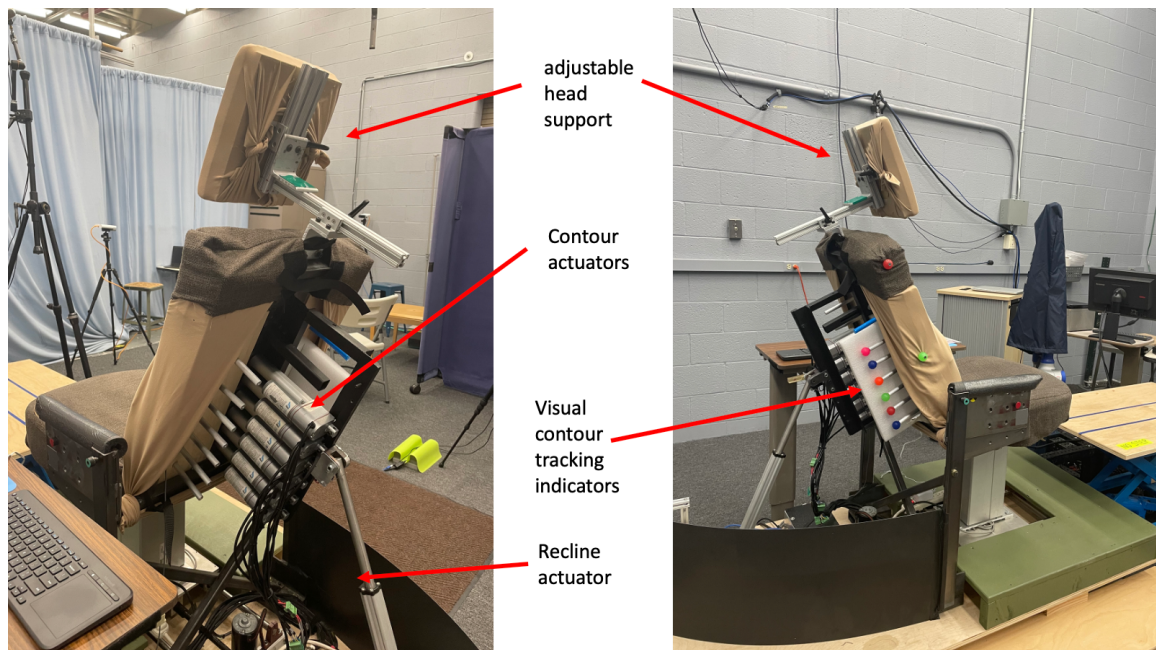


Figure 1a. Test seat. Colored spheres show the locations of the linear actuators used to adjust the seat back contour.

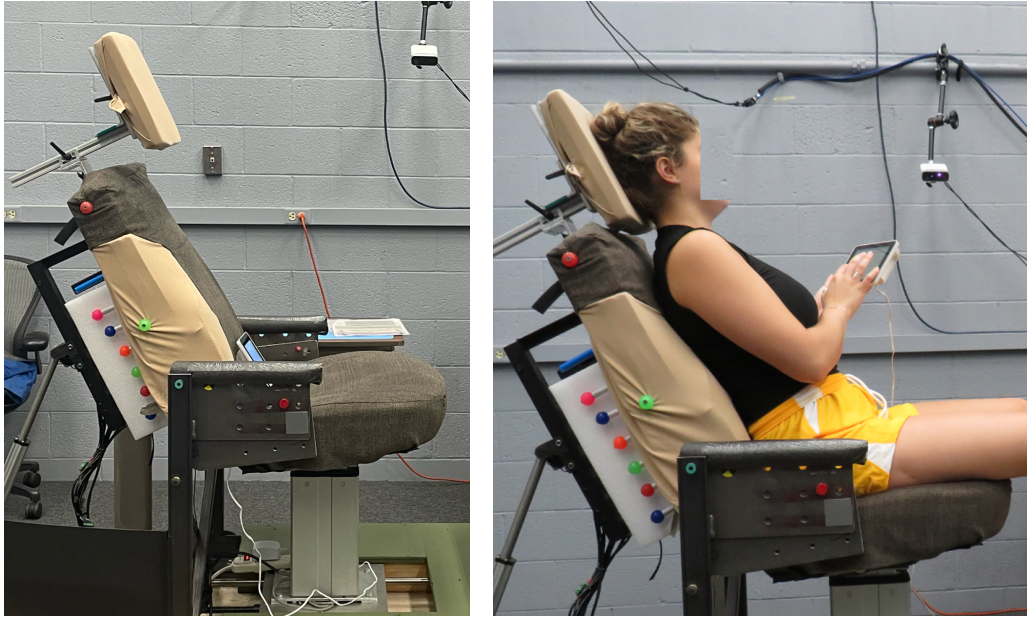


Figure 1b. Test seat. Colored spheres show the locations of the linear actuators used to adjust the seat back contour.

Six linear actuators with integrated displacement sensors and 100 mm of travel were positioned at 50-mm increments along the center of the backrest with parallel lines of action perpendicular to the plane of the seat back. The neutral (flat) contour was defined with the actuators at 25% of travel, leaving 75 mm of travel from minimum to maximum. Hence, the maximum prominence of the seat back curve was 75 mm. The motors were connected to rounded lateral members extending 150 mm laterally from the centerline. A sheet of 3-mm-thick Teflon was anchored at the top of the contoured area and laid over the cross members to provide a continuous surface. A layer of soft foam 15 mm thick was placed atop the Teflon and covered by a flexible cloth surface. To ensure that the Teflon surface contour was an accurate representation of the contour that the sitter experience, the padding was designed to be as thin as possible without causing discomfort due to high pressure against bony prominences.

The seat back angle was measured using the SAE J826 manikin (Figure 2) at a manikin torso angle (SAE A40) of 25 degrees. Seat back angle conditions were defined by the rotation of the seat back relative to the 25-degree position. The seat back contours and head support locations were expressed relative to a “seat back line” that originates at the H-point, is coincident with the manikin torso line at 25 degrees and rotates 1:1 around the H-point with the seat back. Seat back angles that are more reclined than 25 degrees do not necessarily correspond to the angles that would be measured using the H-point manikin in those conditions. Moreover, changes in the seat back contour affect the interaction with the manikin and would also change the relationship between the physical seat back angle and the manikin’s torso angle.



Figure 2. SAE J826 H-point machine and the H-point alignment with the seat back pivot.

The contour actuators were controlled by a custom Python program running on a Raspberry Pi computer interfaced via Bluetooth with a second Raspberry Pi running the user interface software. The sitter was able to adjust the contour using a touchscreen interface (Figure 3).

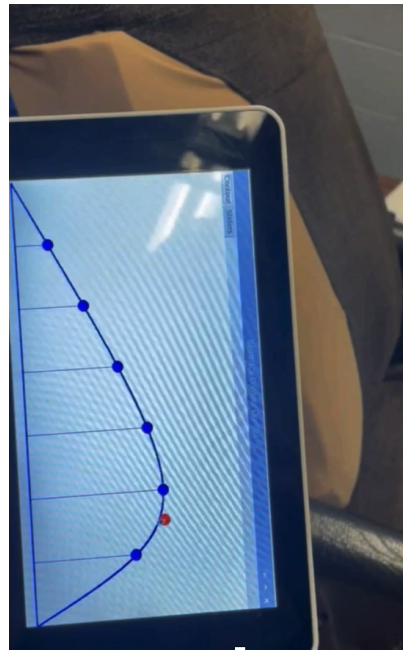


Figure 3. Touchscreen interface. The red dot indicates where the participant has touched the screen; the contour and actuator positions are shown schematically (not to scale).

The seat back contour was specified using a Bézier curve controlled by the participant's input. A Bézier curve interpolates its endpoints through a trajectory generated by a

weighted sum of the locations of the end points and two additional control points. (The Bézier calculations are presented in the Appendix). To generate the contours from a single point, the two internal control points were collocated at the point and the resulting curve was scaled perpendicular to the seat back line (laterally in the display) so that the peak value matched the lateral position of the input point. The displayed contour was not to scale; the full width of the display was mapped to 75% of the motor travel, with 25% set as the neutral (flat) contour. Hence, the control provided participants with up to 75 mm of prominence. The vertical range of the screen spanned the motor locations plus 100 mm, mapping to the range from 30 to 380 mm above the H-point along the seat back line.

Test Conditions and Procedure

The initial contour of the seat was hypothesized to affect the contours that participants would select, so trials were begun with the contour flat or with a prominence high or low on the back (Figure 4). Seat back angles from 25 to 55 degrees in 5-degree increments were presented in random order, with the initial contour randomized within seat back angle. Prior to adjusting the seat for each condition, participants leaned and shifted forward (Figure 5) while the seat back was adjusted, and then shifted and leaned rearward. After finding a comfortable posture, the participant used sliders on the touch screen to rate the contour with respect to prominence, height of the prominence, and overall comfort. Because two of the initial conditions were deliberately chosen to be at extremes rather than contours likely to be comfortable, the subjective data were not analyzed but were included in the procedure to focus the participant's attention on the comfort and contour of the seat back.

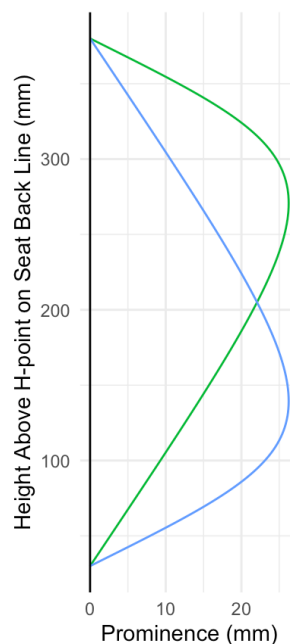


Figure 4. Initial contours (horizontal axis is magnified). Preset 1 is flat (overlies the vertical axis).



Figure 5. Forward-shifted posture during seat back adjustment prior to each test condition.

Measurement of Head Support Location

Four Microsoft Kinect Azure sensors were used to gather 3D point cloud data in each condition. Figure 6 shows the camera locations and an example of the resulting point cloud. In each test condition, after the participant adjusted the seat contour for comfort, the investigator aided the participant in finding a comfortable position for the head support. Participants were instructed to find a posture that would be comfortable for “resting” for a long period of time. The investigator moved the support parallel to and perpendicular to the seat back plane. The resulting head support locations were digitized on the 3D point clouds obtained from the posture measurement system. The data represent the side view location of the padded surface on which the participant’s head rested.



Figure 6. Location of cameras used for posture measurement and an example 3D point cloud.

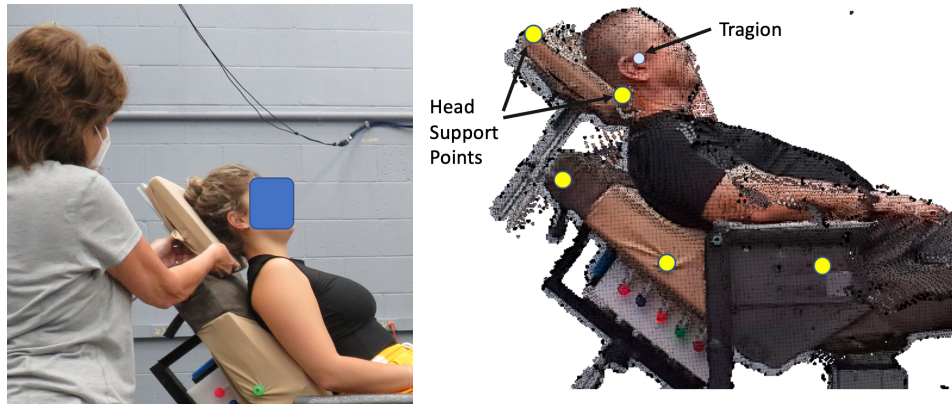


Figure 7. Investigator interactively adjusting head support (left) and landmarks manually digitized on the 3D scan data that were used to quantify head support location.

Participants

A convenience sample of thirty men (N=16) and women (N=14) with a wide range of body size participated in data collection. Table 1 and Figure 8 summarize body dimensions and age.

Table 1
Summary of Participant Descriptors

Dimension	Min	Mean	Max
Stature (mm)	1485	1711	1928
Weight (kg)	47.2	84.0	127.3
BMI (kg/m ²)	19.4	28.5	37.5
Age (years)	20	49.7	75

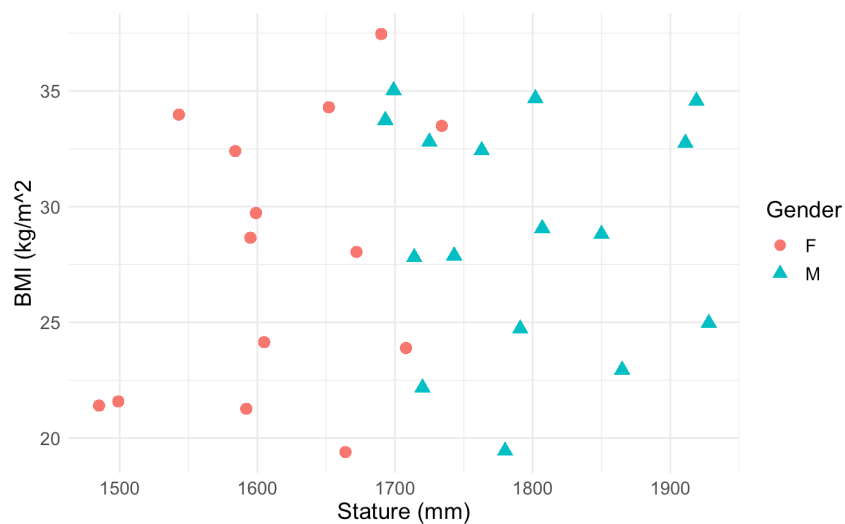


Figure 8. Stature and body mass index for participants.

RESULTS

Seat Back Contour

Figure 9 illustrates the distributions of back contours selected by the participants starting from the neutral (flat) contour. Note that the horizontal axis is scaled to improve visualization. Qualitatively, the selected contours span a wide range of prominences from flat to 45 mm, with most prominences (apex heights) less than 20 mm. The apex is generally in the bottom third of the contour. No trends with seat back angle are immediately apparent.

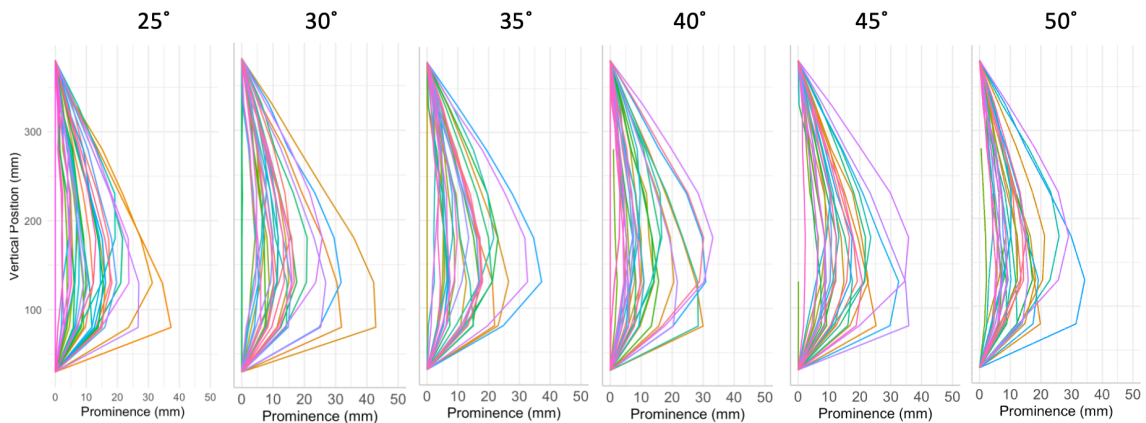


Figure 9. Qualitative view of participant-selected seat back contours across seat back angles. The vertical axis is relative to seat H-point along the seat back line (see text). Horizontal scale is magnified. Each participant's contours have the same color in each plot.

A quantitative analysis was conducted by statistical modeling of the scaled location of the control point used to define the contour. The point is characterized by Bézier parameter X , which determines the prominence, and parameter Y , which determines the apex location along the seat back line. These parameters are scaled relative to the display presented to the participant, i.e., $X=0$ represents a flat contour and $X=1$ corresponds to an apex prominence of 75 mm. The scaled values of Y from 0 to 1 correspond to 30 to 380 mm above seat H-point along the seat back line. Figure 10 shows the distribution of these parameters across seat back angles and presets. Interpreting these as approximately related to apex vertical position and prominence, the participant-selected apex location is generally in the bottom third of the contour with a range of prominence extending over about half of the 75-mm adjustment range.

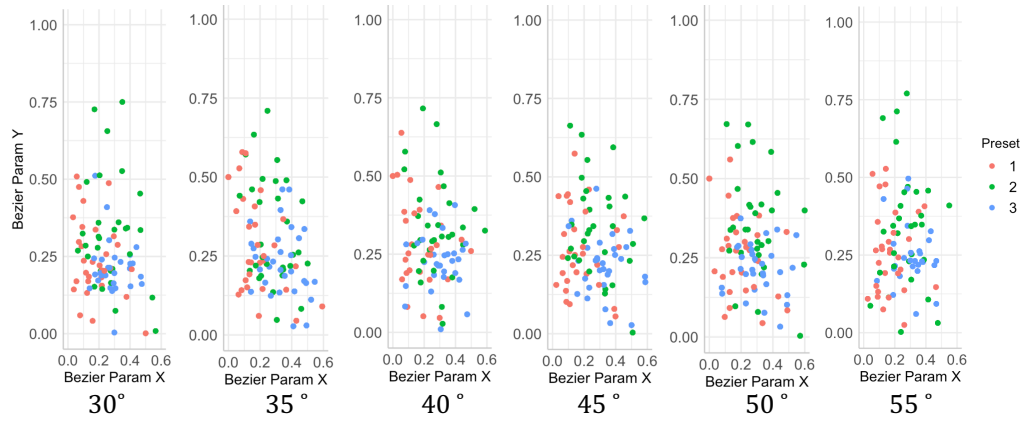


Figure 10. Sitter-selected Bézier parameter values across seat back angles for three presets.

Figure 11 shows the distribution of Bézier X and Y parameter values by preset, combining across seat back angles. The mean values and distributions are notably different by preset, and higher Y parameter values are weakly associated with lower X parameter values.

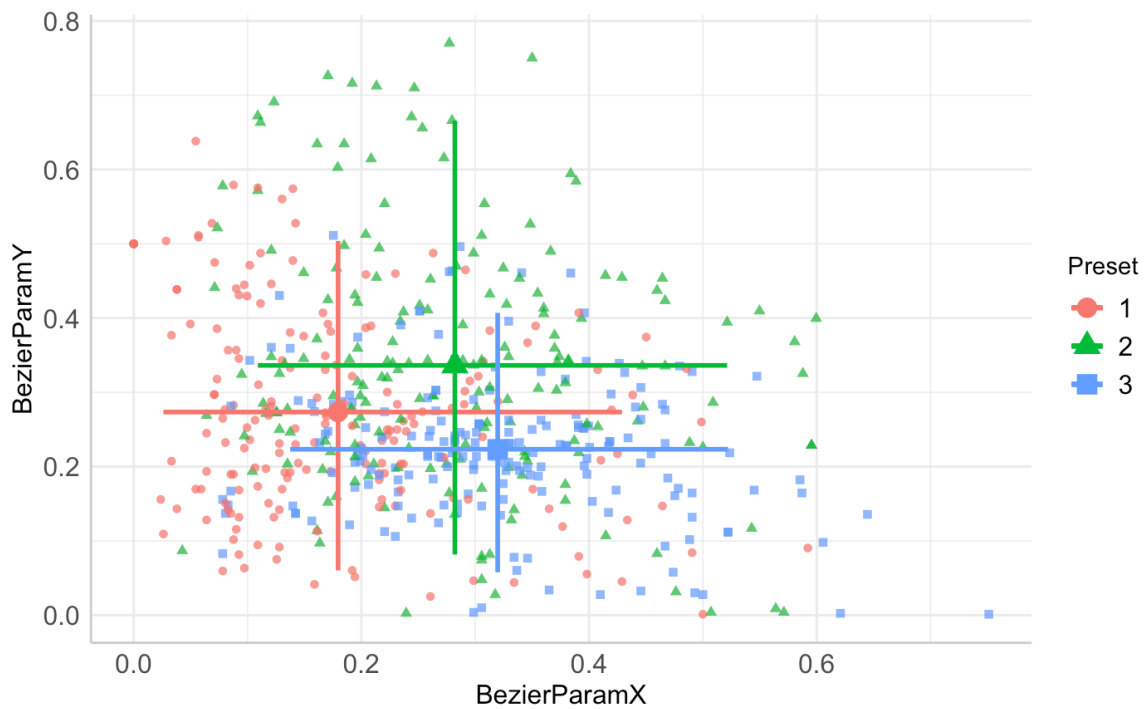


Figure 11. Distribution of Bézier parameter values for sitter-selected contours by preset. Lines connect 5th and 95th percentile values and cross at the mean.

Figure 12 shows the Bézier X and Y parameter distributions across back angle for sitter-selected contours. The presets had a clear effect on the values, but no effect of seat back angle is observed. Figure 13 shows the starting contour and mean sitter-selected contour for each preset. The results show that the sitter-selected contours are biased toward the starting contour.

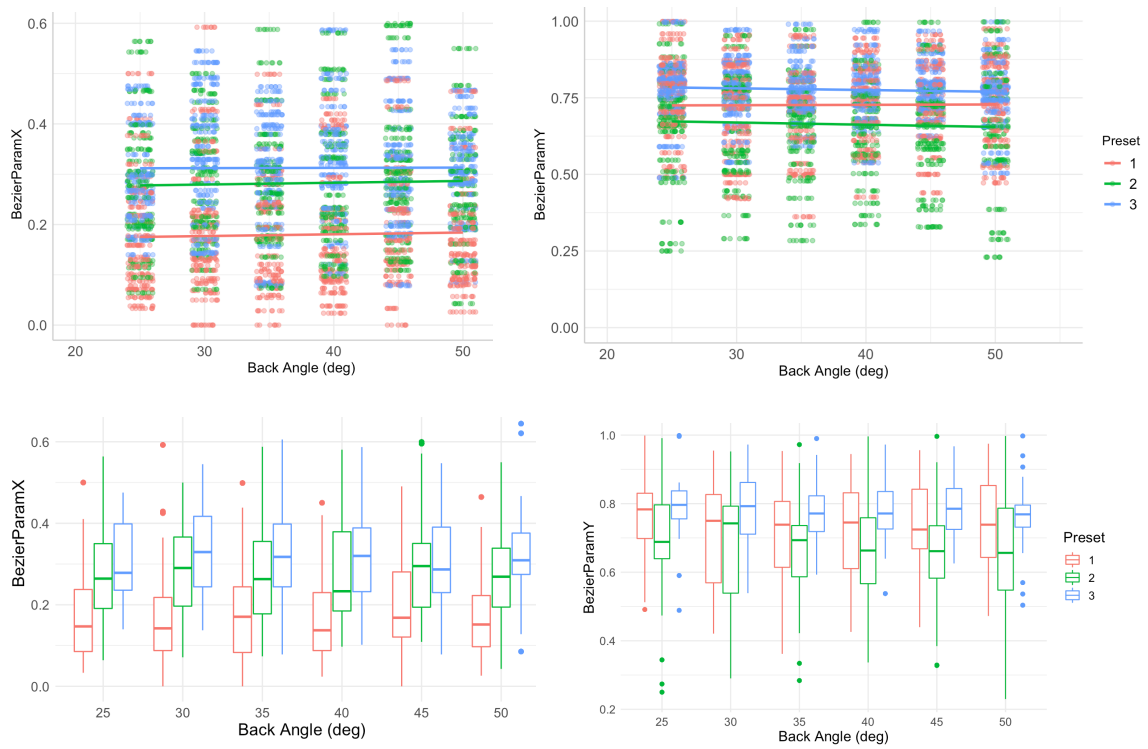


Figure 12. Distribution of Bézier parameters for sitter-selected contours by back angle and preset. The top plots show linear regressions; the bottom plots show box plots of the distributions within each back angle category. (Each box spans the interquartile range and has a line at the median.)

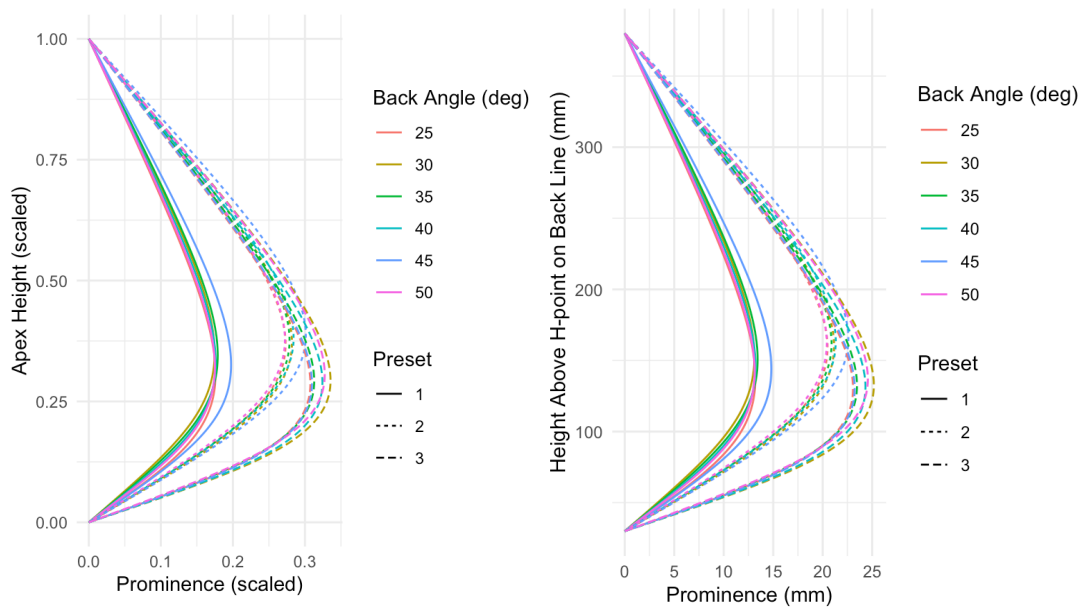


Figure 13. Mean sitter-selected contours by back angle and preset, expressed in scaled coordinates and with respect to the seat. Note that the horizontal scale in the right plot is magnified.

The contour parameters were not strongly associated with participant covariates (Figure 14). On average, taller stature and higher BMI were associated with reduced prominence, but the effect was small compared with the range across participants. The vertical parameter values were not related to these covariates.

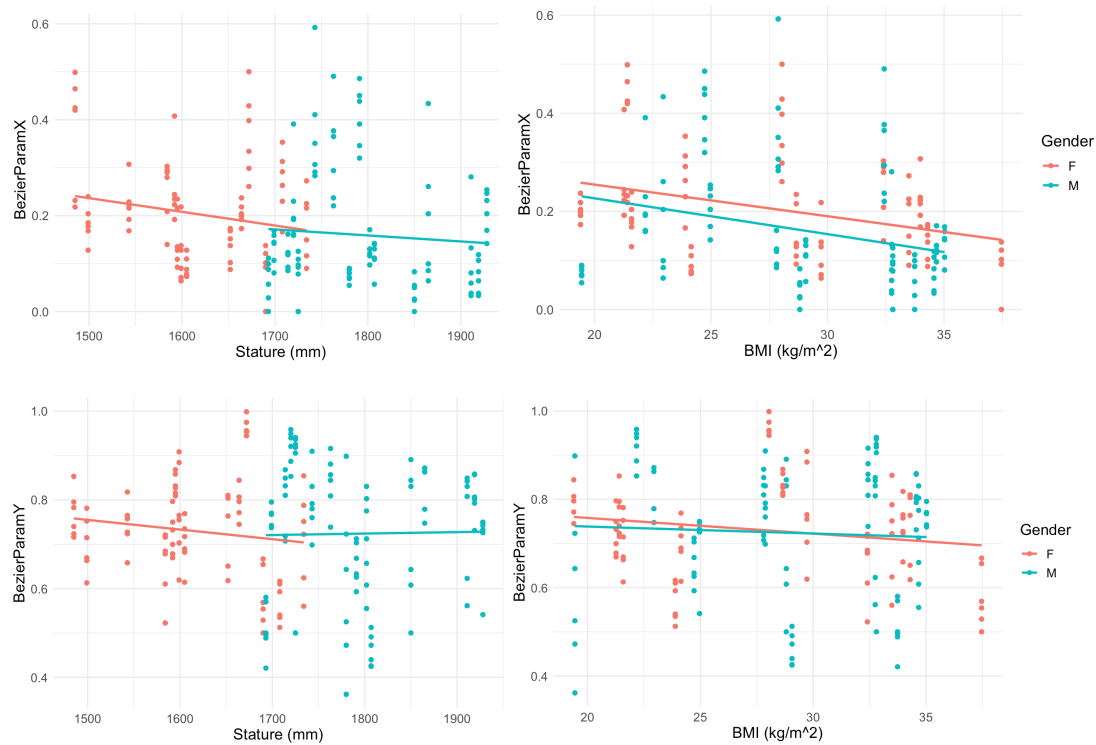


Figure 14. Contour parameters for sitter-selected contour in preset 1 as a function of participant gender, stature, and body weight.

Because the contour values are effectively independent of seat back angle and participant attributes, the distribution of contours needed to accommodate the population can be computed directly from the observed distributions. Using a simplifying assumption is that the X and Y parameter values are independent, the 5th and 95th percentile values for both parameters from preset 1 (flat) were combined to generate contours for comparison with the mean contour (Figure 15). The needed prominence adjustment ranges from approximately zero to 33 mm, and the desired apex locations range from 51 to 206 mm above the seat H-point on the seat back line. The mean prominence is 13 mm located 126 mm above seat H-point.

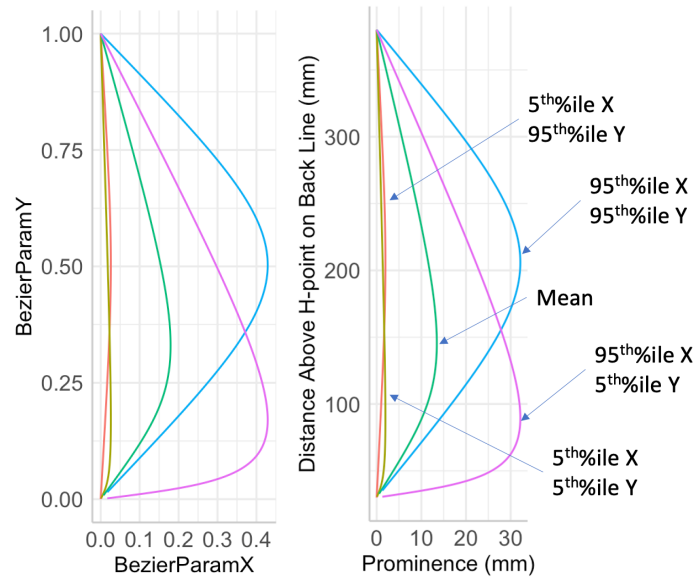


Figure 15. Illustration of the contour adjustment range needed to accommodate the central 95% of the joint X and Z parameter range. Horizontal axis in right plot is magnified for clarity.

Head Support Location

Fore-Aft Location

The participants' preferred fore-aft location of the head support was computed with respect to the seat back line, i.e., a vector passing through the H-point at the side-view orientation of the seat back angle. This is equivalent to the SAE manikin torso line at the nominal seat back angle (25 degrees) but moves with the seat back as the angle is changed. The center point between the upper and lower headrest points (see Figure 7) was projected perpendicularly onto the seat back line and the distance from the support to the back line was computed.

Figure 16 demonstrates that this distance was independent of the seat back angle. A minor trend with respect to stature was observed for men (Figure 17), but this effect was small compared with the overall variability and driven substantially by two outlying participants. The tight clustering of values for each participant (vertical columns of points in Figure 18) indicate that the within-participant variability was minor compared with the between-participant variability. That is, the test seat configuration resulted in participants selecting head support positions that were essentially the same across seat back angles.

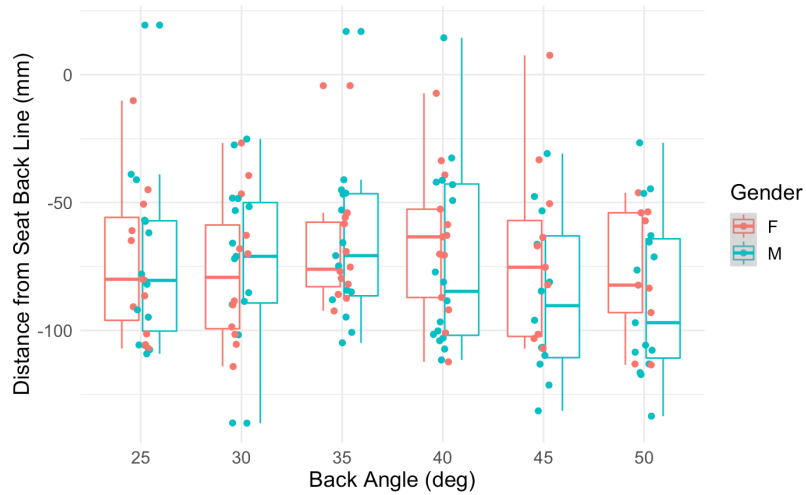


Figure 16. Distance from the head support surface to the seat back line. Negative values indicate that the head support was behind the seat back line.

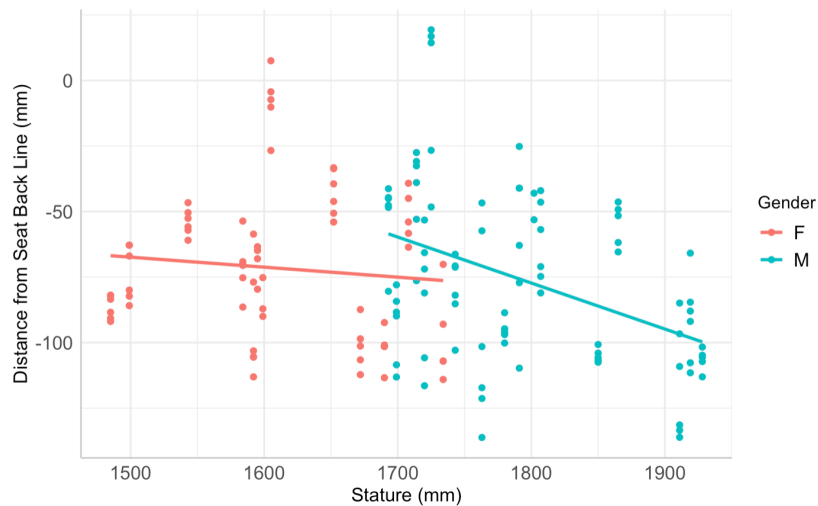


Figure 17. Distance from the head support surface to the seat back line relative to participant stature. Negative values indicate that the head support was behind the seat back line.

Head Support Height

The height of the center of the head support area for each participant was estimated by projecting the right trignon landmark (a point adjacent to the ear) onto the seat back line and computing the distance along the line above the H-point. As expected, this distance was a strong function of stature (Figure 18). The variability associated with seat back angle was small compared to the stature variability (Figure 19), indicating that placing the seat back pivot at the H-point was effective in maintaining the seat back position relative to the torso throughout the recline range. The small increase in this value with

increasing back angle (about 10 mm) is likely due to reduced flexion in the lumbar spine as the torso is increasingly supported by the seat back.

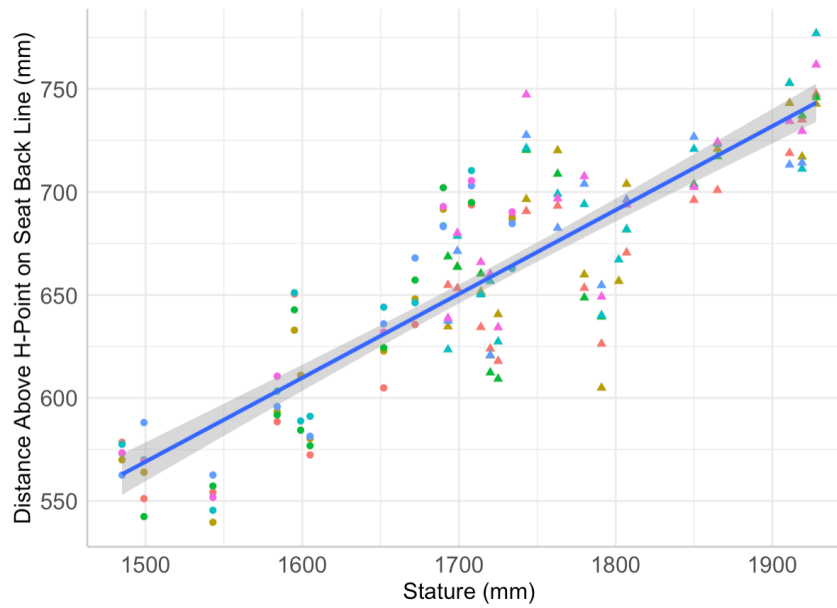


Figure 18. Head (tragion) distance above H-point along seat back line.

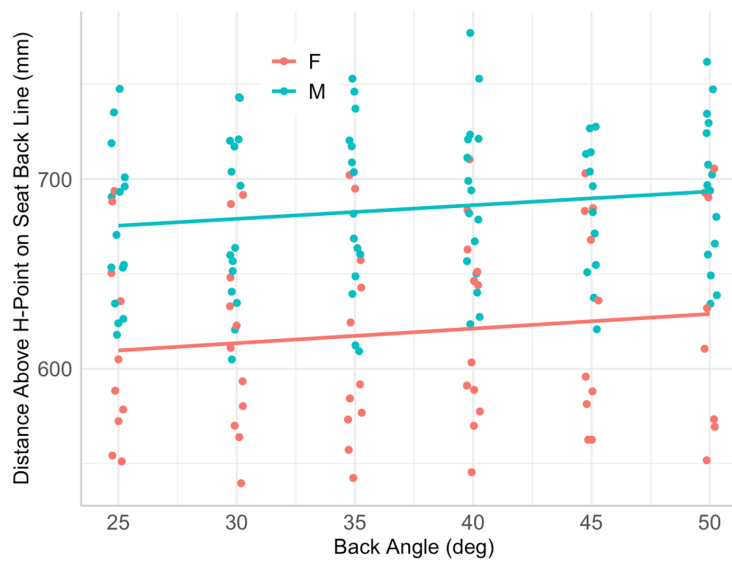


Figure 19. Head (tragion) distance above H-point along seat back line as a function of seat back angle. Linear fits are shown for male and female participants.

DISCUSSION

This study provides unique insight into preferences for seat back contour due to the design of the test seat, selection of test conditions, and the design of the participant interactions. The parameterization of the contour into two variables that completely define a smooth curve enabled a relatively simple statistical analysis that nonetheless captured considerable information about the participants' preferences. This study is the first to examine preferences for lumbar support across a wide range of recline angles, and the H-point seat back pivot enabled an analysis of the effect of recline on lumbar support preferences.

The results demonstrated considerable variability in preference for contour but no important associations with body dimensions were noted, and the preferences did not differ significantly with recline. This has important implications for seat design. For example, a typical seat back pivot results in the lumbar support moving upward relative to the sitter's anatomy when the seat back is reclined. The current results indicate the lumbar support apex would need to move downward as the seat back is reclined to maintain the apex in a sitter's preferred location. That is, the lumbar support preference relative to the torso anatomy is the same regardless of recline angle.

Interpreted as an apex height and prominence, the results suggest that the mean preferred lumbar support height is about 125 mm above the H-point, but the variability was large. Importantly, the mean prominence when starting from the flat preset was only 13 mm; this nearly flat profile means that the participants were likely to be insensitive to the apex height when near the mean contour. The preferred prominence ranged from flat to about 35 mm, with higher apex positions associated with reduced prominence. Consider the apex height with respect to anatomy indicates that the lowest apex positions (around 50 mm above H-point) put the apex behind the pelvis, such that the effective seat contour across the lumbar region is approximately flat regardless of prominence. Due to the demonstrated bias in the sitter-selected contours toward the initial contour for the trial, the true prominence preference is likely to be somewhat higher, though also less than the mean prominence values between 20 and 25 mm obtained with the more-prominent preset contours. Consequently the true mean preferred prominence for these test conditions is likely to be about 16 mm, but the closeness of these values relative to the variance between participants means that in practice adjustability in effective prominence is needed to accommodate a population, whether achieved by adjusting the prominence or by adjusting the person's pelvis location.

The study is also the first to provide quantitative guidance for head support location across a wide range of recline angles. As with the contour findings, the participants' preferred head support locations were independent of recline angle, providing further indication that the H-point pivot resulted in seat back that moved with the torso during recline. The data can be used to guide the design of head supports intended to be used for resting. The needed range of adjustment to accommodate 95% of sitters is from about 50 to 125 mm behind the seat back line, and from about 575 to 725 mm above the H-point along the seat back line.

The study has several important limitations and reasons for caution in applying the results. The study population was small, the sitting duration in each condition was only a few minutes, and the test seat lacked some features typical of production seats, notably side bolsters. The test procedures enforced approximately sagittally symmetric postures and no ride motion that might have affected preferences was included.

The results showed biases due to the preset seat back contour that were large relative to the range within condition. When person adjusts their posture against the seat back, a high initial prominence causes them to sit further forward on the seat, which then affects the perception of the prominence. The participants also could view the contour on the touchpad as they adjusted it, which may have resulted in different contours than if they were only feeling the changes in contour. The use of the Bézier curve to generate the contour may have produced shapes that were not optimal for all participants; some may have preferred a sharper prominence or a different contour above the apex. The flat seat contour (preset 1) may also have been perceived as having more or stronger lumbar support than many production seats, because the software padding in the lumbar area many seats can cause “negative” lumbar support, where the seat contour in the lumbar area is concave. Generally, additional padding over the lumbar area can be expected to reduce the perception of prominence, so that prominence values reported in this study would likely need to be increased to produce the same sensation of support in a more-padded seat.

The head support was manually adjusted by the investigator with feedback from the participant. Although care was taken to prompt the participant to fine-tune the position, some participants may have accepted less than optimal positions to avoid delaying the data collection. The head support also lacked lateral and longitudinal contour, which would likely be desirable for helping to control head position with vehicle ride motion.

These limitations suggest opportunities for improving the generality of the findings in future work, including:

- Additional changes to the seat, such as changes in the seat height, angle of the seat cushion, and the addition of bolsters to the seat back.
- Motorized controls for contour and head support location more typical of what would be used in a production vehicle.
- Use of a wider range of starting conditions to provide a more accurate understanding of preference.
- Longer duration sitting sessions to elicit more fine-tuning of adjustments
- Investigation of sensitivity to seat pivot location.
- Use of a more realistic head support contour.

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APPENDIX

Representing Contours with Bézier Curves

A cubic Bézier curve in two dimensions represents a continuous trajectory defined by four points. The curve interpolates the end points and represents a weighted sum of the four control points at each point along the curve. A parameter t gives varies from zero defines the position along the curve. Figure A1 shows an example of a Bézier curve and the associated control points.

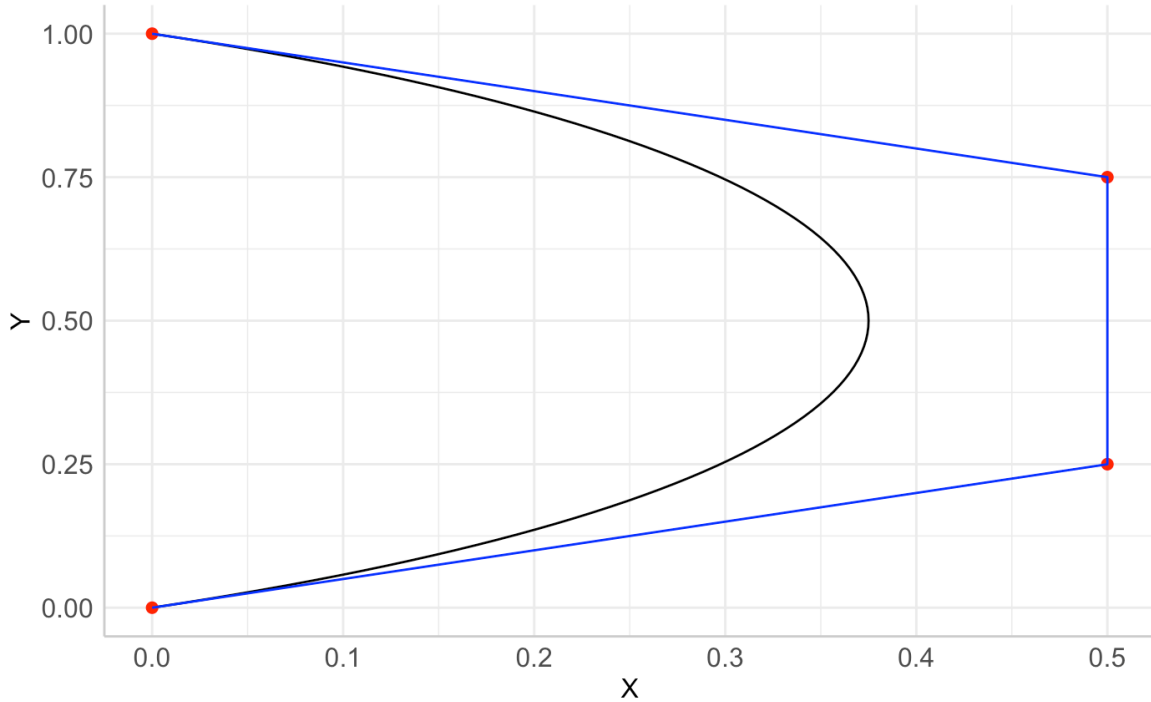


Figure A1. Example Bézier curve (black line) defined by four control points (red). The curve interpolates the first and fourth points and lies within the polygon defined by the four points (blue). The slope of the curve at the start and end points is defined by the vector from the end points to the adjacent control points.

For control points \mathbf{P}_0 , \mathbf{P}_1 , \mathbf{P}_2 , and \mathbf{P}_3 , the cubic Bézier curve is given by

$$\mathbf{B}(t) = (1 - t)^3 \mathbf{P}_0 + 3(1 - t)^2 t \mathbf{P}_1 + 3(1 - t) t^2 \mathbf{P}_2 + t^3 \mathbf{P}_3, \quad 0 \leq t \leq 1.$$

Note that the weighting for each coordinate is identical, and indeed the formula is valid for any number of coordinates in \mathbf{P} . By inspection, if $t = 0$ then $\mathbf{B}(t) = \mathbf{P}_0$, and if $t = 1$, $\mathbf{B}(1) = \mathbf{P}_3$

Rewriting the parametric equation for $\mathbf{B}(t)$, the weighting functions for each point are

$$\mathbf{P}_0: 1 - 3t + 3t^2 - t^3$$

$$\mathbf{P}_1: 3t - 6t^2 + 3t^3$$

$$\mathbf{P}_2: 3 t^2 - 3 t^3$$

$$\mathbf{P}_3: t^3$$

For the current application, the displayed Bézier curve was defined such that \mathbf{P}_0 was coincident with the upper left corner of the control screen and \mathbf{P}_3 was aligned with the lower left corner (that is, the Y axis is positive downward). \mathbf{P}_1 and \mathbf{P}_2 were both set to the selected location on the screen (X axis positive to the right). To achieve a more intuitive response, the resulting curve was scaled horizontally so that the peak was coincident horizontally with the tapped location. Figure A2 shows an example of a curve constructed in this manner.

To reconstruct a seat profile based on the BezierParamX and BezierParamY values, enter those into the equations above for \mathbf{P}_0 and \mathbf{P}_3 set to (0, 0) and (0, 1) and \mathbf{P}_1 and \mathbf{P}_2 both set to the specified X, Y parameter values. Construct points along the curve using, for example, 100 values of t between 0 and 1. Scale the curve in X by multiplying by $\text{BezierParamX}/(\text{maximum value of X on the curve})$.

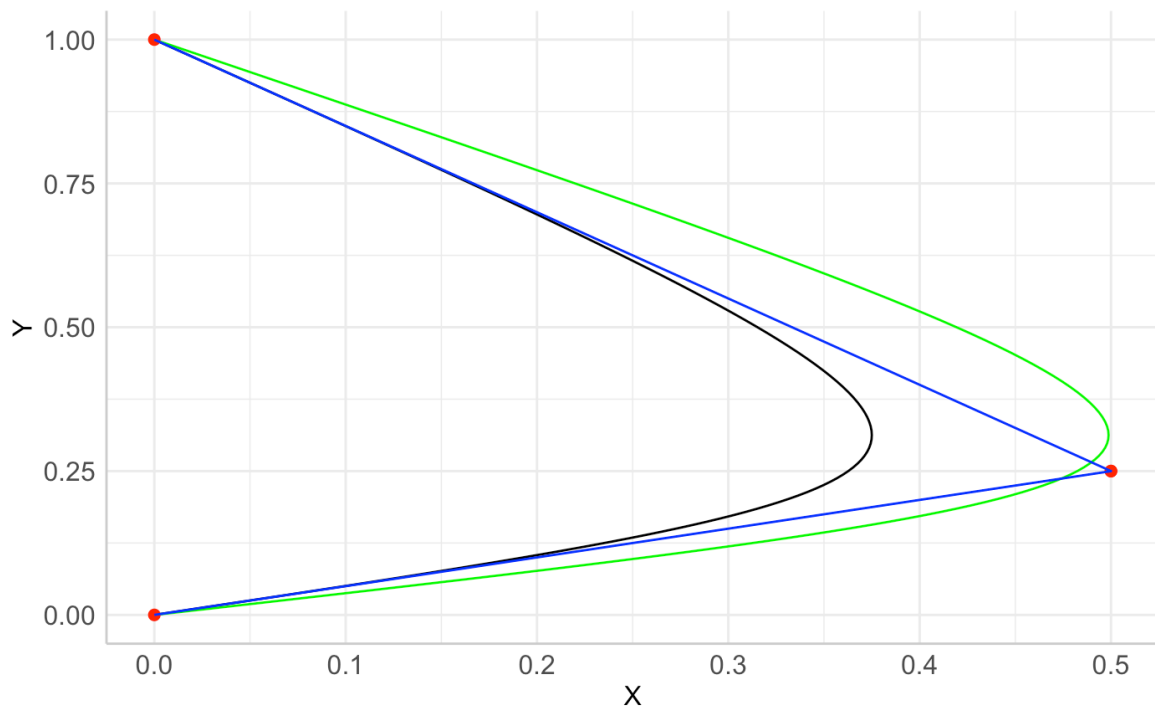


Figure A2. Bézier curve (black) constructed with the two interior control points coincident at (0.5, 0.25). The green line shows the black curve scaled in X so that the apex has the same X coordinate as the interior control points.