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ABSTRACT

Current ATD positioning practices depend on seat track position, seat track travel range, and design seatback angle to determine appropriate occupant position and orientation for impact testing. In a series of studies conducted at the University of Michigan Transportation Research Institute, driver posture and position data were collected in forty-four vehicles. The seat track reference points currently used to position ATDs (front, center, and rear of the track) were found to be poor predictors of the average seat positions selected by small female, midsize male, and large male drivers. Driver-selected seatback angle was not closely related to design seatback angle, the measure currently used to orient the ATD torso. A new ATD Positioning Model was developed that more accurately represents the seated posture and position of drivers who match the ATD statures. Seat position is specified for each adult ATD size to match the mean predicted seat position of drivers matching the ATD reference stature. ATD torso orientation is set to the average driver torso orientation. The new positioning model places the ATDs in postures and positions that are more representative of drivers of similar size.

INTRODUCTION

One of the goals of automotive dynamic testing is to evaluate the potential for occupant injury in vehicle impacts. For occupied vehicle impact tests, the initial position of the ATD relative to the steering wheel and vehicle structures has been shown to have a significant effect on the ATD measures of injury probability, and driver proximity to the vehicle structures has been recognized as a factor in injury potential (1-7). [1] Changes in the seat fore/aft position and seatback angle are also known to affect ATD output associated with assessing injury potential and to affect the levels of head and knee excursion experienced by the ATD (8).

1. Numbers in parentheses designate references provided at the end of this paper.

Laboratory procedures for Federal Motor Vehicle Safety Standard (FMVSS) 208 and the New Car Assessment Program (NCAP) specify that the midsize male ATD be positioned with the seat at the center of the fore-aft seat track travel and with the seatback angle set to a manufacturer-specified value known as the design seatback angle (9,10). Full-forward and full-rearward seat positions are commonly used in tests with the small female and large male ATD, respectively. Once the ATD is seated, the ATD position is adjusted to achieve the H-point measured by the SAE J826 manikin (11) and head and pelvic angles within the ranges specified (9,10).

Few detailed comparisons between human and ATD positions have been published. Parkin et al. (12) measured the distances between drivers' heads and the steering wheel using videotape images of one-thousand drivers as they passed a fixed camera. Parkin noted that the fiftieth percentile of the distribution of distances to the steering wheel for male drivers in the sample was less than the corresponding clearance dimension for the midsize male ATD in one vehicle geometry. Similar observations were made for small female and large male ATDs, suggesting that the ATD positioning procedure located the dummy too far forward relative to humans. However, no anthropometric data for the videotaped drivers were available, nor were measures of vehicle package geometries, so the resulting data cannot reliably be used to predict the seated positions or steering wheel clearances of people of any particular body size as a function of vehicle dimensions.

Husher et al. (13) tested 9 women and 24 men in three vehicles to compare preferred seat positions with the midtrack seat position. The results reported indicate that the median seat position selected in a 1988 Chevrolet Beretta, 1987 Volkswagen Jetta and 1987 Ford Taurus were rearward of midtrack by 97, 57, and 18 mm, respectively. Although basic anthropometric data were collected, the analysis did not employ a weighting strategy to express the observed population in terms of any specific driving population and did not compare the midtrack seat positions with the seat positions selected by midsize male drivers.

Backaitis et al. (14) reported on Hybrid III ATD clearance dimensions and the effects of clearances on dummy impact responses. As part of the investigation, the selected seat positions of twelve midsize male subjects were compared to the ATD seat position in a Ford Taurus. On average, the midsize male subjects sat 32-36 mm rearward of the midtrack seat position, with their heads located 20 to 47 mm further rearward than the ATD.

In the past decade, a series of studies at the University of Michigan Transportation Research Institute (UMTRI) have investigated preferred driver position and posture to create new tools for vehicle packaging, evaluation, and design. In-vehicle testing of hundreds of volunteers has led to the creation of a database of driver position and posture as well as predictive models for driver seat position, eye position, posture, and proximity to the steering wheel (15-19). The UMTRI driver position data allow comparisons between current ATD positioning practices and the selected postures of drivers of similar stature.

The results of the UMTRI driver position studies suggest that positioning the seat at midpoint of the seat track and at the design seatback angle for an occupied vehicle impact test will almost always result in a midsize male ATD position that is further forward and more reclined than the average position selected by drivers of the same stature. This paper quantifies the differences between driver and ATD seat positions and uses the new information about driver preferred seat positions and the associated predictive models to suggest a method for positioning small female, midsize male and large male ATDs that results in ATD positions and postures more like their human counterparts.

METHODS

The methods for collecting driver posture and position have been comprehensively reported previously (15-19) and are summarized concisely for this paper.

TEST CONDITIONS – Driver-selected seat position and driving posture were measured in 44 vehicles over the course of ten investigations. In all of the vehicles, preferred position data were collected immediately after the subjects had driven the vehicle for 10 to 20 minutes. All vehicles are listed in Table 1, along with selected vehicle package dimensions.

SUBJECT POPULATIONS[2] – Subjects were adult drivers selected to fill twelve gender/stature groups described in Table 2. These stature groups span the range of stature in the anthropometric specifications of the small female, midsize male and large male Hybrid III crash dummies. A total of 606 subjects were tested in these studies.

For the analyses in this paper, statures corresponding to the anthropometric specifications of the Hybrid III ATDs are necessary for comparison with driver postures. The anthropometric specifications of the Hybrid III family of ATDs do not include standing height (stature), but rather are expressed in terms of five primary seated dimensions: erect sitting height, buttock-to-knee length, knee height, arm length, and forearm length. For the midsize male Hybrid III, these dimensions were based primarily on the 1962 Health Examination Survey (HES) data (20, 21), augmented with data from studies of U.S. Army and Air Force personnel (22-24). The erect sitting height in the Hybrid III specification is 906.8 mm (20, 25-27), although the curvature of the lumbar spine may prevent the ATD from actually attaining that sitting height (28). In the UMTRI data for midsize males (group 8), the ratio of sitting height to stature is 0.517. Dividing the Hybrid III sitting height by 0.517 gives a scaled stature estimate of 1754 mm. In the data from the 1974 National Health Examination and Nutrition Study (NHANES), the median male stature is 1753 mm (29), which is very close to the estimated Hybrid III reference stature.

The body dimensions of the small female and large male Hybrid III ATDs were developed by scaling from the midsize male to match on the five anthropometric dimensions of data collected by Schneider et al. (30), in which the small female and large male subjects were selected to match the 5th-percentile female and 95th-percentile male statures, respectively, according to the NHANES data. Based on this analysis, small-female, midsize-male, and large-male anthropometry was defined for the purposes of the current study by statures of 1511, 1753, and 1869 mm, which are the 5th-percentile female, 50th-percentile male, and 95th-percentile male values, respectively, from the NHANES data (29).

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2. The rights, welfare, and informed consent of the volunteer subjects who participated in this study were observed under guidelines established by the U.S. Department of Health and Human Services on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, Medical School, The University of Michigan.

Table 1. Summary of Test Vehicles

Vehicle	Seat Height: H30 (mm)	Seat Cushion Angle: L27 (degrees)	Horizontal Wheel-to-Ball of Foot (BOF) Distance (mm)	Design Seatback Angle: L40 (degrees)	Seat track Adjuster Type	Seat track Rise (deg)	Seat track Length (mm)
Firebird†	154	15.5	650	27.0	2-way	6.5	180
TransAm†*	165	14.0	623	24.0	2-way	8.7	256
Camaro*	177	13.0	616	26.0	2-way	11.5	293
Avenger 2	189	16.6	577	24.0	2-way	5.5	230
Avenger 6	189	adjustable	577	24.0	6-way	5.5	230
Laser 2*	197	11.3	550	25.0	2-way	5.0	180
Laser 6*	197	adjustable	550	25.0	6-way	5.0	180
Neon†	212	22.5	565	24.0	2-way	8.6	210
Celica 1	215	13.0	587	--	2-way	7.5	239
Celica 2†	215	13.0	587	--	2-way	7.5	239
Probe	216	adjustable	576	24.0	6-way	4.7	232
Acclaim 2 *	220	17.7	559	24.0	2-way	9.0	188
Acclaim 6*	220	adjustable	559	24.0	6-way	9.0	188
Monte Carlo*	231	11.0	597	27.0	2-way	8.0	262
Civic	232	18.0	546	25.0	2-way	6.1	240
Mazda 626†	234	18.0	561	25.0	2-way	5.1	232
Grand Am 1	230	15.0	588	25.0	2-way	8.1	210
Grand Am 2†	234	17.0	587	25.0	2-way	8.1	210
Camry	240	13.0	567	25.0	2-way	4.5	225
Cadillac DeVille*	240	8.0	590	26.0	2-way	9.0	262
BMW 740	240	18.0	552	25.0	6-way	3.0	211
Lexus 400	249	13.0	572	25.0	6-way	6.0	240
Grand Prix	250	12.0	623	24.0	2-way	8.0	282
Tercel†	250	16.0	530	25.5	2-way	7.5	218
LHS 2	250	17.7	597	24.0	2-way	8.2	221
LHS 6	250	adjustable	597	24.0	6-way	8.2	221
Olds Tour Sedan	250	18.0	564	26.0	2-way	8.5	249
Grand Prix*	254	adjustable	610	24.0	6-way	7.9	279
Taurus SHO†	257	12.0	557	24.0	2-way	7.0	184
Pontiac 6000*	266	16.0	583	26.0	2-way	7.5	196
Acclaim 0*	278	9.0	555	24.0	2-way	0.0	188
Blazer*	288	7.5	591	23.0	2-way	11.1	231
Grand Cherokee 2	298	11.3	607	24.0	2-way	9.4	192
Dakota Pickup†	298	12.0	600	22.0	2-way	2.9	135
Grand Cherokee 6	298	adjustable	607	24.0	6-way	9.4	192
CK Pickup Truck*	303	12.5	570	21.0	2-way	5.7	310
Previa	324	13.0	472	25.0	2-way	1.5	183
Voyager 2	326	14.0	504	22.0	2-way	7.6	190
Voyager 6	326	adjustable	504	22.0	6-way	7.6	190
Cherokee Sport†	333	adjustable	589	24.0	6-way	9.9	189
Ram Pickup†	346	13.0	512	20.0	2-way	5.8	189
Windstar	349	adjustable	504	26.0	6-way	3.3	181
APV*	381	12.0	518	24.0	2-way	0.0	300
Econoline†	420	9.5	447	21.0	2-way	4.5	130

* Indicates vehicles that were modified from design to meet specific criteria of the studies. All package dimensions were measured directly from the vehicles to assure accuracy.
† Denotes manual-transmission vehicles.

Table 2. Subject Groups

Group	N*	Gender	Percentile Stature Range by Gender (29)	Stature Range (mm)
0	25	Female	< 5th	Under 1511
1	60	Female	5-15	1511 - 1549
2	52	Female	15-40	1549 - 1595
3	60	Female	40-60	1595 - 1638
4	52	Female	60-85	1638 - 1681
5	52	Female	85-95	1681 - 1722
6	52	Male	5-15	1636 - 1679
7	52	Male	15-40	1679 - 1727
8	60	Male	40-60	1727 - 1775
9	56	Male	60-85	1775 - 1826
10	60	Male	85-95	1826 - 1869
11	25	Male	> 95th	Over 1869
Total:	606			

*Total from all studies.

TEST PROTOCOL – The same general test procedure was used in each of the studies. The subject completed a consent form, health questionnaire, and survey asking about their current vehicle and driving habits. A set of twenty standard anthropometric measures were taken, including stature, weight, and erect sitting height. The three to six vehicles in each study were tested in random sequence. The initial positions of the seat, seatback, and steering-wheel tilt prior to testing in each vehicle were the same for every subject and were set to the mean expected positions based on previous research. The subject was instructed on the operation of the seat position, seatback angle, and steering-wheel tilt adjustments, and was asked to experiment extensively with the adjustments while driving over a 10-to-20-minute road route. During the drive, the subject was asked to find the most comfortable driving position and to note the posture of his/her head in straightahead driving. Immediately after returning from the drive, driver-selected seat position and posture were measured while the subject maintained a relaxed, normal driving posture.

RESULTS

DETERMINING MEAN SEAT POSITION FOR ANTHROPOMETRIC GROUPS – In some vehicles, examination of the seat position data showed that censoring occurred, meaning that the seat track length or position restricted the seat positions of some subjects. Censoring is indicated by histograms that show an unusually large number of observations at full-forward or full-rearward seat track positions. For this analysis, estimates of the seat positions that subjects would have chosen independent of the limitations of the particular seat track installed in the vehicle are desired.

Figure 1 shows seat position relative to stature for 120 drivers in one vehicle. Seat position is defined as the translated H-point location aft of the ball of foot (BOF) landmark on the accelerator pedal. In the figure, the seat position histogram shows censored observations at the ends of the seat track.

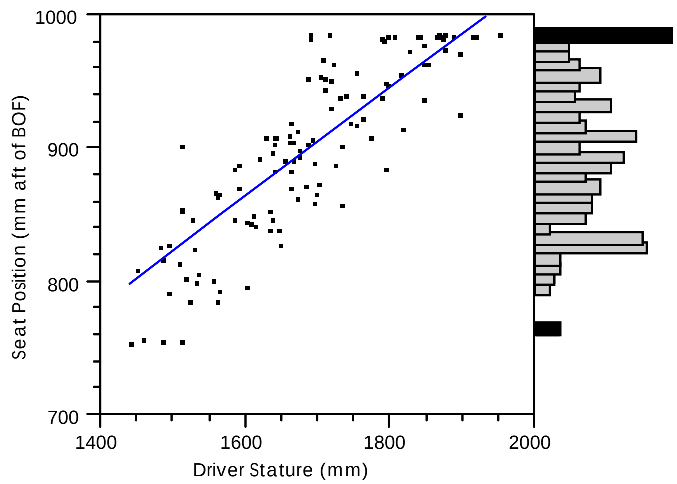

Figure 1. Relationship between stature and seat position for 120 drivers in one vehicle. Dark bars on seat position histogram indicate censored observations at the ends of the seat track travel. Linear regression, excluding the censored observations, gives R2 = 0.67.

When observations at the end points of the seat track (i.e., censored data) are excluded, the relationship between stature and seat position is linear in every vehicle. Using the uncensored observations, seat position was regressed on stature to determine the vehicle-specific relationship between the two variables. To estimate the mean positions of people corresponding to the ATD anthropometry, the 5th-percentile female, 50th-percentile male, and 95th-percentile male statures, based on the 1974 HANES survey (29), were entered into the regression equations to calculate the corresponding seat positions in each vehicle. The resulting values represent the mean seat position of drivers of the specified stature in each vehicle.

For drivers in the middle stature ranges, values estimated by the regression technique are generally similar to those estimated by averaging the seat positions of people with similar statures, but the regression technique is more reliable across vehicles, and also provides an estimate of the residual variance. The variance in seat position for people who are a specific stature can be estimated, even though there may be few subjects in the database whose posture exactly matches the target stature. Moreover, the regression technique produces accurate estimates of mean seat position for people who sit near the ends of the seat track, such as small women and large men. Seat positions calculated in this manner can lie beyond the ends of the seat track. However, examination of data from vehicles with extended, non-restrictive seat track travel shows that the regression-estimated seat positions accurately represent where drivers sit when track travel is available.

The regression approach to calculating average seat positions relies on certain assumptions, but rigorous examination of the data shows that these assumptions are justified (16). Most importantly, the linearity of the relationship between stature and seat position has been verified for every vehicle, and the assumption of equal residual variance over the stature range has been confirmed. Moreover, the consistency of the linear relationship throughout the range of statures, in vehicles without censoring, and across vehicles with different interior dimensions strongly support the validity of the method.

DRIVER-SELECTED SEAT POSITIONS RELATIVE TO VEHICLE SEAT TRACKS – Figure 2 compares the mean selected seat position of midsize males obtained using the procedure outlined above, compared to the mid-track seat position for 26 vehicles where seat heights (H30) span the range from sporty cars to SUVs and light trucks. In all of the vehicles, the mean selected seat position of midsize males is further rearward than mid-track seat position, by an average of 46 mm. Similarly, Figures 3 and 4 compare mean observed small female and large male seat position with the full forward and full rearward seat track locations. Table 3 summarizes the offsets between the seat positions and the corresponding seat track landmarks. In these 26 vehicles, midsize males sit with average seat positions about 46 mm rearward of the center of the seat track. Large-male seat position coincides closely, on average, with the rearmost position on the seat track, although there is considerable variance across vehicles. Small-female seat position is about 42 mm rearward of the front of the seat track, on average. The large offset standard deviations in Table 3 indicate that the front, middle, and rear locations on the seat track are poor predictors of small female, midsize male, and large male seat positions, since the offsets are inconsistent across vehicles.

Drivers of any particular stature will sit with a range of seat positions because of variations in body proportions and preferred body extremity postures. Regression analysis of data from individual vehicles indicates that this residual variance is well modeled by a normal distribution with a standard deviation of 29.8 mm for all statures of interest (16). Centering this normal distribution on the predicted seat positions for midsize males in Figure 2 enables calculation of the percentage of 1753-mm-tall drivers (i.e., midsize males) who sit forward of the mid-seat-track position. Averaging across vehicles, about ten percent of male drivers with a stature of 1753 mm are estimated to sit forward of the center of the seat track. Using the same procedure, about twelve percent of small-female drivers' preferred seat positions lie further forward than the front of a typical seat track, and about 58 percent of large-male drivers prefer to sit at positions further forward than the typical rearmost seat track position.

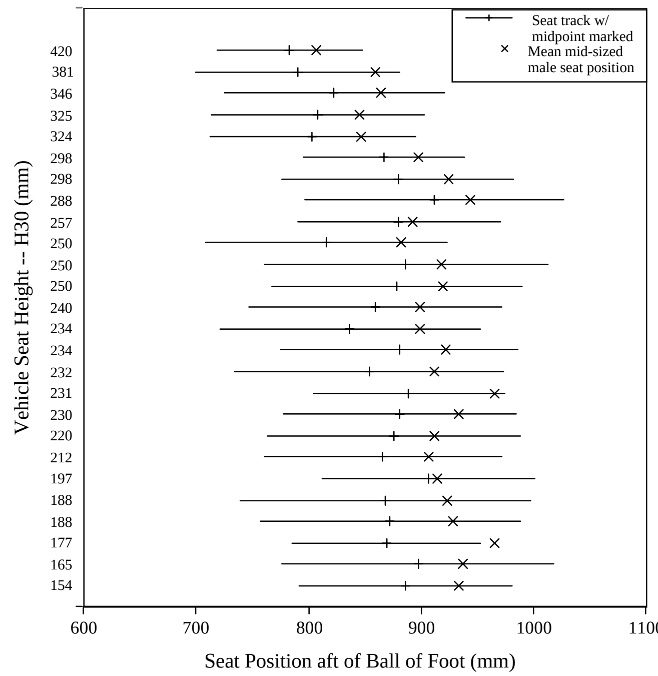

Figure 2. Mean midsize male seat position relative to the seat track in 26 vehicles. Vehicles are rank-ordered by seat height (H30) on the vertical axis.

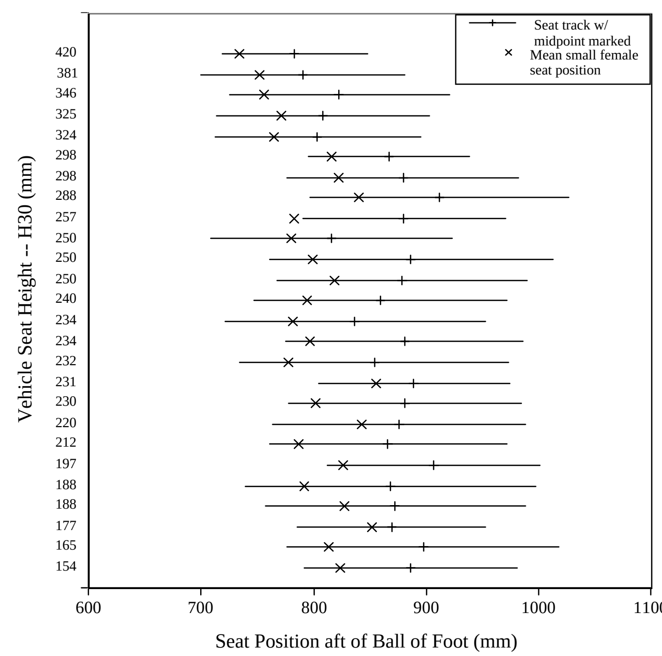

Figure 3. Mean small female seat position relative to the seat track in 26 vehicles. Vehicles are rank-ordered by seat height (H30) on the vertical axis.

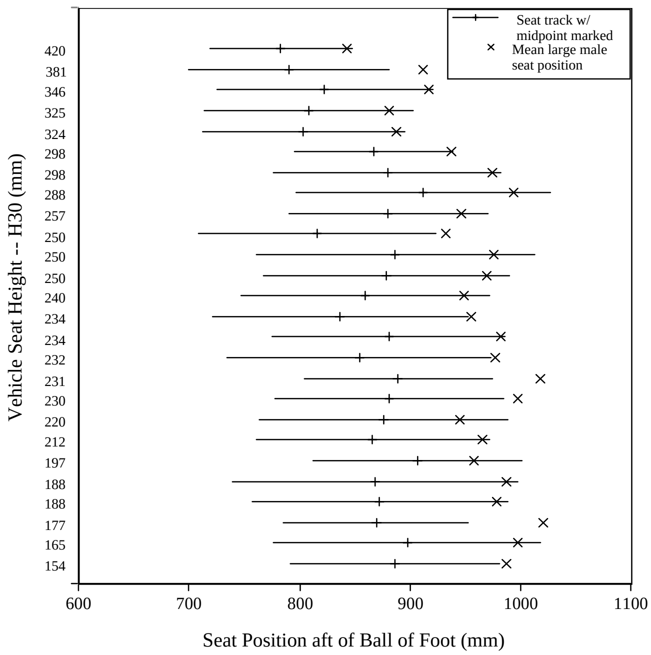

Figure 4. Mean large male seat position relative to the seat track in 26 vehicles. Vehicles are rank-ordered by seat height (H30) on the vertical axis.

Table 3. Mean Differences Between Seat Positions of ATD-Sized Drivers and Seat Track ATD-Positioning Reference Points for 26 Vehicles

Stature/ Gender Group	Stature (mm)	Reference Position on Seat Track	Mean Offset (mm) †	Std. Dev. of Offset (mm)	Percentage Forward of Reference*
Small Female	1511	Front	42.2	20.6	12.1%
Midsize Male	1753	Center	45.5	19.0	9.5%
Large Male	1870	Rear	-5.7	25.2	57.6%

† Offset is relative to seat track reference point, positive rearward.
* Refers to the average, across vehicles, of the percentage of people of the specified stature who are estimated to sit further forward than the reference point.

DRIVER-SELECTED SEATBACK ANGLE – Typical automotive design practice leaves the selection of design seatback angle to the discretion of the designer or package engineer. Most design seatback angles are between 20 to 27 degrees, as measured with the SAE J826 manikin (11), and tend to be less reclined at higher seat heights. Previous UMTRI studies of driver-selected seatback angle have shown that mean preferred seatback angles are, on average, approximately two degrees more upright than design (17). Figure 5 compares design and mean selected seatback angle for 37 of the test vehicles. In 31 of the 37 vehicles, the design seatback angle is larger than the mean seatback angle selected by drivers, with a mean difference of 2.1 degrees. In general, design seatback angle is a poor predictor of mean selected seatback angle. For example, mean selected seatback angles for seats with design seatback angles of 24 degrees range from 19 to nearly 27 degrees.

Contrary to the expectation implied by conventional design procedure, seat height does not strongly influence driver-selected seatback angle. Figure 6 illustrates that there is only a weak relationship between preferred seatback angle and seat height, consistent with previously reported observations (19).

DRIVER TORSO POSTURE – For some of the study vehicles, driver body landmark data are available that provide a more detailed description of driver posture than that given by the seat position and seatback angle data. The overall torso recline of the driver can be measured by calculating the angle with the vertical formed by a side-view vector from the H-point to the left infraorbitale landmark, a skin surface landmark on the orbit directly below the pupil of the left eye. This measure, illustrated in Figure 7, is termed "torso recline angle" for purposes of this discussion.

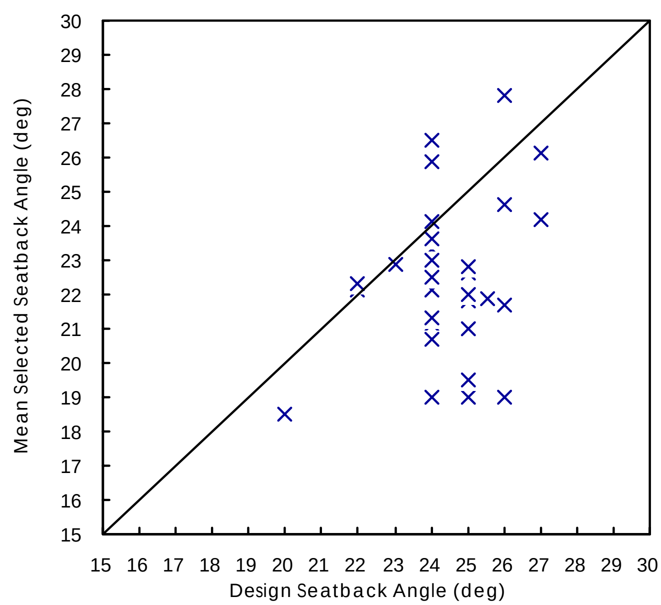

Figure 5. Comparison of design and mean selected seatback angle for 37 vehicles.

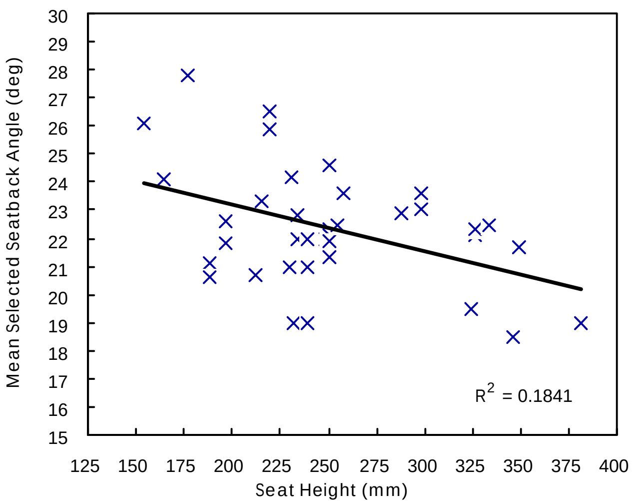

Figure 6. Relationship between seat height and mean selected seatback angle for 37 vehicles.

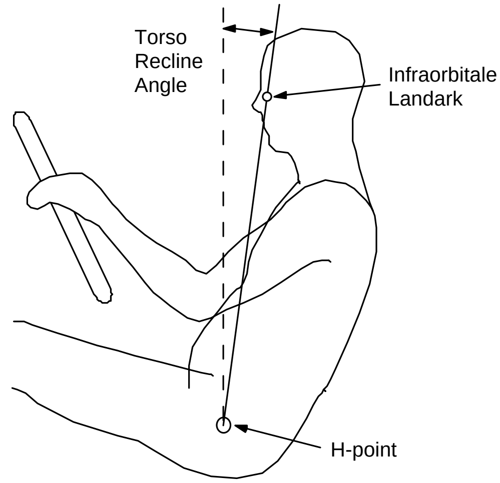

Figure 7. H-point-to-eye vector used to measure overall torso recline angle.

Table 4. Torso Recline Angle in Six Vehicles

Vehicle	N*	Seat Height: H30 (mm)	Horizontal Wheel-to-BOF Distance (mm)	Seat Cushion Angle: L27 (degrees)	Design Seatback Angle (degrees)	Mean (SD) Torso Recline (degrees)	Mean (SD) Driver-Selected Seatback Angle (degrees)
Avenger	113	189	577	16.6	24.0	5.0 (3.2)	20.6 (4.0)
Laser	120	197	550	11.3	25.0	5.2 (3.1)	21.8 (3.7)
Acclaim	120	250	559	17.7	24.0	3.6 (3.7)	26.5 (2.4)
LHS	120	250	597	17.7	24.0	5.9 (3.4)	22.3 (3.8)
Grand Cherokee	119	298	607	11.3	24.0	5.7 (3.6)	23.0 (3.4)
Voyager	119	326	504	14.0	22.0	5.9 (3.3)	22.1 (3.7)
					Mean:†	5.2 (3.4)	22.7 (3.5)

* Number of subjects used in analysis.
† Average value across vehicles.

Table 4 demonstrates that the mean driver-selected seatback angle does not vary closely with torso recline. Both variables differ across vehicles in a narrow range, but higher mean selected seatback angles do not imply higher torso recline angles due to differences between the J826 manikin and people. Stature is also not closely related to torso recline. Figure 8 shows the torso recline angle plotted against driver stature for all of the vehicles in Table 4. Separate linear regression lines are shown for each vehicle. The regression was significant ($p<0.05$) only for the Grand Cherokee, but even in that vehicle the relationship was weak ($R2 = 0.10$). Other similar studies have shown that there are also no important interactions among vehicle and anthropometric variables in their effects on torso posture (15-19).

Table 4 lists the mean and standard deviation of torso recline angle for all sizes of drivers in six vehicles, along with several package variables. These six vehicles were selected to represent a range of horizontal wheel-to-pedal distance at a range of seat heights. However, the small range of mean torso recline angles across the vehicles illustrates that neither of these variables has important effects on torso recline. For example, the average torso recline angle for the two lowest seat height vehicles (Avenger and Laser) is 5.1 degrees, while the average for the two highest seat-height vehicles (Grand Cherokee and Voyager) is 5.8 degrees, a difference of less than one degree.

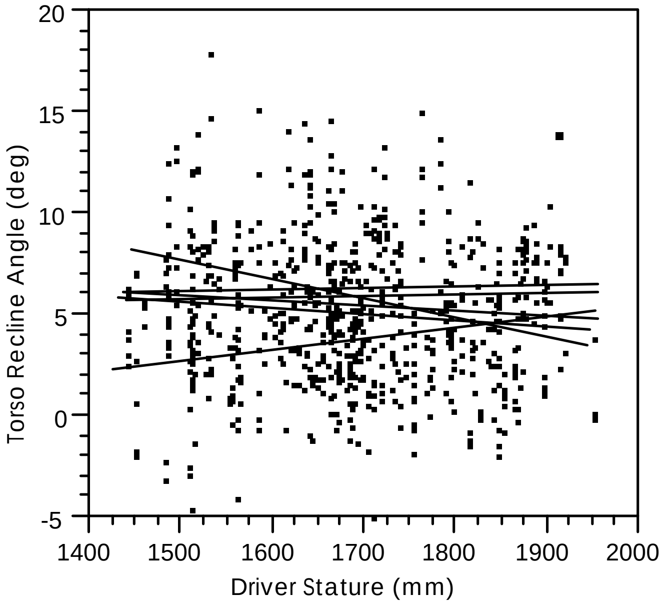

Figure 8. Relationship between stature and torso recline for six vehicles, 113 to 120 subjects per vehicle. Lines are linear fits to the data from each vehicle.

MODEL DEVELOPMENT

SEATING ACCOMMODATION MODEL – The current SAE Recommended Practice for predicting the distribution of driver-selected seat positions is SAE J1517 (33). Many of the studies from which data were obtained for the current analysis were conducted with the purpose of improving SAE J1517. As a result of this research, a new model of driver-selected seat position, called the Seating Accommodation Model (SAM) has been developed (16). SAM predicts the distribution of seat positions for any driver population in any passenger car.

Seat position data from 60 to 120 drivers in each of 36 vehicles were used in the development of SAM. The subject data in each vehicle were weighted to represent a 50-percent-male U.S. driver population by stature, according to the distributions in NHANES (29), and averaged to obtain a mean seat position in each vehicle. Mean seat position was then regressed on seat height (H30), the horizontal distance between the steering wheel center and the Ball-of-Foot (BOF) landmark, seat cushion angle (L27), and transmission type (manual or automatic). Figure 9 illustrates these variables. The regression function is:

$$\hat{\mu} = 746 - 0.24\, h - 2.19\, p + 0.41\, w - 18.2\, t \qquad \text{(Eq. 1)}$$

where,

$\hat{\mu}$ = predicted mean seat position (mm aft of BOF)
h = seat height: H30 (mm)
p = seat cushion angle (degrees)
w = wheel-to-BOF distance (mm), and
t = transmission type (0 if automatic; 1 if manual).

Equation 1 describes the mean population seat position as a function of vehicle and seat geometry. The R2 value for the regression is 0.90, indicating an excellent prediction for 36 vehicles. Seat height, steering wheel fore-aft position, and seat cushion angle have linear effects on seat position. The transmission effect shifts predicted seat positions forward by about 18 mm for a manual transmissions relative to predictions for vehicles with automatic transmissions (no clutch).

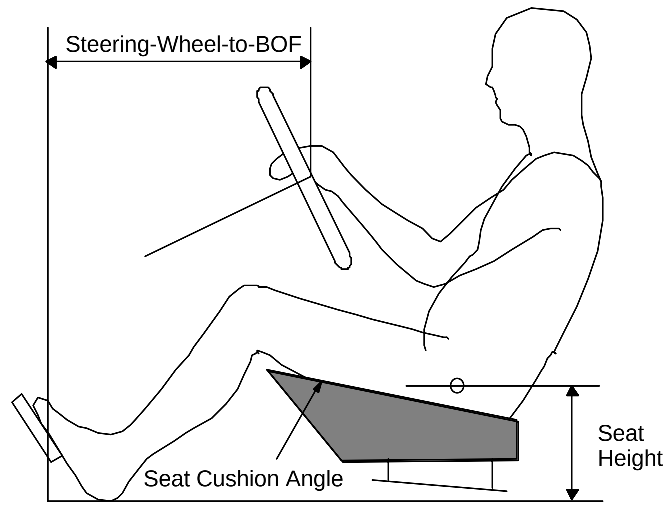

Figure 9. Illustration of vehicle and seat factors used as input to the Seating Accommodation Model.

Equation 1 predicts the mean seat position for a particular U.S. driver population, but a more flexible model was desired that could be used with any driver population, as defined by a specified stature distribution. Two important findings from the analysis of seat position data facilitated the development of such a model. First, stature does not interact with any of the vehicle variables in its effect on seat position. This allows the stature effects to be assessed without reconsidering the vehicle variable coefficients in equation 1. Second, the effect of stature on seat position is the same for males and females, allowing a single predictive equation to be used for both.

As noted above (see Figure 1), the relationship between stature and seat position within an individual vehicle has been uniformly found to be linear. To incorporate stature effects into SAM, data from 21 vehicles with minimal seat-position censoring were selected. After excluding the remaining censored observations, seat position was regressed on stature for each vehicle. The stature coefficients for the 21 vehicle regressions were averaged, weighting each by the number of subjects analyzed for each vehicle. The resulting weighted stature coefficient is 0.433 (mm/mm), indicating that a 100 mm difference in stature corresponds to a 43.3 mm difference in fore-aft seat position, on average.

Equation 1 was re-expressed as a function of stature by considering that the mean stature for the 50-percent-male U.S. driver population used to generate equation 1 is 1684 mm. To obtain a prediction from the staturedependent model that is identical to that obtained with the population-dependent model, the sum of the intercept and the stature term in the new model must be equal to the intercept in equation 1. Taking 746 – 0.433 * 1684 = 16.83, the new prediction equation is

$$\hat{\mu} = 16.83 + 0.433\mu_s - 0.24h - 2.19p + 0.41w - 18.2t \quad \text{(Eq. 2)}$$

where μ_s is stature and the other variables are as defined in equation 1. Equation 2, from SAM, predicts the mean selected seat position, aft of the ball-of-foot accelerator pedal reference point, for a single-gender population with the specified stature. The form of equation 2 is such that entering any selected stature gives a prediction for the average seat position of individuals with that stature. Thus, the average seat position of drivers who match the ATD reference anthropometry can be predicted directly.

PREDICTION OF DRIVER SEAT POSITION FOR ATD POSITIONING – The reference point from which the seat positions are referenced in SAM (the Ball-of-Foot landmark on the accelerator pedal) is not ideally suited for use in positioning an ATD in a vehicle. The location of BOF can be difficult to determine in a vehicle, and it is difficult to make in-vehicle measurements relative to the accelerator pedal. The steering-wheel-to-ball-of-foot dimension used as a predictor in SAM is also less commonly available than other measures of steering wheel fore-aft position. For ATD positioning, equation 1 from SAM was algebraically manipulated to predict seat position relative to the center of the steering wheel, rather than relative to BOF, and to use an input variable for steering wheel position that is more readily available. The new model uses L11, defined in SAE J1100 (34) as the horizontal distance from the steering wheel center to accelerator heel point (AHP). Both H30 (seat height) and L11 are routinely reported for production vehicles, and should be readily available for use in ATD positioning.

The UMTRI ATD Position Model (ATDPM) predicts the mean seat position (translated H-point location) of drivers who are the same stature as the small-female, midsize, or large-male ATDs. In the ATDPM, the center of the steering wheel is defined as the intersection of the steering column centerline and a plane tangent to the upper surface of the steering wheel rim (i.e., measures made to recessed or protruding wheel hubs should be corrected to the plane of the wheel rim). Equation 4 predicts the seat position aft of the steering wheel center for drivers 1753 mm tall, i.e., midsize males.

$$\mu_{mm} = 776 - 0.24h - 0.59w - 2.19p - 119.77\cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(Eq. 4)}$$

where,

μ = predicted mean seat position (mm aft of steering wheel center)
h = seat height: H30 (mm)
w = AHP to steering wheel center distance: L11 (mm), and
p = seat-cushion angle: L27 (degrees).

Equations 5 and 6 predict mean seat position for small females and large males (1511 and 1870 mm tall, respectively).

$$\mu_{sf} = 671 - 0.24h - 0.59w - 2.19p - 119.77\cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(Eq. 5)}$$

$$\mu_{lm} = 827 - 0.24h - 0.59w - 2.19p - 119.77\cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(Eq. 6)}$$

Note that these equations are identical except for the intercepts, since the predictor variables affect the seat positions of the three stature groups equally. The cosine and second-order seat-height term reflect the fact that steering-wheel-to-ball-of-foot distance and L11 are related by a pedal plane angle that is defined in SAE J1516 as a second-order function of seat height (35). Figure 10 illustrates the dimensions used in the ATDPM.

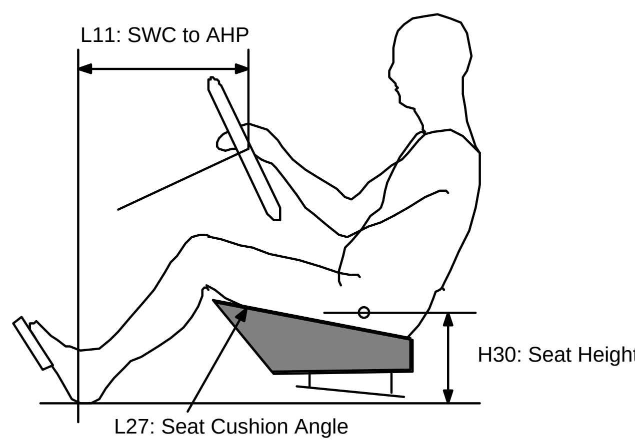

Figure 10. Illustration of inputs to ATD Positioning Model.

The ATDPM predicts mean driver selected seat position with good accuracy across vehicles. Figure 11a, 11b, and 11c show the observed and predicted mean seat positions, expressed as translated H-point locations, for small-female, midsize-male, and large-male drivers. The predictions are generally within 25 mm of the mean observed values, with greater accuracy for small females and midsize males than for large males.

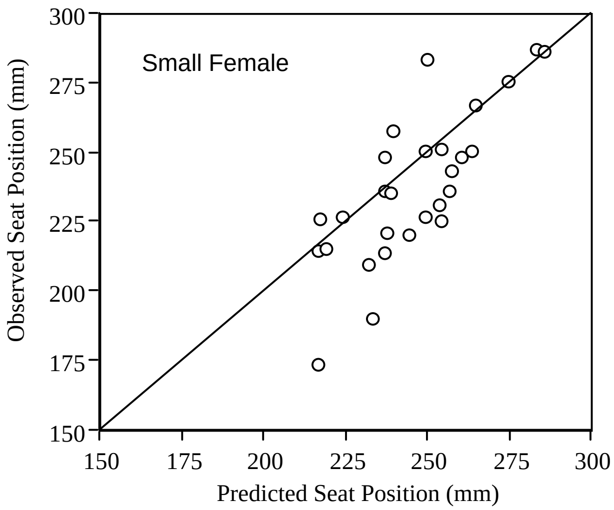

Figure 11a. Seat positions (H-points locations) aft of steering-wheel center predicted by the ATDPM, compared with observed mean seat positions for small-female drivers in 30 vehicles.

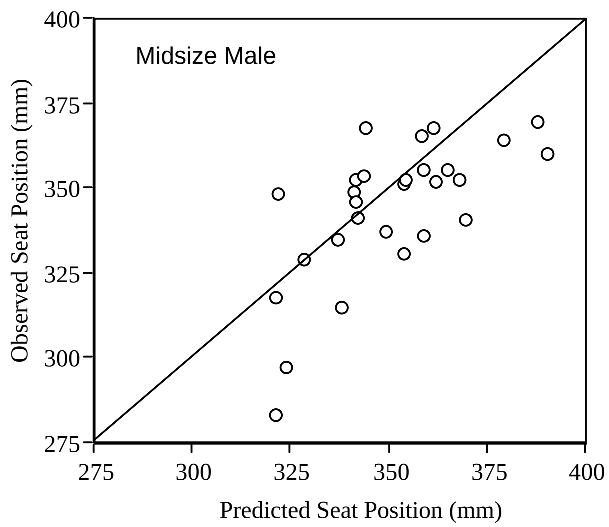

Figure 11b. Seat positions (H-points locations) aft of steering-wheel center predicted by the ATDPM, compared with observed mean seat positions for midsize-male drivers in 30 vehicles.

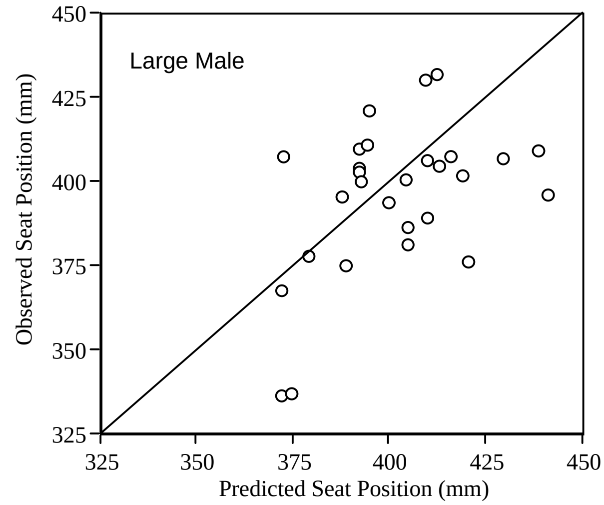

Figure 11c. Seat positions (H-points locations) aft of steering-wheel center predicted by the ATDPM, compared with observed mean seat positions for large-male drivers in 30 vehicles.

PREDICTION OF DRIVER TORSO POSTURE FOR ATD POSITIONING – The foregoing analyses of driver seatback angle data indicate that the manufacturer-specified design seatback angle is generally a poor predictor of driver-selected seatback angle. Further, mean selected seatback angles are not closely related to mean torso angles, suggesting that the current techniques for measuring seatback angle using the SAE J826 manikin do not adequately reflect the average relationship between driver torso posture and seatback angle. The data in Table 4, taken together with other research at UMTRI (19), suggest that driver torso posture is largely independent of package and seat geometry, as well as stature. Large changes in these variables alter the mean torso recline only over a range of three to four degrees (19). These observations lead to the conclusion that a single uniform ATD torso orientation could be used to represent mean driver torso posture for all three ATD sizes in passenger cars, light trucks, and SUVs.

Several different methods of specifying and measuring the ATD torso orientation were considered. Ultimately, a procedure was developed to orient the torso by specifying the angle with respect to vertical of a side-view line from the ATD H-point through the head center of mass (CM). Figure 12 illustrates the angle dimension schematically. This approach positions the masses of the torso segments relative to the pelvis at locations that closely match the average locations of these masses for actual drivers, and establishes a good representation of the mean initial condition of the driver's body for a dynamic crash simulation.

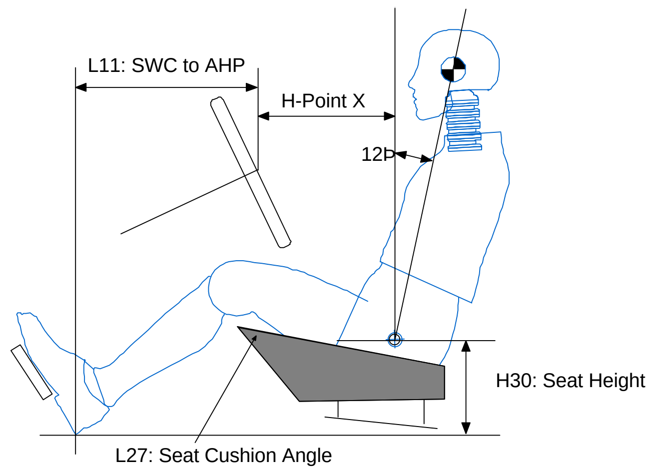

Figure 12. Schematic showing application of ATDPM. The location of the seat H-point aft of the steering wheel center is predicted using equation 4, 5, or 6. The orientation of the ATD torso is adjusted so that the vector from H-point to head center of mass is at an angle of 12 degrees relative to vertical, while maintaining the head level and the pelvis orientation within specification.

An estimate of the drivers' head CM locations was made, for the purpose of defining torso angle, using data from Schneider et al. (30). In a study of driver anthropometry for the development of ATD specifications, body landmark locations in driving postures were measured on twenty-five drivers in each of the small-female, midsize-male, and large-male categories. Head CM locations were estimated using regression equations from McConville et al. (31) and the measured head landmark locations. Table 5 shows the head CM locations from Schneider et al. relative to the infraorbitale landmark with the head in a driving posture (Frankfurt plane approximately level). Noting the similarities in the values, the head CM location was estimated for all occupant sizes using the average offset of 80.3 mm rearward and 27.3 mm above the infraorbitale landmark location. Estimated head CM locations were calculated for 113 to 120 subjects in each of the six vehicles listed in Table 4 and the angle of the vector from the H-point to the driver's head center of mass with respect to vertical was calculated. The ATDPM uses the overall average value across these vehicles of 12.0 degrees.

Table 5. Head CM Locations Relative to Infraorbitale Landmark (mm)*

Stature/Gender Category	X (positive rearward)	Z (positive up)
Small Female	81	28
Midsize Male	83	26
Large Male	77	28
Average:	80.3	27.3

* Based on analysis in Schneider et al. (30) with heads in normal driving orientation.

DISCUSSION

Driver-selected seat position data collected in the course of ten studies at UMTRI show that the seat positions chosen by small female, midsize male, and large male drivers often differ considerably from seat positions commonly used in ATD testing. The full-forward, midtrack, and full rearward seat track reference points currently used to position the ATDs have been shown to be poor predictors of the seat positions actually chosen by people who match the ATDs anthropometrically. Further, the manufacturer-supplied seatback angle is not a good predictor of driver-selected seatback angle. Posture data indicate that overall driver torso recline is not substantially affected by seat height, steering-wheel position, design seatback angle, or driver stature.

These observations and the UMTRI posture database have led to the development of a new ATD Positioning Model (ATDPM) that specifies ATD positions that more accurately represent driver postures than ATD positions obtained using current methods. The ATDPM locates the ATD H-point aft of the center of the steering wheel using a function of seat height (H30), steering-wheel position (L11), and seat cushion angle (L27). A separate function is provided for each of the adult Hybrid III ATD sizes. The ATDPM specifies a uniform ATD torso orientation, rather than a fixed seatback angle, for all passenger car tests with adult ATDs. This procedure is designed to place the ATD head center of mass in a location that is representative of the head centers of mass of drivers matching the ATD anthropometry. In practice, the seatback angle could be adjusted to the angle that best supports the ATD with the specified torso orientation.

An alternate approach to positioning the ATD torso based on the UMTRI driver proximity model (18) was considered but was found to have few advantages when compared to the uniform torso orientation method. The UMTRI driver proximity model predicts the driver position relative to the center of the steering wheel given driver population stature, wheel-to-pedal distance, and seat cushion angle. The model is based on chin-to-steering-wheel, manubrium-to-steering-wheel, and minimum-horizontal-chest-to-steering-wheel distances collected for 60 to 120 subjects tested in each of 22 vehicles. Applying the model to ATD positioning is problematic, however, because the distances predicted are to body surfaces and substantial differences in torso external contour exist between the Hybrid III ATDs and human data as documented by Schneider et al. (30). The uniform torso orientation approach in the ATDPM places the ATD joints and segment centers of mass close to the corresponding locations for similar size occupants.

The ATDPM is intended to form the basis for further investigation of ATD positioning, and is not presented as a completed procedure. Previous studies have demonstrated that ATD positioning affects test outcomes (1-8), so any change to the ATD procedures should be considered carefully. A full study of the effect of the suggested changes on test outcomes is beyond the scope of this paper.

The database used in this analysis is much larger than previous databases applied to prediction of driver posture and position. A large range of vehicle types is represented, with seat heights ranging from 154 to 420 mm. There is also considerable variation in other important parameters, notably steering-wheel position and seat cushion angle, that have previously been found to influence driver posture (15-19). The relevant vehicle interior geometry has been documented fully, using measurements made on the test vehicles. Vehicles were tested with both two-way (fore-aft) and six-way seats (adjustable in fore-aft and vertical position, as well as seat cushion angle), and the subjects drove each vehicle before measurement. Many of the vehicles were equipped with an adjustable steering wheel angle.

The Seating Accommodation Model (SAM), on which the ATDPM is based, includes a transmission effect, accounting for the tendency of drivers to sit further forward in vehicles equipped with a clutch. Recognizing that many vehicles are sold with both manual and automatic transmissions, the ATDPM has been formulated without the forward adjustment for manual transmission.

The ATDPM is not applicable to seats with fixed seatback angles, and should be applied with considerable caution outside of the range of variables described in Table 1. The data suggest that the ATDPM is equally accurate with two-way and six-way seat tracks, but the effects of other vehicle adjustments, such as telescoping steering columns and adjustable pedals, have not yet been studied. Because the ATDPM references seat position to the steering wheel, it is not directly applicable to passenger seat position. Passenger seat positions and postures can be expected to differ in some ways from drivers. Studies of passenger posture and position are currently underway.

One result of using the ATDPM might be to reduce the influence of extraneous factors on the positioning of the ATD. Using the current ATD positioning procedure, changes in the location or length of a vehicle seat track result in changes in ATD positioning, even though such changes do not usually affect midsize male seat positions, and often do not affect the positions of small females or large males. For example, increasing the forward travel of a seat track to facilitate access to the rear seat of a 2-door coupe would change both the full forward and midtrack seat positions, even though this change would not be expected to affect midsize male driver seat positions. Similarly, design seatback angle is not closely related to actual driver torso postures, so using a consistent orientation rather than the manufacturer-selected design seatback angle to position the ATD torso will result in more humanlike ATD postures.

Because the ATDPM can specify seat positions for the small female and large male ATDs that are beyond the range of track travel in a particular vehicle, contingencies should be developed for those cases. Similarly, seats with restricted seatback travel that prevent the ATD torso from being oriented according to the ATDPM specification would require special procedures. In both cases, testing at the end of the range of adjustment may be most appropriate, but further investigation may suggest alternatives.

CONCLUSIONS

A new ATD Positioning Model has been developed by analysis of data on driver postures in a large number of vehicles. The data and model demonstrate that current ATD positioning practices frequently result in unrealistic ATD positions. ATD positions generated by the new model will result in the ATDs being placed in positions that are representative of the driving position of the size of people that the ATDs represent.

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