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ABSTRACT

The ASPECT program, conducted to develop new Automotive Seat and Package Evaluation and Comparison Tools, used posture and position data from hundreds of vehicle occupants to develop a new physical manikin and related tools. Analysis of the relationships between anthropometric measures established the criteria for subject selection. The study goals and the characteristics of the data collected determined the sampling approach and number of subjects tested in each study. Testing was conducted in both vehicle and laboratory vehicle mockups. This paper describes the subject sampling strategies, anthropometric issues, and general data collection methods used for the program's eight posture studies.

INTRODUCTION

Detailed knowledge of how anthropometric, vehicle, seat, and task factors affect occupant posture and position is essential to the development of valid physical and computer models to represent humans in the automotive environment. A large database of driver posture and position has been collected and compiled by UMTRI researchers over the past ten years, particularly with regard to the effects of vehicle package factors (1-4).[1] The ASPECT program provided an opportunity to collect additional posture data to answer some of the remaining questions about the effects of vehicle package factors on occupant posture, but particularly to establish relationships between seat and task factors and posture. These data were collected in a wide range of vehicle and seat configurations for both passenger and driver situations. The effects of vehicle, seat, and task factors on occupant posture and position have been used in the ASPECT program to formulate posture-prediction models for use with CAD manikins, and to guide the design of the ASPECT manikin and usage procedures.

Anthropometric criteria for selecting subjects for these studies were examined carefully during the initial phases of the ASPECT program. Existing anthropometric databases were analyzed to determine both subject selection criteria and the sizes of sample populations needed for the various phases of posture testing. The primary data collected in all the studies were occupant posture and position, but some studies also included subject comfort ratings and measurement of seat pressure distributions. The test facilities included vehicles that were driven by the subjects or, in the case of passenger testing, by another person, as well as laboratory vehicle mockups. The latter allowed for independent variation of vehicle interior geometry or seat factors and included testing of a wide range of vehicle seats.

This paper provides an overview of the important considerations for this posture research, including subject selection criteria, test protocol, sampling strategies, and test facilities. A summary of each of the eight different posture studies conducted in the ASPECT program is provided. Further details on the findings from these studies will be provided in future reports and papers.

ANTHROPOMETRIC FACTORS

Human body dimensions vary among individuals and populations and are known to affect occupant posture and position within the vehicle package space. Consequently, any study of occupant posture must consider anthropometry in the experimental design. In most cases, subjects are selected in large part based on anthropometric factors, so that the data adequately represent the targeted user population. An understanding of the relationships among anthropometric variables is therefore necessary to select subjects effectively.

Although a large number of anthropometric measurements can be taken on any one subject, many of these measurements are highly correlated (i.e., a small person has small measurements on most body dimensions). As a result, the number of measures needed to characterize a person's size and proportions is fortunately relatively small. By identifying those key measurements that best account for the variance in body dimensions, the selection of subjects for testing can be greatly simplified.

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

Table 1. Measures Selected for Analysis from Anthropometric Databases

Anthropometric Measure	**U.S. Army**	**HES**	**UMTRI**
Age	x	x	x
Stature	x	x	x
Weight	x	x	x
Arm Reach	x		x
Forearm Length	x		x
Shoulder-Elbow Length	x		x
Sitting Height	x	x	x
Seated Eye Height	x		x
Knee Height	x	x	x
Popliteal Height	x	x	x
Buttock-Knee Length	x	x	x
Buttock-Popliteal Length	x	x	x
Shoulder Breadth	x	x	x
Seated Shoulder Height	x	x	x
Hip Breadth	x	x	x
Leg Length (Stature - Sitting Hgt)		x	x
Aspect Ratio (Sitting Hgt/Stature)		x	x

In the ASPECT program, data from several sources were analyzed to identify a set of primary anthropometric measurements that could be used for selecting and defining subjects. These sources were the Anthropometric Survey of U.S. Army Personnel from 1988 (5), the U.S. Health Examination Survey from 1965 (6), and an UMTRI database of measurements gathered from test subjects over the past seven years. Each of these databases was analyzed using factor analysis to identify the set of anthropometric measurements that best explain the variance in the complete dataset (7). These analyses used the set of measures shown in Table 1 and produced very similar results for both males and females on all three datasets. It should be noted that leg length and aspect ratio (sitting height/stature) could not be included in the analysis for the two published surveys because individual subject data were not available.

Table 2. Anthropometric Variable Correlation Groupings for Males

Factor 1 (Limb length)	**Factor 2 (Torso length)**	**Factor 3 (Weight)**
Leg Length†	Sitting Hgt	Hip Breadth
Popliteal Hgt	Eye Hgt	Shoulder Breadth
Knee Hgt	Seated Shoulder Hgt	Weight
Forearm Length	Stature	
Shoulder-Elbow Len.	Aspect Ratio	
Stature		
Aspect Ratio		
Butt-Popliteal Len.		
Butt-Knee Length		
Arm Reach		

† Leg length calculated as stature minus sitting height.

Table 3. Anthropometric Variable Correlation Groupings for Females

Factor 1 (Limb length)	**Factor 2 (Torso length)**	**Factor 3 (Weight)**
Leg Length†	Sitting Hgt	Weight
Aspect Ratio	Eye Hgt	Hip Breadth
Popliteal Hgt	Seated Shoulder Hgt	Shoulder Breadth
Knee Hgt	Stature	Butt-Knee Len.*
Shoulder-Ebw Len.		Butt-Popliteal Len.*
Forearm Length		
Stature		
Butt-Knee Length		
Arm Reach		
Butt-Popliteal Len.		

† Leg length calculated as stature minus sitting height.

*These variables are not included in the weight factor in the analysis of Army data. That data set is restricted to Army personnel, who may be more fit and less overweight on average than the populations in the other two studies.

In each case, three groups of anthropometric “factors” were identified. In this context, a factor corresponds to a group of correlated variables. These include a measure of torso length, such as erect sitting height, a measure of limb length, such as leg length, buttock-knee length, or forearm length, and a measure of girth or weight, such as hip breadth or total body mass. Variables strongly associated with each factor are given in Tables 2 and 3. These three factors account for about 75 percent of the variance in the selected anthropometric measures for both males and females.

There are two interesting observations from the results of this factor analysis. First, stature appears in both the limb length and torso length factors. Given that stature is a combination of leg length and torso length, it makes sense that it would be correlated with both. Second, the results for males and females are very similar, except for two components of the weight factor. For males, buttock-knee and buttock-popliteal lengths appear only on the limb-length factor. For females, weight is associated with these measures as well, suggesting that extra weight in females may be more likely to affect measures involving the buttocks.

From these analyses, stature, sitting height, and weight were chosen as the primary anthropometric measures. Sitting height and weight represent the torso and body mass factors, respectively. Leg length can be used to represent limb length, but since leg length was calculated by subtracting sitting height from stature, the measured variable is essentially the same as stature. It is not important that the three variables be strictly orthogonal (as the factors are constrained to be). These three variables make a good set for subject selection because they account for much of the variance in anthropometry, they can be used to predict most other anthropometric measurements with reasonable accuracy, they are easily measured, and they are familiar. If necessary, they can be orthogonalized by using variables related to ratios of sitting height or weight to stature (e.g., body mass index).

Other similar analyses have reached equivalent conclusions. RAMSIS, a computer model of human occupants developed for automotive design applications, uses similar variables, namely stature, waist circumference, and aspect ratio (limb length/torso length) to describe the anthropometric space (8). Because waist circumference is highly correlated with weight, the three primary measures selected for ASPECT do not differ in any important way from the three anthropometric axes used in RAMSIS.

SUBJECT SAMPLING CONSIDERATIONS

Potential strategies for choosing test subjects for vehicle occupant posture studies can be divided into three categories: random selection, representative selection, and stratified selection. These strategies differ in the extent to which one or more subject factors is used to guide the selection of subjects. Gender can be used as a simple example of a subject factor. Assume that about half the drivers are male and half female in the target population for a particular study of driving posture. With random sampling, subjects are sampled as they are available, without regard to gender. Given a large enough sample, a random sample will accurately represent the larger population from which it was taken, with close to half of the subjects being males and half being females. With representative sampling, subjects are chosen to make sure that the number of male and female subjects in the completed subject population matches the proportion in the target population -- in this case 50% males and 50% females. In contrast to random sampling, the experimenter does not rely on chance to produce a sample that represents the larger population on the specific characteristic.

Representative sampling is a specific case of stratified sampling. In the more general form of stratified sampling, defined subject groups are sampled in any designated proportion that is determined by the goals of the study. In the gender example, it may be that data for females are more critical to the outcome of a particular study and females would be oversampled (i.e., a greater number of females would be recruited than males). The final subject population might include, for example, 75% females and 25% males.

The primary advantage of random sampling is that the resulting data conform to the assumptions of most statistical tests without requiring weighting of the data. The disadvantage is that random sampling requires more subjects to ensure that the sample is appropriately matched to the target population. As an illustration, it is not particularly unusual to have seven heads out of ten flips of a fair coin, an event with a probability of 0.17 (i.e., 17%). However, it would be very surprising to see 70 heads out of 100 flips of the same coin, an event which has a probability of 0.0000393 (i.e., 0.004%). A larger sample will be more likely to match the distribution in the target population.

In contrast, stratified sampling provides a way of controlling the sample and ensuring that all groups are adequately sampled. It can also be used to emphasize groups that are more crucial to the results, and that might not be well represented by random or representative sampling. Fewer subjects are required than for random sampling, but accurate analysis of the data relies on the validity of the weighting scheme, which is necessary to calculate statistics that appropriately estimate parameters of the target population. Representative sampling does not require weighting, but it does not have the flexibility to reflect the relevance of the different groups to the study. For example, extreme stature groups (short females and tall males) were often of particular interest in ASPECT studies. Representative sampling requires a larger sample size than other stratification schemes to ensure good estimates of behavior in extreme groups.

In the ASPECT research, stratified sampling was typically used, with the stratification groups based on a combination of stature and gender. The specific stratification scheme depended on the goals of the study. A typical stratification scheme used equal sampling in each of several stature/gender groups. Such a scheme was used for studies in which the goal was to measure behavior (posture or position) across the range of vehicle occupants and to predict that behavior of occupants of any size. Often, the most extreme groups (tall males and short females) are of particular interest because a goal of several studies was to develop accommodation models, which are used to define limits for vehicle design criteria. Such limits are typically most relevant in the extremes, or tails, of a distribution.

In other cases, the stratification scheme emphasized one group, often midsize males, because they match the ASPECT manikin reference anthropometry (9). Other stature/gender groups were also sampled to verify that driver behavior across a range of statures is consistent. However, such a strategy typically does require large samples at the extremes of the stature distribution.

SAMPLE SIZES – The number of subjects in each ASPECT study depended on the objectives of the study. For several studies, the primary goal was to generate a point estimate of posture or position for a specific stature (typically the reference stature for the manikin). Another common goal was to model posture or position across the entire range of statures (e.g., for posture-prediction models). Because central-point estimates are easier to obtain with a specified degree of accuracy than are estimates of variability and/or estimates of extreme behavior, the first type of study usually required fewer subjects.

The power of the test is one criterion often used to determine the appropriate sample size. Power is the probability that a given difference (between two groups) will be detected, and depends primarily on sample size and random variability in the dependent variable. The primary limitation of power as a determiner of sample size is that it can be calculated only for a specific difference in one dependent variable. Studies for ASPECT were typically aimed at a number of dependent and independent measures, so one of these was chosen to determine the sample size required to achieve a particular level of power. By combining power calculations with general heuristics, sample sizes selected for ASPECT studies of posture or position of midsize males generally ranged from 15 to 30, while sample sizes for studies designed to understand behavior across the stature range were 24 to 68 subjects.

STRATIFICATION SCHEMES – Having chosen stratified sampling as the best approach to subject sampling for ASPECT, the next step was to determine a specific stratification scheme for each study. As described previously, three anthropometric measures (stature, weight, and sitting height) are sufficient to account for most of the variance in anthropometry within gender. Any or all of these could be used to define the strata, or groups from which subjects are sampled. Across all ASPECT studies, however, stature is used to define such groups. Sitting height and weight were allowed to vary randomly within the groups and were inspected to confirm that the sample was not unusual relative to norms for these variables.

While stature, weight, and a sitting height comprise a key set of anthropometric variables, there are two primary reasons for using stature alone to determine sampling groups. The first reason is that sampling on two or more characteristics simultaneously makes finding subjects to fit the categories difficult, especially since people usually know their stature better than they know their sitting height or even their weight. It is difficult enough to find short and tall volunteers without adding requirements for their sitting height and weight.

The second reason is that adding other variables to the stratification scheme provides minimal additional value to the posture results. Previous research at UMTRI has shown that sitting height and weight add little predictive power to that of stature when modeling most posture and position variables (4). In analyses of those few variables in which weight or sitting height is a better predictor than stature, stratifying the sample on the basis of stature ensures an adequately wide range of sitting heights and weights as well. The only sample characteristic not guaranteed by stratification on stature is a range of sitting heights or weights *within* each stature group. In other words, sitting height *relative* to stature is sampled randomly, but actual sitting height is correlated with stature such that stratification on stature guarantees a wide range of sitting heights. Sitting height and weight relative to stature do not provide sufficient additional value to predicting occupant posture and position to justify the increased sampling complexity required to fill specific gender/stature/weight categories.

Subject age was not a subject selection criterion and was allowed to vary over a normal range. The subjects who participated in the ASPECT studies ranged from 20 to 73 years of age. Analyses of the UMTRI data collected previously have indicated that age does not affect driver preferred seat position or seatback angle, and, in the ASPECT studies, subject age has not been found to have an effect on occupant posture.

Twelve stature groups were defined for ASPECT studies. Table 4 below describes the stature ranges for each of the groups, along with the number of subjects sampled in each group for the eight studies summarized later in this paper. When posture behavior across the range of statures was of primary interest (e.g., the driver posture study, in-vehicle passenger posture study), all groups were sampled relatively evenly. For studies in which midsize-male behavior was of primary interest (e.g., midsize-male passenger posture study), midsize males were oversampled relative to other groups. Other studies represent a compromise between these goals. For example, seat factor study III emphasized male behavior (to estimate midsize-male behavior), but included data from all groups so that the data would be applicable to any population.

TEST FACILITIES

VEHICLES AND LABORATORY SEATING BUCKS – Subject testing for ASPECT was conducted both in vehicles and in carefully designed laboratory vehicle mock-ups, depending on the data collection requirements of the study. Testing in actual vehicles provides the most realistic situation and was used in a portion of the studies of driver and passenger posture. However, testing in vehicles often limits the types of measurements that can be safely and accurately made, and also present limitations in the vehicle package and seat conditions. Occupant posture is measured by digitizing palpated bony landmarks on the subject, and only a subset of the required set of body landmarks can be feasibly measured in vehicles. Studies that required a complete set of landmarks were therefore conducted in seating bucks. The laboratory vehicle mock-ups also allowed seat and package features to be independently adjusted over wider ranges of conditions than is possible in vehicles.

Table 4. Subject Sampling Strategy for ASPECT Studies

Subject Groups				ASPECT Study							
Group	Gender	Percentile Stature Range by Gender (10)	Stature Range (mm)	Driver Posture	Seat Factors I & II	Seat-Factors III	Kinematic Model Validation	Midsize Male Passenger Posture	In-Vehicle Passenger Posture	Manikin Validation	Total of All Studies
0	Female	< 5th	Under 1511	6	2	3	0	0	2	0	15
1	Female	5-15	1511 - 1549	5	2	3	1	0	2	0	15
2	Female	15-40	1549 - 1595	6	2	3	2	0	2	0	17
3	Female	40-60	1595 - 1638	5	2	3	2	0	2	0	16
4	Female	60-85	1638 - 1681	6	2	3	2	0	2	0	17
5	Female	85-95	1681 - 1722	6	2	3	1	0	2	0	16
6	Male	5-15	1636 - 1679	6	2	5	1	0	2	5	23
7	Male	15-40	1679 - 1727	6	2	5	2	0	2	5	24
8	Male	40-60	1727 - 1775	5	2	5	2	15	2	5	38
9	Male	60-85	1775 - 1826	6	2	5	2	0	2	5	24
10	Male	85-95	1826 - 1869	5	2	5	1	0	2	5	22
11	Male	> 95th	Over 1869	6	2	5	0	0	2	5	22
	Total			68	24	48	16	15	24	30	249

The fidelity of the UMTRI laboratory test environment was assessed in earlier studies by comparing posture and position data obtained in the laboratory with equivalent data collected in actual vehicles (1, 2). These analyses ensure that the UMTRI laboratory bucks produce results that are comparable to in-vehicle conditions. Each buck is equipped with actual automotive seats, pedals with realistic force-deflection properties, a steering wheel with typical movement and feel, a driving scene or simulator to provide a visual task, and an appropriately positioned instrument panel. In some cases, a roof liner was used to provide realistic head and vision constraints. The position and orientation of these components were adjusted through ranges typical of automotive package designs.

All subject test environments were calibrated and measured to document the test conditions before and after the study. Multiple SAE J826 H-point drops and seat cushion angle measurements were made, and the position and travel range of all vehicle features were recorded using a FARO arm or sonic digitizing system as discussed below. The contours of the vehicle and buck surfaces were also scanned to document their positions and shapes and to facilitate visualization in CAD programs. Fixed hardware targets were incorporated into each test environment and were digitized with every subject tested to verify component positions.

HARDWARE FOR MEASURING DRIVER POSTURE – *Sonic Digitizer* - A Science Accessories Corporation sonic digitizer, shown in Figure 1, was used to measure subject position and posture in five of the eight studies. The system uses a fixed array of four microphones to detect the three-dimensional locations of sonic emitters with an accuracy of 2 mm. A sonic probe is placed on a palpated body landmark and the two emitters on the probe are fired in rapid sequence. The three-dimensional coordinates of the probe tip are calculated from the measured locations of the probe emitters.

Figure 1. Sonic digitizer hardware.

FARO Arm – A portable, articulated arm for coordinate measurement, manufactured by FARO Technologies, Inc. and shown in Figure 2, was used to measure occupant position in three of the eight studies. The FARO arm is a three-link mechanical coordinate measurement device instrumented at each of six joints with rotary transducers. The joint angles and the lengths of the three articulated links are used to calculate the position of the probe tip. To measure subjects' positions and postures, the subjects were asked to maintain their driving or riding posture while the FARO arm apparatus was aligned to the data collection coordinate system by digitizing three reference points on the vehicle or laboratory mockup. The FARO arm was then used to record the driver's posture and position by measuring the locations of the key body landmarks. Digitization of all body landmarks was completed in approximately thirty seconds. The FARO arm accuracy under data collection conditions was determined to be ± 2 mm.

Figure 2. FARO arm digitizer hardware.

GENERAL TEST PROTOCOL

Subjects were recruited for testing from the greater southeastern Michigan area through the use of classified advertisements. An effort was made to recruit subjects from both inside and outside the University community and to recruit subjects of all ages. The subjects were paid $10-$20 per hour for their participation. All subjects were required to have four years of driving experience and to wear comfortable, non-bulky clothing and low-heeled shoes. Information on the subjects' current vehicle and driving habits were collected and each driver was screened using a health questionnaire. Informed consent was obtained from every subject, according to the University of Michigan protocols for research involving human subjects.[2]

Subjects selected were naive to the specific conditions of the study and were told that the experimental goals were to determine comfortable automotive seated positions. They were not informed of any of the specific test configurations or differences between test conditions nor were they allowed to observe the changing of test conditions. No manufacturers or brand names were used when identifying the different seats or vehicles.

Prior to posture testing, each subject was measured to determine their body size and dimensions. These measures were taken using a calibrated GPM anthropometer. The anthropometric measures included: stature, weight, age, sitting height, eye height, shoulder height, buttock-to-knee length, knee height, arm length, forearm length, hip breadth and shoulder breadth. These measures are illustrated in Figure 3. The full set of palpated bony landmarks shown in Figure 4 were also digitized on each subject seated in a specially designed hardseat, shown in Figure 5. This documented each subjects' torso shape and the relationship between the body landmarks, including back and spine landmarks that are inaccessible while the subject is seated in a vehicle seat.

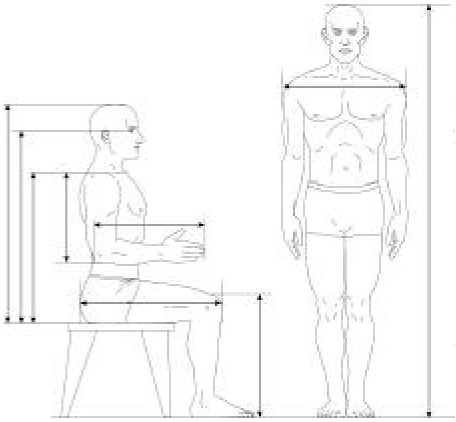

Figure 3. Illustration of anthropometric measures (age and weight not illustrated).

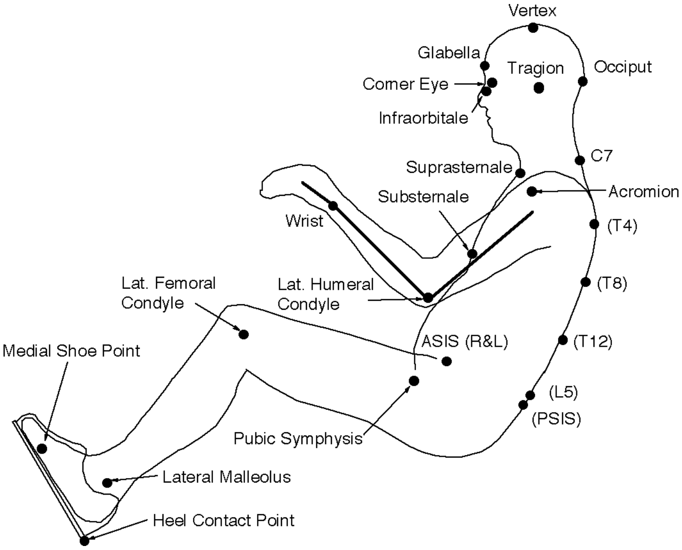

Figure 4. Digitized body landmarks.

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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.

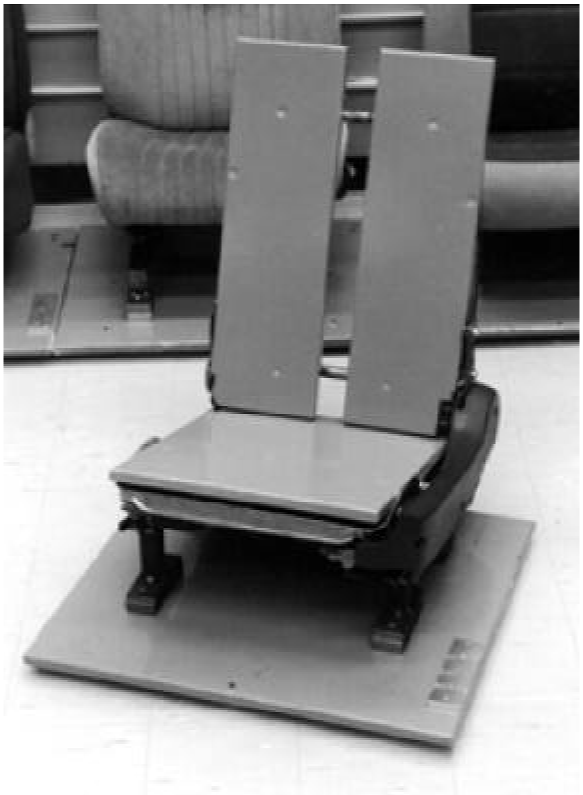

Figure 5. Hardseat.

Many steps were taken to eliminate potential sources of error or bias associated with the test protocol. Test sessions were limited to a maximum of 2-1/2 hours to maintain the subjects' motivation level. The order of the test conditions was randomized for each subject and conditions were identified by a configuration number rather than descriptive terms (i.e., "configuration 10" rather than "high cushion angle"). Prior to the subject entering the vehicle or laboratory mockup, the initial positions of the seat and seatback were set to a standardized position representing the expected mean positions in order to minimize bias associated with the initial positions. Subjects were instructed to find a comfortable driving or riding position using the adjustments provided, experimenting with their position while driving/riding.

Data were collected immediately after a 10 to 20 minute drive or after the subject had found a comfortable driving or riding position in the laboratory buck. Previous UMTRI studies have shown differences of less than 2 mm in preferred seat fore/aft position between pre- and post-drive measurements, suggesting that short exposure testing is acceptable for collecting driver preferred position and posture data (11,12). Also, analysis of National Personal Transportation Survey data indicates that 60% of all vehicle trips are 15 minutes or less in duration, and that 80% of vehicle trips are 30 minutes or less (12). This suggests that 10-20 minutes is an adequate drive time for characterizing occupant seated posture.

In every study, data collected included driver preferred seat fore/aft position, driver preferred seatback angle, driver preferred steering-wheel tilt position (if applicable), and the 3D locations of body landmarks. The landmark data were used to calculate driver posture measures, using a process described by Reed et al. (13). In most cases, driver comfort ratings and subject evaluations of the positions of the controls were also collected. In the manikin validation study, pressure-distribution data were collected for every subject using an X-Sensor pressure mapping system. Figure 6 shows the mats installed in the laboratory buck setting.

Figure 6. Pressure mapping system installed in test seat.

OVERVIEW OF ASPECT POSTURE STUDIES

Eight posture studies were conducted in ASPECT. Table 5 summarizes the sample size, test conditions, and data collected. The findings from this research will be published in future papers and reports.

KINEMATIC MODEL VALIDATION STUDY – This study examined the kinematics of the spine in response to torso recline and lumbar spine flexion. The primary purpose of the study was to quantify the accuracy of the accessible-landmark method for estimating T12/L1 (i.e., upper lumbar) joint location with a seated subject. The accessible landmark method is used in all other ASPECT studies to calculate the measures of lumbar spine posture from the digitized landmarks that are accessible when the subject is sitting in a vehicle seat (13). The study was conducted using the hardseat with passenger postures and enforced spine extensions about the lumbar support. Sixteen subjects were tested, as described in Table 4. Body landmark location data were collected using the sonic digitizing system. Each subject's posture was measured in the hardseat with and without a prominent lumbar support at seatback angles of 19, 23, and 27 degrees. The hardseat has an opening along the center of the backrest that allows direct palpation and measurement of the spinous processes. These data provide for direct comparison between the position of the T12/L1 joint estimated using the accessible-landmark method and a more direct measure of the actual location of the T12/L1 joint by palpation and measurement of spinal landmarks. The results of this study confirmed that the accessible-landmark method is sufficiently accurate for locating the T12/L1 joint of subjects in vehicle seats to achieve the goals of ASPECT.

Table 5. Summary of ASPECT Posture Studies

Study	# of Subjects	Factors	# of Conditions	Setting	Data Collected
Kinematic Model Validation Study	16	Seatback angle Lumbar support prominence	6	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture
Driver Posture Study	68	Seat height (H30) Steering-wheel-to-BOF distance Seat cushion angle (L27) Lateral bolsters Seat type (sport vs. sedan)	19	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture
Seat Factors Study I	24	Seat cushion angle (L27) Seat cushion length Lumbar support prominence Task (driver vs. passenger)	16	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture
Seat Factors Study II	24	Lumbar support prominence Lumbar support height Task (driver vs. passenger)	8	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture
Seat Factors Study III	48	Seat cushion angle (L27) Seat cushion length Seat cushion stiffness Lumbar support prominence Lumbar support height Task (driver vs. passenger)	44	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture Subjective rating
Midsize-Male Passenger Posture Study	15	Seatback angle Lumbar support prominence Seat contour level Task (driver vs. passenger)	12	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture
In-Vehicle Passenger Posture Study	24	Task (driver vs. passenger) Vehicle type Seating location (frt/rear)	13	Vehicle	Seat-fore/aft and seatback position Occupant posture
Manikin Validation Study	30	Task (driver vs. passenger) Seat type (12 production seats)	24	Laboratory Mockup	Seat-fore/aft and seatback position Occupant posture Subjective rating Pressure distribution
Totals	249		142		

DRIVER POSTURE STUDY – The driver-posture study determined the effects of selected interior vehicle dimensions on driver posture. Vehicle package factors considered as potential predictors of driver posture included seat height (H30), seat-track angle, steering-wheel fore/aft position (relative to pedals), steering-wheel vertical position, transmission type, vision restrictions and head clearance. This experiment benefited from recent UMTRI research on driver seat position (1, 2, 4), which determined that four vehicle dimensions and driver stature are the dominant factors affecting driver seat fore/aft position. This previous work led to the detailed study of two package factors (seat height and wheel-to-ball-of-foot distance) and three seat features (seat-cushion angle, lateral thigh bolstering, and overall seat type). Other seat features were the focus of a set of seat factor studies described below.

The factors studied in the ASPECT program included seat height: (H30), steering-wheel-to-pedal distance (L6) and seat-cushion angle (L27), as illustrated in Figure 7. Testing was conducted in the reconfigurable buck shown in Figure 8, which allowed the vehicle factors to be varied independently to determine the factor effects and interactions. Sixty-eight subjects (34 men and 34 women) were selected to fill twelve stature/gender groups as described in Table 4. Each subject was tested in 11 to 19 conditions. The two seats tested included a mid-contour, moderately stiff sedan seat and a firm sports-car seat with a prominent lumbar support. The seat-cushion angles tested ranged from 11 to 18 degrees, values spanning the majority of seat-cushion angles observed in the current vehicle fleet. The seat height used in the laboratory buck ranged from that of a typical sports car (180 mm) to that of a typical minivan (360 mm). Steering-wheel-to-BOF distance was varied over a 100-mm range, selected appropriately for each seat height tested. Subjects were instructed to adjust the seat and seatback angle to find a most-comfortable driving position and posture in each test condition. A set of body landmarks were then digitized using the sonic digitizing system previously described. Subject-selected seat fore/aft position and seatback angle were also recorded.

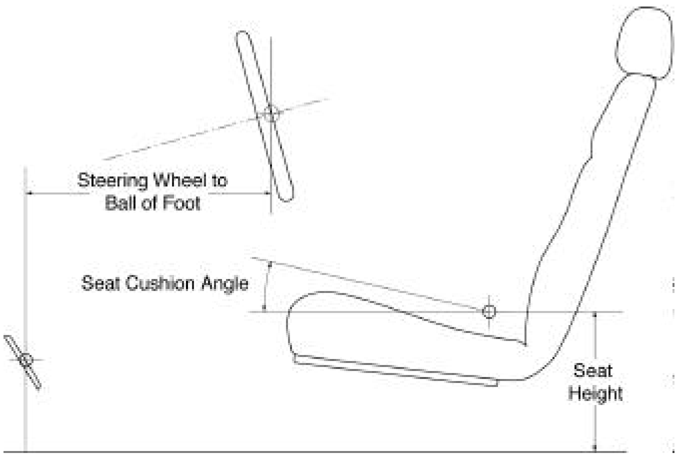

Figure 7. Illustration of vehicle factors.

Figure 8. One of the UMTRI reconfigurable vehicle mockups.

SEAT FACTORS STUDY I – This study quantified the main effects of, and interactions among, three seat design factors and also studied the effects of task constraints (driver versus passenger) on posture. The primary goal was to examine two-way interactions between seat factors to reduce the number of trials necessary for seat-factors study III. The seat factors studied include seat cushion angle, seat cushion length, lumbar support prominence, as illustrated in Figure 9. Twenty-four subjects were selected on the basis of stature and gender, as described in Table 4. Subjects were tested in the laboratory using reconfigurable seat A, shown in Figures 10a and 10b, to determine the primary effects and two-way interactions of the three seat factors on measures of driver posture and position. In each condition, the subjects were asked to use the seat fore/aft and seatback angle adjustments to find a comfortable driving or riding position. Driver posture was measured with the subject's hands on the steering wheel and the right foot resting on the accelerator pedal, while passenger posture was measured with the subject's hands in his or her lap and with both feet on the floor.

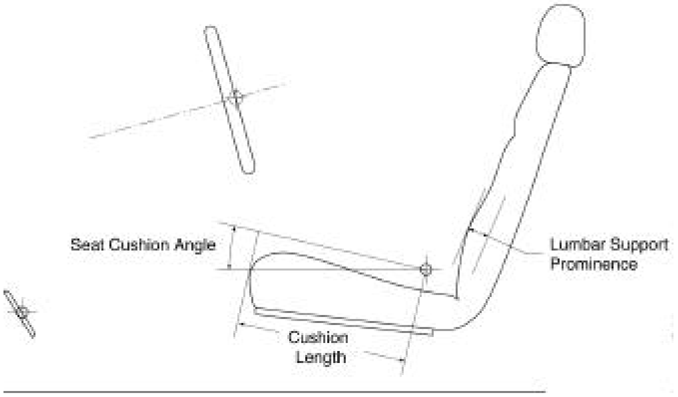

Figure 9. Illustration of factors studied in seat factors study I.

Figure 10a. Reconfigurable seat A, front view.

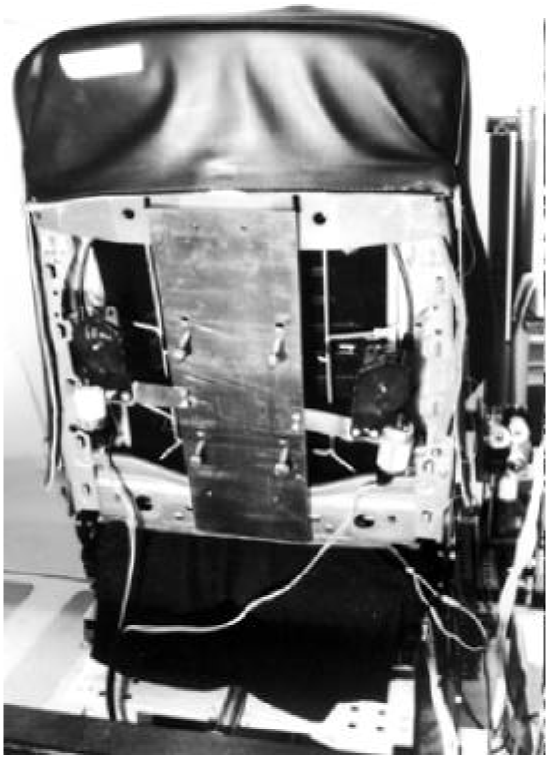

Figure 10b. Reconfigurable seat A, rear view.

SEAT FACTORS STUDY II – This study quantified the main effects of, and interactions among, two seat design factors: lumbar support prominence and lumbar support height. The effects of task constraints (driver versus passenger) on occupant posture were also studied. The primary goal was to study the two-way interaction between lumbar support prominence and lumbar support height to assist in determining the test conditions for seat factors study III. Twenty-four subjects were selected on the basis of stature and gender, as described in Table 4. Subjects were tested in the laboratory using reconfigurable seat B equipped with a Schukra backrest adjuster, shown in Figures 11a and 11b, that allowed the lumbar support height and lumbar prominence to be adjusted independently.

Subjects adjusted the seat fore/aft position and seatback angle to find a comfortable driving or riding posture. The driving condition required the subject's hands to be grasping the steering wheel and right foot to be on the accelerator pedal. Figure 12 illustrates the experimental factors.

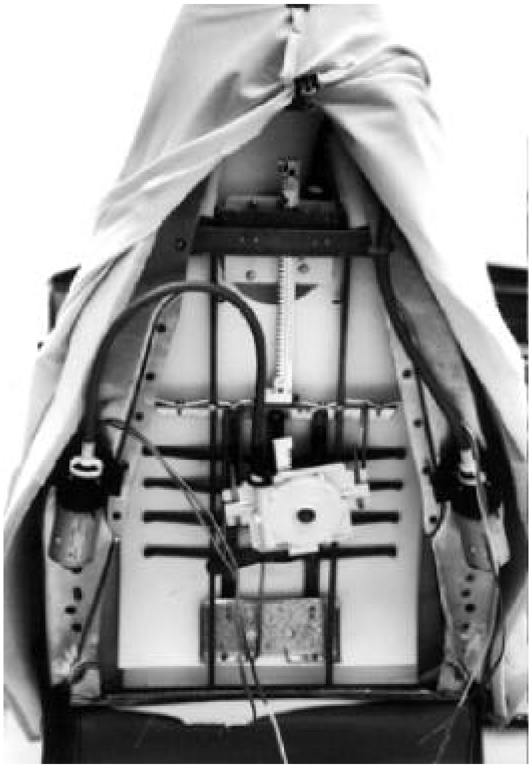

Figure 11a. Reconfigurable seat B used for seat factors study II.

Figure 11b. Reconfigurable seat B used for seat factors study II.

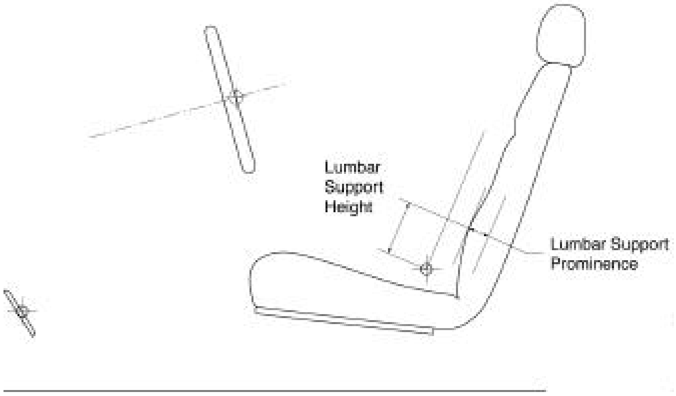

Figure 12. Illustration of factors investigated in seat factors study II.

SEAT FACTORS STUDY III – This study quantified the effects of five seat factors on driver and passenger posture and comfort. The factors studied were those identified in the driver posture study and the seat factor studies I and II as those having quantifiable effects on occupant posture. The results were used to determine manikin performance specifications and to integrate seat factor effects into vehicle occupant posture-prediction models.

Forty-eight subjects were selected for testing on the basis of stature and gender, as described in Table 4. Subjects were tested in a reconfigurable seat, shown in Figure 9, created by installing a Schukra backrest, that allowed vertical adjustment of the lumbar support and adjustment of the prominence of the lumbar support, into a luxury seat already equipped with cushion length and cushion angle adjusters. The seat cushion was modified to allow the foam in the buttock area to be changed to achieve two different foam stiffness levels. Each factor was manipulated independently to determine main effects and factors interactions. The factors studied include seat cushion angle, seat cushion length, lumbar support prominence, and occupant task (driver or passenger), as illustrated in Figure 13.

The seat was installed in a laboratory seating buck set to a midsize-sedan package configuration. Subjects were asked to find a comfortable position for each of 40 test conditions outlined in Table 5, tested in the course of two sessions. Subjects selected a comfortable seat fore/aft position for the driver posture trials, and adjusted the seatback angle in both driver and passenger posture trials. Certain conditions were tested in both sessions to assess repeatability issues. Subjective comfort data were collected for each subject in each seat configuration. The results from this study quantify the effects of seat factors on posture, and indicate those seat factors that the ASPECT manikin should measure.

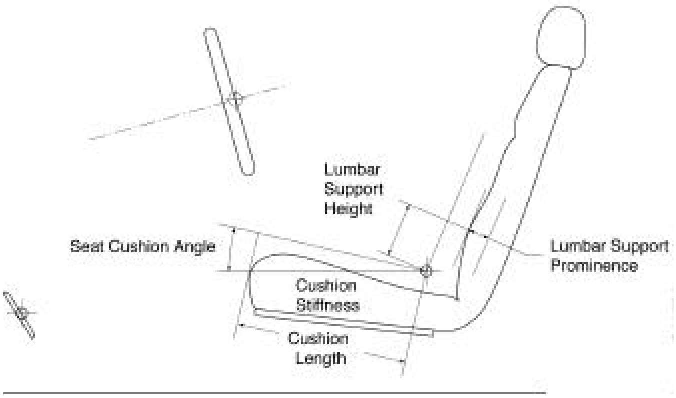

Figure 13. Illustration of factors studied in seat factor study III.

MIDSIZE PASSENGER POSTURE STUDY – This study collected data on midsize-male passenger postures in three seats at three seatback angles. The conditions tested were identical to those used for the AAMA/UMTRI H-point study of driving postures (14). Comparing these datasets provided insight into the differences in posture that can be attributed to occupant task (driver versus passenger). Fifteen midsize-male subjects (Group 8) were recruited for testing. The subjects were instructed to find comfortable riding positions in the three seats: a soft, noncontoured Caprice seat, a moderately firm, moderately contoured Pontiac seat, and a firm, highly contoured Saturn seat with the lumbar support adjusted to the most prominent position. The seatback angles tested were 19, 23, and 27 degrees, as measured with the SAE J826 H-point machine (15). Use of a fixed seatback angle condition makes these data particularly applicable to passenger seats without seatback angle adjustment, such as the majority of seats in rear-seat positions. Subject posture was measured by using the sonic digitizer to collect several body landmarks. These data were analyzed to determine the effect of task and imposed seatback angle on occupant posture.

IN-VEHICLE PASSENGER POSTURE STUDY – This study compared driver and front-seat passenger postures, and determined the effects of legroom restriction on rear-seat occupants. Twenty-four subjects were selected on the basis of stature and gender, as described in Table 4. Subjects were tested in eight vehicles, including sports cars, sedans, pickup trucks, a minivan, and a sport utility vehicle (SUV). These subjects had already been tested as drivers in the same vehicles for an UMTRI eye-position study (3). The subjects were instructed to find a comfortable front passenger riding posture during a 10-15 minute ride, in which the investigator was the driver. The same midsize-female driver was used for all trials to control the effect of the driver's seat position, which may influence passenger seating position. Immediately after the ride, the subject's seat fore/aft position, seatback angle, and riding posture were recorded using a FARO arm coordinate measurement system. Subjects were then instructed to find comfortable riding positions in the back seat of the static vehicle under minimum and maximum legroom conditions (i.e., with the front seat positioned full forward and full rearward). The data collected in this study quantify the effect of task (driver versus passenger) on occupant posture through comparison of the data collected with the driver position data available for the identical subjects from the UMTRI eye position study.

MANIKIN VALIDATION STUDY – This study generated a database of human posture in twelve different production seats for use in evaluating and validating final prototypes of the ASPECT physical manikin (APM). Thirty subjects, described in Table 4, were tested in the twelve seats. This set of seats was selected to represent a wide range of seat types and features. A seating buck was constructed to allow each seat to be installed while maintaining the vehicle package dimensions of a midsize sedan in terms of seat height, steering-wheel position, pedal positions, and orientation, and instrument-panel height and location. Subjects were tested in six vehicle seats in each of two sessions, and were instructed to adjust the seat fore/aft position for driver trials and adjusted the seatback angle to find a comfortable position and posture for both driving and riding in each seat. Each subject's driver and passenger postures were recorded with a sonic digitizing system. Subjects also assessed the comfort of each seat using subjective rating forms. Upon completion of the posture testing in each seat, the seat cushion and seatback pressure distributions generated by each subject was measured using the X-Sensor system. This study generated a set of human posture data that was used to assess the performance and measures of the ASPECT physical manikin.

CONCLUSIONS

The posture data collected in these studies has played a key role in the success of the ASPECT program. The rationale and strategies for selecting study participants assured adequate and efficient subject sampling. The studies enhanced an existing posture database and the combined data set provides a detailed understanding of the effects of package, seat, task, and anthropometric factors on occupant posture. The results have been used to guide the design and performance of the ASPECT physical manikin and the development of new concepts for using the manikin and other design tools (16, 17). They have also been used to develop accurate posture-prediction models for use with a full range of occupant sizes represented by computer models of vehicle occupants (4).

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