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Effects of Seat Height, Cushion Length, Seatpan Angle, and Pedal Force Level on Resting Foot Force and Maximum Comfortable Displacement of the Accelerator Pedal

FINAL REPORT

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Revised December 1994

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16. Abstract

An adjustable laboratory seating buck was developed to study the optimal design and performance characteristics of automotive throttle systems and their relationship to interior package geometry and seat characteristics. The buck allows for quick adjustment of vehicle package and seat dimensions. A total of 48 male and female subjects ranging in stature from 5th-percentile female to 95th-percentile male were tested for 24 different buck configurations using three levels of seat height, two levels of cushion length, two levels of seatpan angle, and two levels of throttle pedal force. Testing was conducted using a split-plot experimental design by which each subject was tested in 12 of the 24 configurations. Resting foot force (RFF) and maximum comfortable pedal displacement (MCPD) were the primary dependent variables measured, but preferred seat fore/aft position, seatback angle, knee, leg, and thigh angles, heel position, and foot orientation angles were also recorded for each subject.

Equivalent RFF at the center of the accelerator pedal ranged from approximately 2 to 9 lb across subjects and was affected very little by the different levels of independent variables. The overall mean RFF values for the independent variables range from 4.6 to 5.2 lb. Maximum comfortable pedal displacement (MCPD) was influenced most by pedal force level, such that overall mean pedal displacement decreased from 65.5 mm to 47.6 mm when the opening pedal force was changed from 4 lb to 8 lb. The corresponding overall mean ankle extension angles are 14.3 degrees at the HIGH pedal force and 20.2 degrees at the LOW pedal force, while the overall mean changes in 95th-percentile manikin foot angle are 13.9 and 17.7 degrees, respectively.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

An adjustable laboratory seating buck was developed to study the optimal design and performance characteristics of automotive throttle systems and their relationship to interior package geometry and seat characteristics. The buck allows for quick adjustment of vehicle package and seat dimensions. A total of 48 male and female subjects ranging in stature from 5th-percentile female to 95th-percentile male were tested for 24 different buck configurations using three levels of seat height, two levels of cushion length, two levels of seatpan angle, and two levels of throttle pedal force. Testing was conducted using a split-plot experimental design by which each subject was tested in 12 of the 24 configurations. Resting foot force (RFF) and maximum comfortable pedal displacement (MCPD) were the primary dependent variables measured, but preferred seat fore/aft position, seatback angle, knee, leg, and thigh angles, heel position, and foot orientation angles were also recorded for each subject.

The overall mean values for measured and derived dependent variables for the different levels of independent variables are given in the table on the following page. Equivalent RFF at the center of the accelerator pedal ranged from approximately 2 to 9 lb across subjects and was affected very little by the different levels of independent variables. The overall mean RFF values for the independent variables range from 4.6 to 5.2 lb. Maximum comfortable pedal displacement (MCPD) was influenced most by pedal force level, such that overall mean pedal displacement decreased from 65.5 mm to 47.6 mm when the opening pedal force was changed from 4 lb to 8 lb. The corresponding overall mean ankle extension angles are 14.3 degrees at the HIGH pedal force and 20.2 degrees at the LOW pedal force, while the overall mean changes in 95th-percentile manikin foot angle are 13.9 and 17.7 degrees, respectively.

Use of analysis of variance (ANOVA) to examine for relationships between dependent and independent variables indicates that:

- driver seat position is influenced by driver size, gender, seat height, and seat cushion angle such that more rearward seat positions result for taller drivers, male drivers, lower seat heights, and lower cushion angles;
- seatback angle is affected by seat height and cushion angle such that higher seat heights and lower cushion angles produce lower (i.e., more vertical) seatback angles;
- preferred fore/aft heel position is a function of seat height and cushion angle such that the heel is placed more rearward for lower seat heights and higher cushion angles;

- preferred lateral heel position is different for males and females, with males placing their heel further to the left and rotating the foot more to the right to reach the accelerator pedal;

- driver knee angle and leg angle (i.e., between knee and ankle) are influenced by seat height and cushion angle, such that the knee angle is larger and the leg angle is lower (to horizontal) for lower seat heights and lower cushion angles;

- thigh angle tends to be different for males and females and is a function of seat height such that higher seat heights produce lower thigh angles and females tend to have lower thigh angles than males;

- resting foot force is relatively independent of vehicle package and seat factors, being only weakly influenced by seat height and cushion angle;

- foot/pedal contact zone is influenced by pedal force such that for higher pedal forces subjects position their foot lower on the pedal;

- driver ankle extension and pedal displacement during maximum-comfortable pedal displacement are influenced by cushion angle and pedal force such that higher cushion angles and higher pedal forces result in lower pedal displacements and ankle extensions;

- downward thigh displacement during maximum comfortable pedal displacement is reduced for higher seat heights, higher cushion angles, higher pedal forces, and, to a lesser extent, for longer cushion lengths, and these reductions are accompanied by increased pressure exerted by the thigh on the front of the seat cushion;

- forward heel slide is affected by seat height and pedal force such that higher seat heights and lower pedal forces result in less forward heel slide.

On the following page is a listing of the overall mean values for the dependent measures for each of the independent seat factors.

Overall Mean Values* of Dependent Measures

Dependent Variable	Seat Height			Seat Pan Angle		Cushion Length		Pedal Force		Page
	Low	Med.	High	Low	High	Low	High	Low	High	
Sample Size	192	192	192	288	288	288	288	288	288	
H-Point-to-BOF distance	885	802	825	861	854	857	857	859	856	59
Seatback angle	25.5	23.2	21.4	23.1	23.6	235	23.2	23.4	23.3	60
Right heel-to-AHP distance	21	17	10	13	20	17	16	18	15	68
Foot pitch angle	57.9	50.6	42.1	51.3	49.2	50.2	50.2	50.8	49.7	69
Heel-to-accel. pedal lateral dist.	38	37	36	38	36	37	37	38	36	74
Foot rotation angle	8.4	8.6	8.6	8.6	8.4	8.4	8.6	8.5	8.6	75
Knee angle	129	125	120	126	123	125	124	124	125	77
Leg angle	36.2	45.0	54.9	44.2	46.5	45.2	45.6	45.5	45.3	78
Thigh angle	14.7	10.2	5.3	9.9	10.3	9.8	10.3	10.2	9.9	79
Pedal contact zone	4.2	4.3	4.4	4.3	4.3	4.3	4.3	4.5	4.1	84
Initial Ankle Angle	88.8	86.9	86.1	87.0	87.5	87.4	87.1	86.4	88.1	87
Resting foot force - actual	4.2	4.4	4.6	4.6	4.2	4.4	4.4	4.4	4.4	90
Resting foot force - at pedal ctr.	4.6	4.9	5.2	5.1	4.7	4.9	4.9	5.0	4.8	91
Max. Comfortable Pedal Disp.	55.6	56.9	57.2	58.6	54.6	56.8	56.3	65.5	47.6	98
Ankle extension angle re MCPD	16.5	17.2	18.0	18.2	16.3	17.6	16.9	20.2	14.3	99
Δ 95th manikin foot angle	15.6	15.8	15.9	16.2	15.4	15.8	15.8	17.7	13.9	102
Δ 50th manikin foot angle	12.2	12.5	12.6	12.9	12.1	12.5	12.4	14.2	10.7	104
Downward thigh displacement	26	23	19	26	20	23	22	25	20	108
Δ Knee angle	7	6	5	7	5	6	6	7	5	109
Seat pressure @ front FSR	1.1	1.2	1.4	1.0	1.5	1.4	1.0	1.2	1.3	110
Seat pressure @ back FSR	1.0	1.1	1.2	1.0	1.2	1.2	1.1	1.1	1.2	111
Heel slide distance	11	10	7	10	9	10	9	8	11	113

* units are mm, degrees, and lb, as applicable.

1. INTRODUCTION

Automotive engineers have been designing accelerator pedals and throttle linkage assemblies for many years using a range of opening pedal force levels and wide-open throttle pedal displacements. However, little is known about driver preference for accelerator pedal displacement and gain characteristics, or of the effect of seat design and vehicle packaging factors on the preferred accelerator pedal parameter values. Stocker at Ford Motor Company (unpublished) has suggested that it is ergonomically undesirable for the accelerator pedal to be depressed (i.e., opened) by the force exerted by the resting foot (i.e., without any ankle exertion), since this would require a driver to constantly exert effort to maintain a partially depressed pedal when cruising on the highway at constant speed (assuming no cruise control). In order to design a pedal linkage system to minimize the need for drivers to resist acceleration, but still keep the pedal force level low to minimize required exertion during acceleration, data on resting foot force and the relationship of resting foot force to seat and vehicle package dimensions are needed. Also, with regard to pedal displacement at wide-open throttle, it has become the practice at Ford to design throttle systems to achieve a maximum pedal displacement that produces a change in the 95th-percentile manikin foot angle of 12 to 14 degrees, but there is no clearly established basis for this criteria.

In this study, an adjustable laboratory seating buck was designed and assembled to allow measurement of resting foot force (RFF) and maximum-comfortable pedal displacements (MCPDs), and to study the interactions of these variables with vehicle package geometry, seat design, and pedal force level. Subject testing was conducted in the seating buck for different seat heights, seat cushion angles, seat cushion lengths, and with high and low pedal forces using male and female drivers with statures from 5th-percentile female to 95th-percentile male based on U.S. population data from the 1974 Health and Nutrition Examination Survey (Abraham, et al., 1979a, 1979b). Resting foot force (RFF) and maximum-comfortable pedal displacements (MCPDs) were determined for each test condition and were compiled with preferred driver seat, leg, and foot position data to determine dependent variable statistics and relationships with the independent subject, package, and seat variables. Section 2 of this reports describes the test facility and experimental procedures, and Section 3 describes the results.

2. PROCEDURES

2.1 GENERAL APPROACH

In developing a research plan for this investigation, the following independent variables were identified with Ford engineering staff:

- opening accelerator pedal force,
- seat height from accelerator heel point (AHP),
- seat cushion angle, and
- seat cushion length.

For different levels of these vehicle and seat factors, it was desired to measure the driver's maximum-comfortable accelerator pedal displacement, as well as the foot force applied to the undepressed accelerator pedal with the ankle relaxed (i.e., resting foot force or RFF).

Because of the need to quickly and easily adjust from one test configuration to another, as well as the need to vary the seat and pedal conditions for a range of package seat heights from sport cars to light-truck and van-type vehicles, testing subjects in actual vehicles was determined to be impractical. Use of a simulated vehicle environment was also necessary to provide unlimited accelerator pedal travel during testing for maximum comfortable pedal displacement. An instrumented laboratory seating buck was therefore designed and developed to allow quick adjustment among a number of different package and pedal conditions in a single test session, and to enable quantitative measurement of resting foot force, pedal displacement, and driver seat and body positioning. The seating buck incorporates a 1992 Mercedes-Benz power seat with 288 mm of fore/aft seat-track travel, and adjustable seat cushion length, seat cushion angle, and seatback angle. It also includes an interactive driver simulation display that provides a driving-like task while subjects determine their preferred seat and body positions.

2.2 SUBJECT SAMPLING STRATEGY

A sample of 48 subjects[1], representing short, medium, and tall males and females of the U.S. adult population, participated in the study. Table 1 shows the definitions of the six

[1] 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, Education, and Welfare (now 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 Investigation Involving Human Beings, Medical School, The University of Michigan.

stature/gender groups for which the stature percentiles are based on the 1971-1974 HANES database (Abraham). In each group, an attempt was made to obtain subjects whose weight fell within normal limits for their stature and gender group, and to obtain a reasonably representative distribution of age.

Table 1
Subject Stature Groups

Group	Percentile Range	Stature Range (mm)	Stature Range (in)	Sample Size
Females				
1	5-15	1499-1562	59.0-61.5	8
2	40-60	1587-1638	62.5-64.5	8
3	85-95	1676-1727	66.0-68.0	8
Males				
4	5-15	1626-1676	64.0-66.0	8
5	40-60	1727-1778	68.0-70.0	8
6	85-95	1829-1880	72.0-74.0	8

2.3 INDEPENDENT VARIABLES AND TEST MATRIX

The final test matrix was established in consultation with Ford engineering staff and required testing subjects at three different seat heights of 180 mm, 270 mm, and 360 mm, two seat cushion lengths, two seat cushion (i.e., seatpan) angles, and two accelerator pedal force conditions. These four independent variables (i.e., factors) with three levels for one factor and two levels for each of the other factors, resulted in 24 possible test conditions for a full-factorial experimental design (i.e., 3 x 2 x 2 x 2 factorial). Table 2 summarizes the resulting matrix of test conditions.

To measure seatpan angle, a legless J826 manikin procedure described in Section B1 of Appendix B was used. Based on measurements of typical vehicles and seats using this procedure, the LOW seatpan angle was set to 9 degrees for all seat heights. The high seatpan angle was initially proposed to be 18 degrees for all seat heights, but preliminary testing with a small sample of short female subjects indicated that these drivers could not effectively reach the pedals with this seatpan angle at the high and mid seat heights. It was therefore decided that the HIGH seatpan angle would vary with seat height and would be set at 18 degrees, 16 degrees, and 14 degrees for the 180-mm, 270-mm, and 360-mm seat heights, respectively.

Table 2
Full-Factorial Test Matrix

Configuration #	Seat Height (H30)	Seatpan Angle	Seat Cushion Length	Pedal Force Level
1	LOW	LOW	LOW	LOW
2	LOW	LOW	LOW	HIGH
3	LOW	LOW	HIGH	HIGH
4	LOW	LOW	HIGH	LOW
5	LOW	HIGH	LOW	LOW
6	LOW	HIGH	LOW	HIGH
7	LOW	HIGH	HIGH	HIGH
8	LOW	HIGH	HIGH	LOW
9	MID	LOW	LOW	LOW
10	MID	LOW	LOW	HIGH
11	MID	LOW	HIGH	HIGH
12	MID	LOW	HIGH	LOW
13	MID	HIGH	LOW	LOW
14	MID	HIGH	LOW	HIGH
15	MID	HIGH	HIGH	HIGH
16	MID	HIGH	HIGH	LOW
17	HIGH	LOW	LOW	LOW
18	HIGH	LOW	LOW	HIGH
19	HIGH	LOW	HIGH	HIGH
20	HIGH	LOW	HIGH	LOW
21	HIGH	HIGH	LOW	LOW
22	HIGH	HIGH	LOW	HIGH
23	HIGH	HIGH	HIGH	HIGH
24	HIGH	HIGH	HIGH	LOW

For this study, cushion length was measured by placing a straight edge on the seat cushion of the unloaded seat at the midline. As illustrated in Figure 1, cushion length was defined as the distance from a line perpendicular to this straight edge that is tangent to the front edge of the seat to a second line that is also perpendicular to the straight edge but tangent to the lower seatback contour.

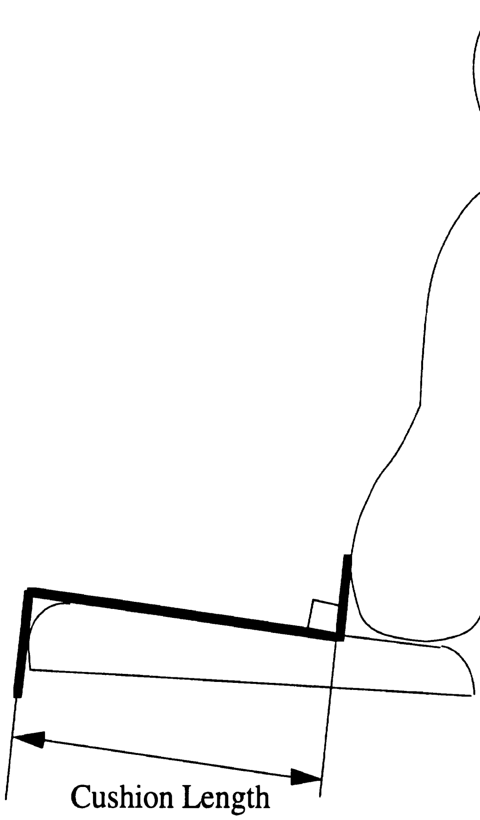


Figure 1. Cushion length measurement.

Using this definition, cushion length was measured in a number of different production vehicles with a resulting range of 445 mm to 508 mm. The adjustment range for cushion length in the Mercedes test seat ranges from 452 mm to 527 mm, and the two cushion lengths selected for testing were 460 mm and 500 mm.

The accelerator pedal linkage assembly selected for the study has a fixed (i.e., nonpivoting) curved pedal pad similar to that used in the Taurus vehicle. Based on information from Ford engineers, the two accelerator pedal conditions selected for testing were an opening force of 4 lb with approximately 2 lb of hysteresis, and an opening force of 8 lb with 3 to 4 lb of hysteresis.

Because it was not reasonable to test each subject in all 24 test conditions, a split-plot experimental design was implemented in place of a full-factorial design. The subject population was divided into two groups, referred to as Group A and Group B, and each subject was tested for 12 of the 24 conditions, as shown in Table 2. Four subjects in each gender/stature group were tested for conditions A1-A12 and four for conditions B1-B12. Each subject group was tested for the same twelve combinations of three levels of seat height, two levels of seatpan angle, and two levels of seat cushion length. The two levels of pedal force were assigned to Group A and Group B subjects as indicated in the last column of Table 3. Subjects completed testing in two sessions of six configurations each with the order of the twelve conditions randomized to remove possible bias in the test results due to order of testing or subject fatigue.

Table 3
Split-Plot Test Matrix

Configuration #	Seat Height (mm)	Seatpan Angle (degrees)	Cushion Length (mm)	Opening Pedal Force (lb)
A1	180	9	460	4
A2	180	9	500	8
A3	180	18	460	8
A4	180	18	500	4
A5	270	9	460	4
A6	270	9	500	8
A7	270	16	460	8
A8	270	16	500	4
A9	360	9	460	4
A10	360	9	500	8
A11	360	14	460	8
A12	360	14	500	4
B1	180	9	460	8
B2	180	9	500	4
B3	180	18	460	4
B4	180	18	500	8
B5	270	9	460	8
B6	270	9	500	4
B7	270	16	460	4
B8	270	16	500	8
B9	360	9	460	8
B10	360	9	500	4
B11	360	14	460	4
B12	360	14	500	8

2.4 ADJUSTABLE LABORATORY SEATING BUCK

2.4.1 Design and Construction

Figure 2 shows the completed seating buck, which is comprised of separate support/adjustment assemblies for the seat, steering wheel, and pedals. Each unit or module provides support and position adjustment of the vehicle components required to achieve the conditions of Table 2. An interactive road-scene display provides the subject with a driving task when adjusting the seat position.

Figure 3 shows a schematic of the seat and seat adjustments, while Figure 4 illustrates the coordinate axes of the buck. The base structure of the seating buck is fabricated with 2-in x 2-in unistrut tubing. A 1992 Mercedes-Benz power seat with 288 mm of front/back seat travel is used for all test conditions and is mounted to a power-driven scissors jack that allows for seat-height adjustment. The base of the scissors jack is mounted to horizontal rails through pillow-block linear bearings to establish the horizontal location of the design H-point (SgRP). Up/down and front/back movement of the seat assembly are powered by screw-motor actuators that are controlled by a hand-held module shown in Figure 5. A rotary switch on the top of the module is used to select a particular screw motor and two momentary push-button switches on the side activate movement in a particular direction. A sliding clamp mechanism is used as shown in Figure 6 to stabilize the seat platform at each test position prior to a subject entering the seat.

Figures 7a and 7b illustrate the steering wheel assembly and support structure that allow the steering wheel location to be adjusted to the appropriate position for a given seat height setting. A 15-in-diameter steering wheel is mounted to the end of a 3/4-in-diameter aluminum rod that is attached to the end of a braced cantilevered beam by a pivot joint. The angle of the steering wheel is set at 22 degrees to the vertical for all test conditions. The other end of the support beam is fastened to a plate that is driven up and down and front to back by a screw-motor actuator power. Positioning of the steering wheel is controlled by the same hand-held module used to position the seat assembly.

Figure 8 shows the pedal assembly support and adjustment mechanism. The accelerator and brake linkage assemblies from a 1992 Ford Taurus sedan are mounted to an aluminum plate that attaches to the base structure by a mechanism that allows adjustment of the pedal angles

Figure 2. Completed seating buck.

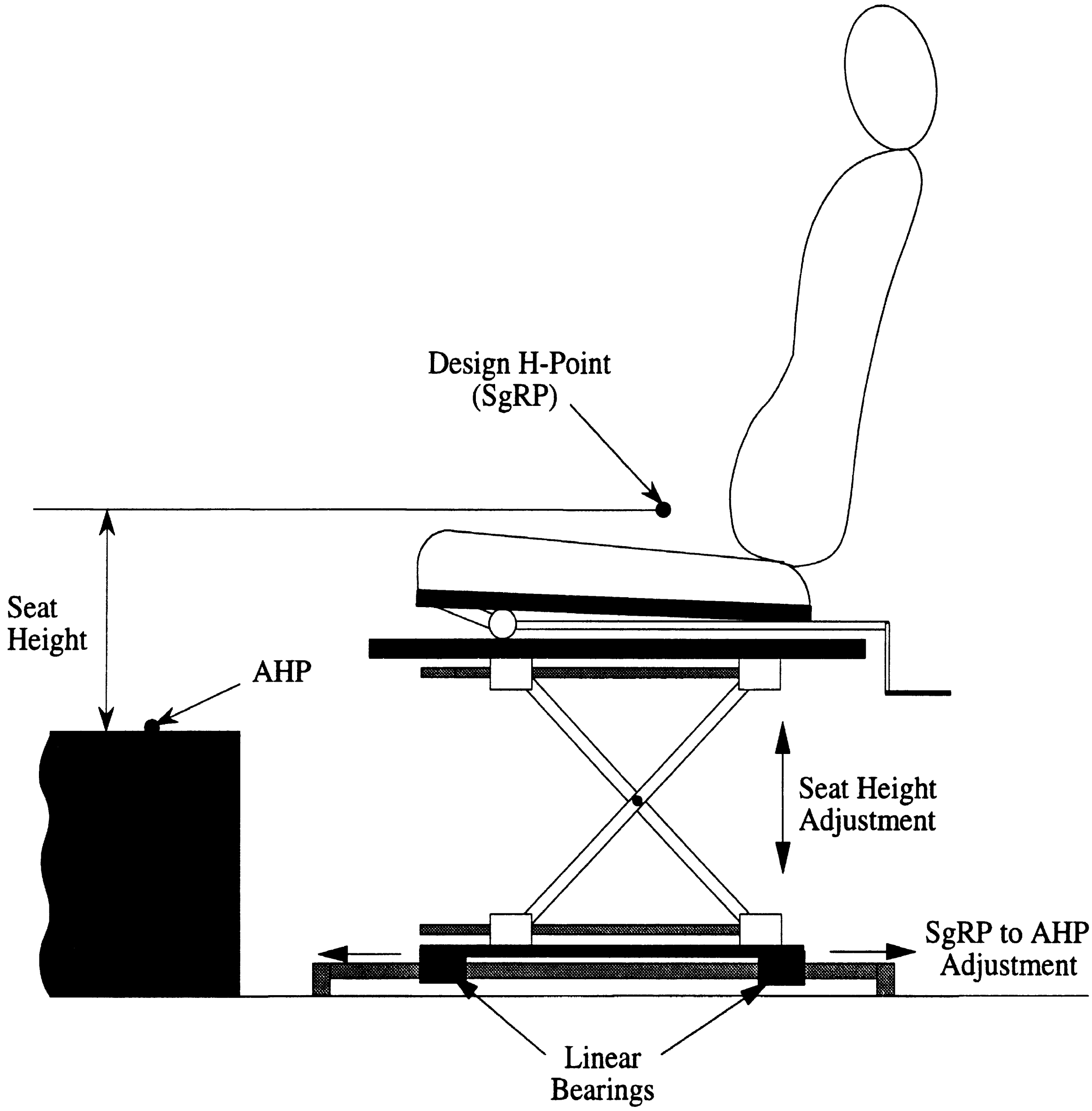
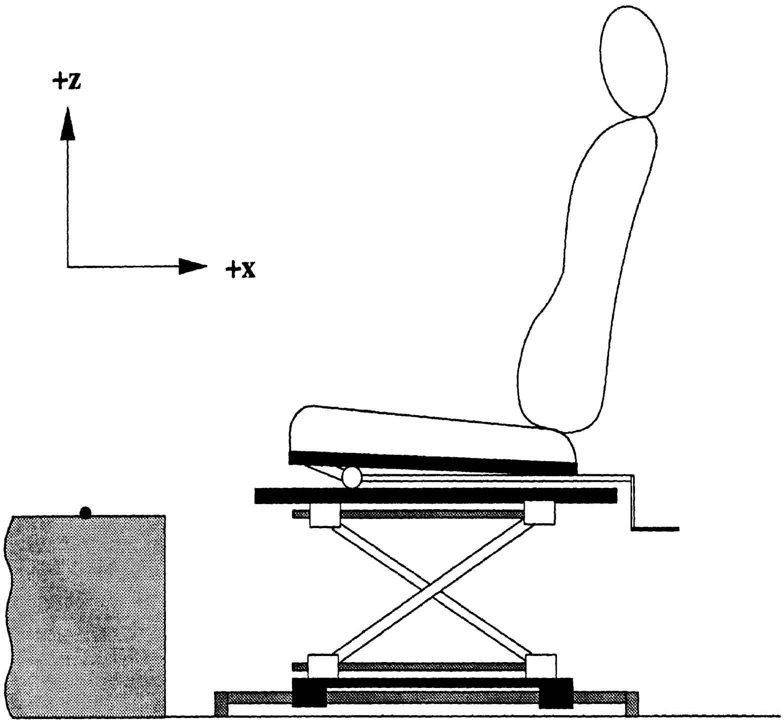
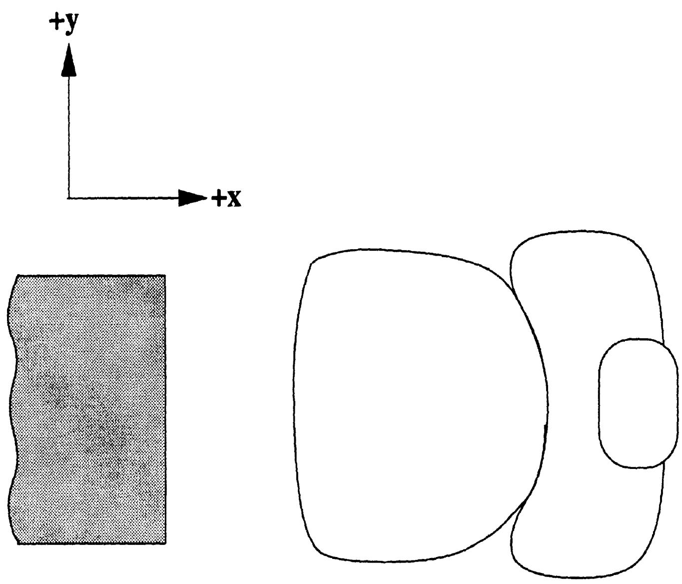


Figure 3. Schematic of the SgRP vertical and horizontal adjustment mechanisms.



Side View



Top View

Figure 4. Schematic of seating buck, illustrating coordinate axes.

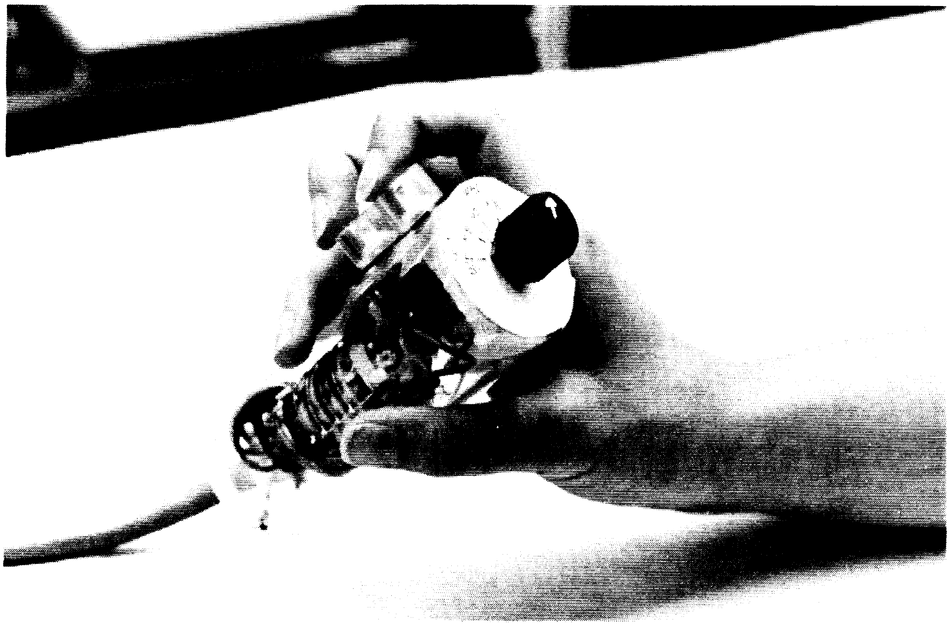


Figure 5. Hand-held module used to adjust up/down and front/back movement of the seat and steering wheel assemblies.

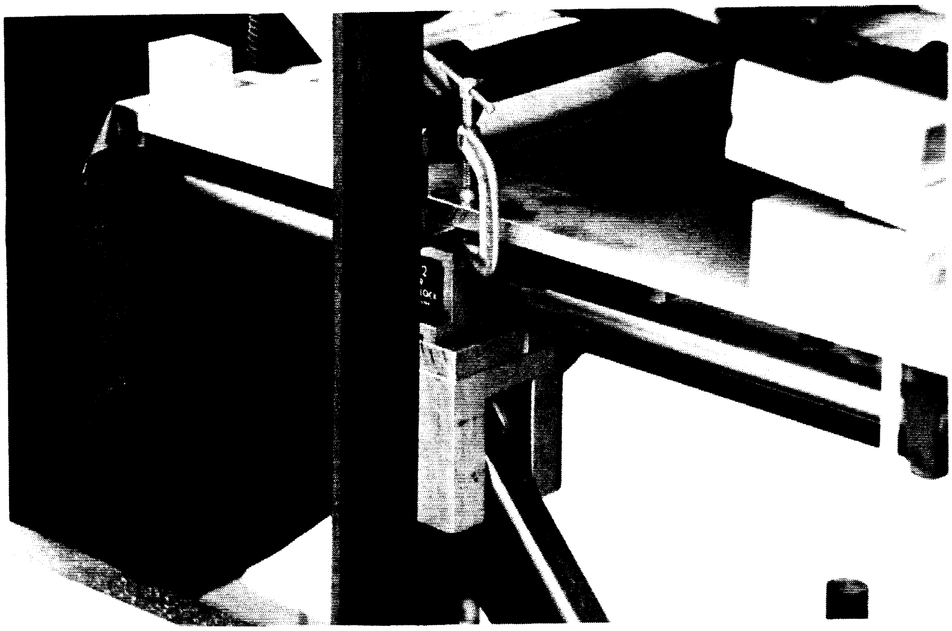


Figure 6. Clamp mechanism used to stabilize seat platform.

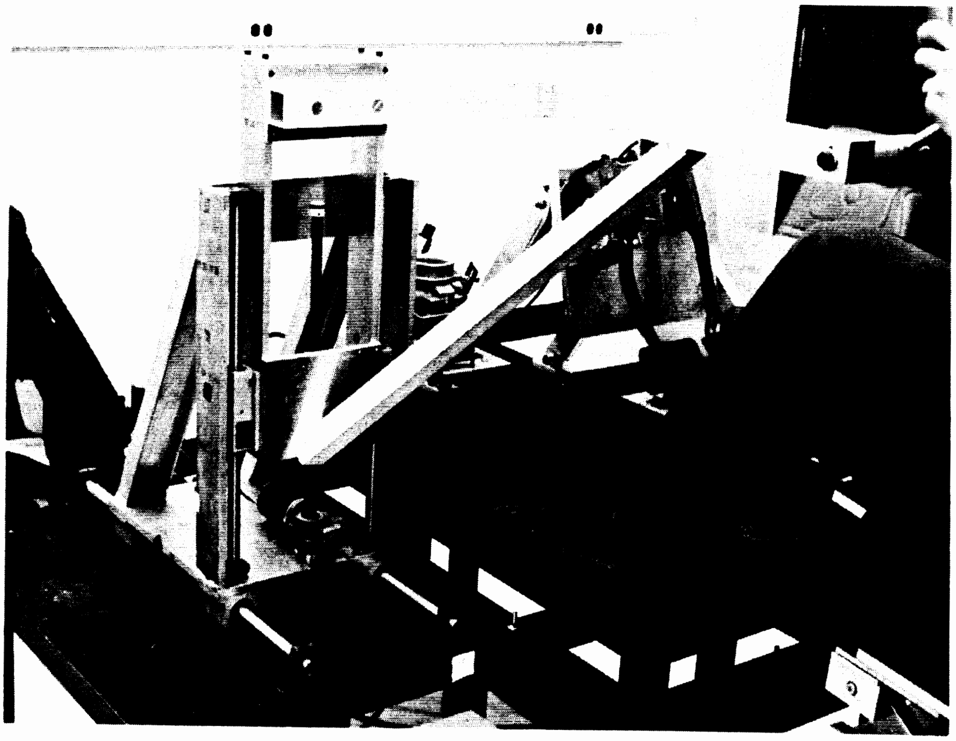


Figure 7a. Steering wheel assembly and support structure.

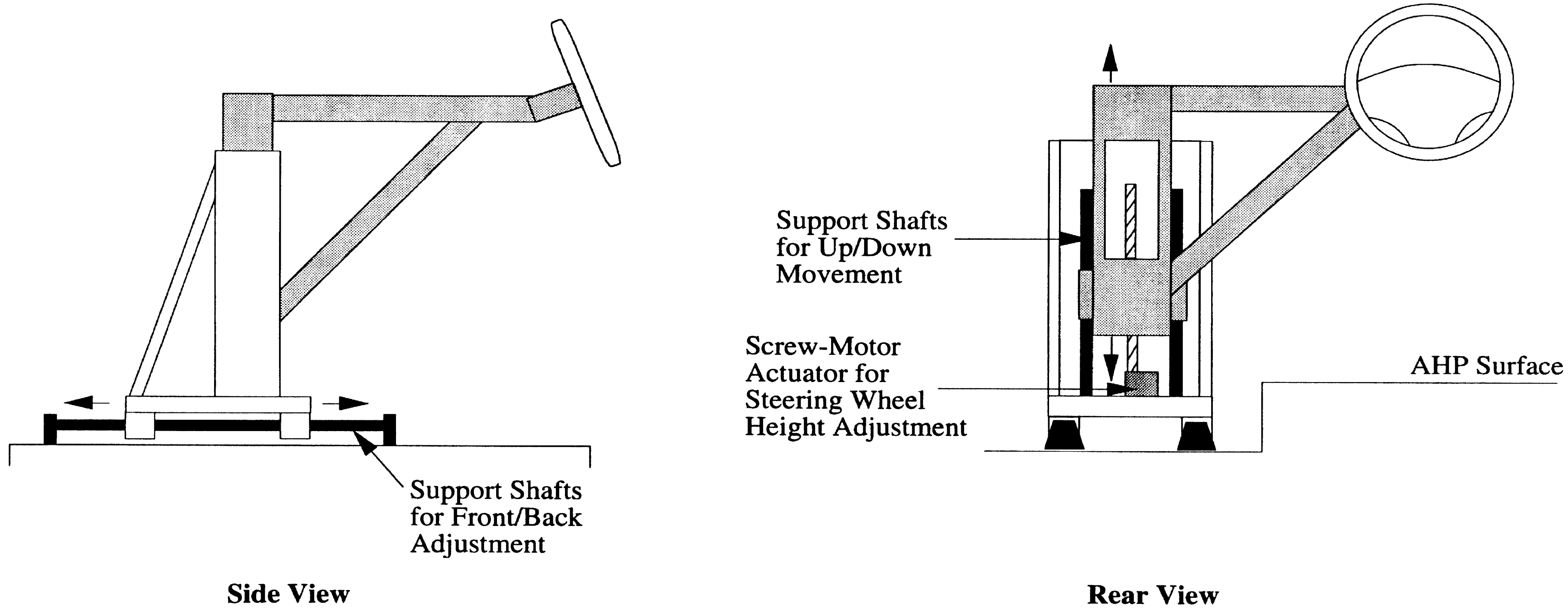


Figure 7b. Schematic of the steering wheel assembly and support structure.

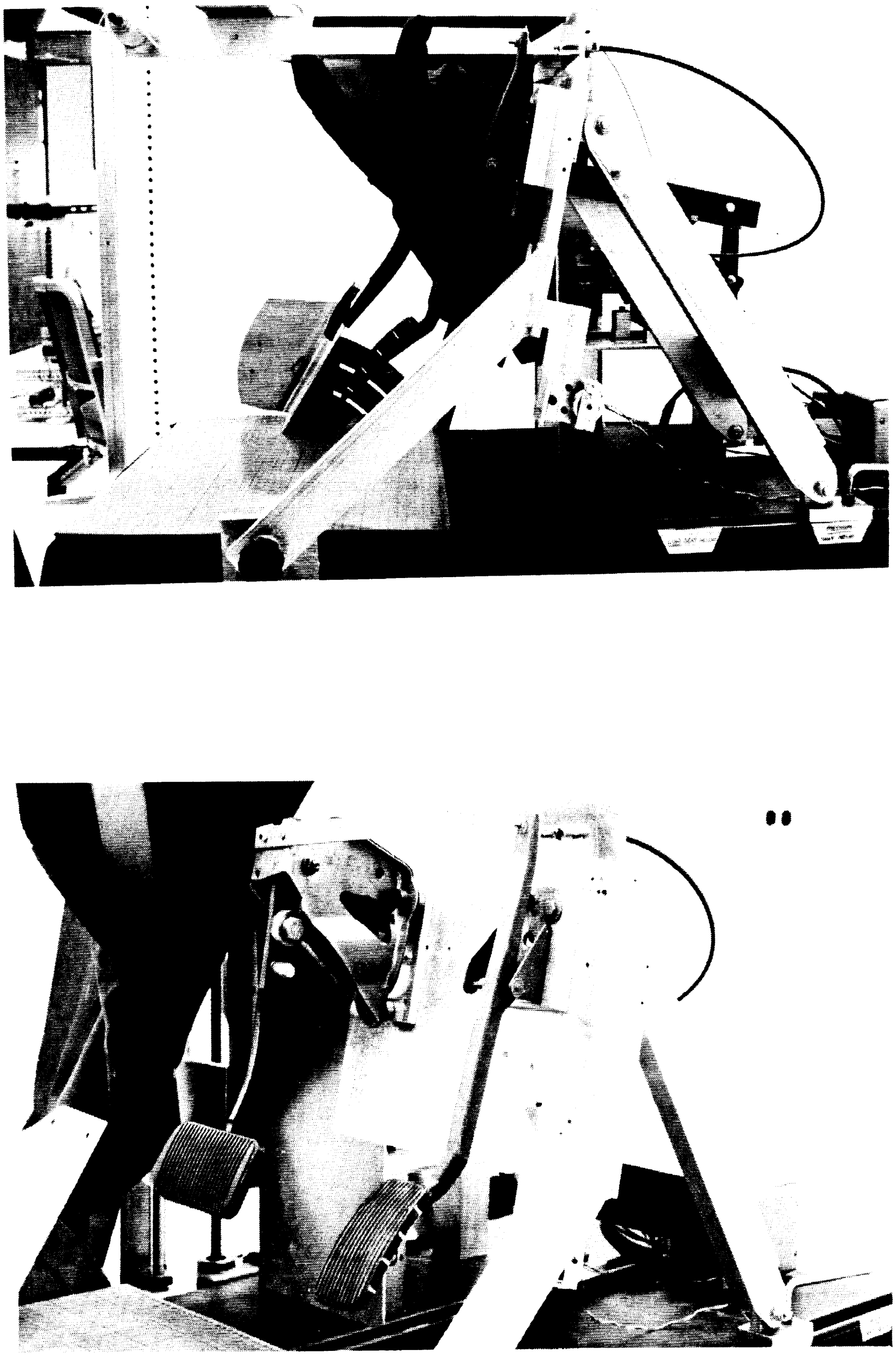


Figure 8. Pedal assembly and support structure.

for each seat height. The pedal mounting plate pivots about an axis that runs laterally through the accelerator heel point (AHP) so that the AHP remains at a fixed location on the buck heel surface for all test conditions. To change the orientation of the pedals between tests, Allen-head bolts are loosened on two unistrut slide assemblies toward the front of the buck, and the slides are translated to a precalibrated position. The pedals are locked in a desired orientation by retightening the Allen-head bolts. Because the brake and accelerator pedal assemblies move as a unit, the relative positions of the brake and accelerator pedals and their stroke lengths are the same for all test conditions.

A switchbox containing the Mercedes power seat controls is mounted on a platform to the right of the seat as shown in Figure 9. Momentary toggle switches provide for the adjustment of the front and back power seat risers to achieve the desired seatpan angles measured using modified legless J826 manikin procedures described in Section B1 of Appendix B. Metric readout scales and pointers are attached to the seat frame to indicate riser positions corresponding to the desired seatpan angles for each test condition. Another toggle switch controls seat cushion length.

Seatback angle and seat front/back position are controlled by two momentary toggle switches located at the front of the control box. The design seat position, based on 95th-percentile seating accommodation position from SAE J1517, is set at 100 mm forward of full rear for all seat heights, leaving approximately 188 mm of travel forward of SgRP for subject seat adjustment. For each seat height, the desired distance of the SgRP from AHP is calculated by subtracting the horizontal distance from Ball-of-Foot (BOF) point to AHP based on the manikin foot angle from J1516 and the 95th-percentile H-point-to-BOF distance from equations in J1517. These values are listed in Table 4 along with the design foot angle from J1516 and the manikin knee, hip, and back angles obtained from generic package drawings for seat heights of 180, 270, and 360 mm.

Adjustment of the incline angle of the Mercedes seat track is accomplished using a tilt mechanism installed between the base of the Mercedes seat track and the seat mounting plate. This mechanism is illustrated in Figure 10a and 10b. The Mercedes seat track is fastened to the seat mounting plate by a hinge at the back and a spring-loaded linkage/roller mechanism at the front. A hand crank behind the seat platform turns a worm gear that moves the roller/linkage and raises or lowers the front of the seat.

Using this mechanism, the seat track incline angle is set to 8 degrees for LOW seat height

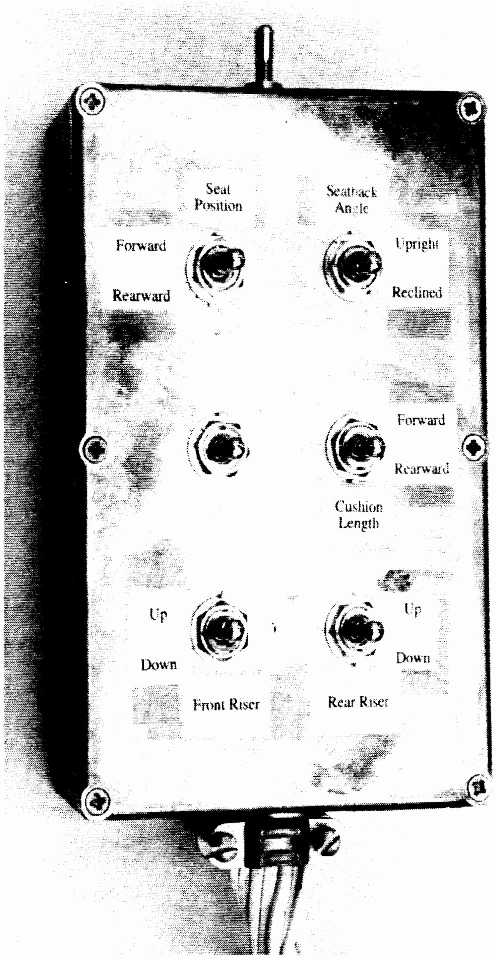


Figure 9. Control module for the Mercedes power seat.

Table 4
J826 Manikin Measurements for Test Seat Heights

Manikin Measurement	Desired Settings		
H30 (mm)	360	270	180
H-Point-to-AHP X-distance (mm)	775	858	904
Foot Angle (deg)	50.5	61.5	70
Knee Angle (deg)	116	126	131
Hip Angle (deg)	95	97	97
Back Angle (deg)	21	24	27

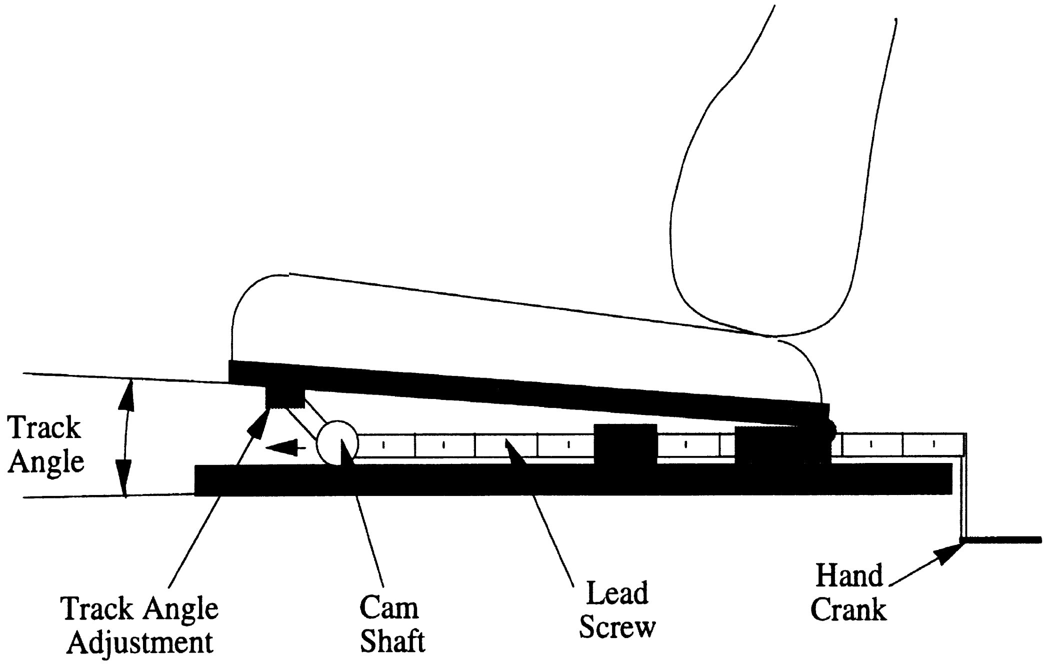


Figure 10a. Illustration of the seat track tilt mechanism.

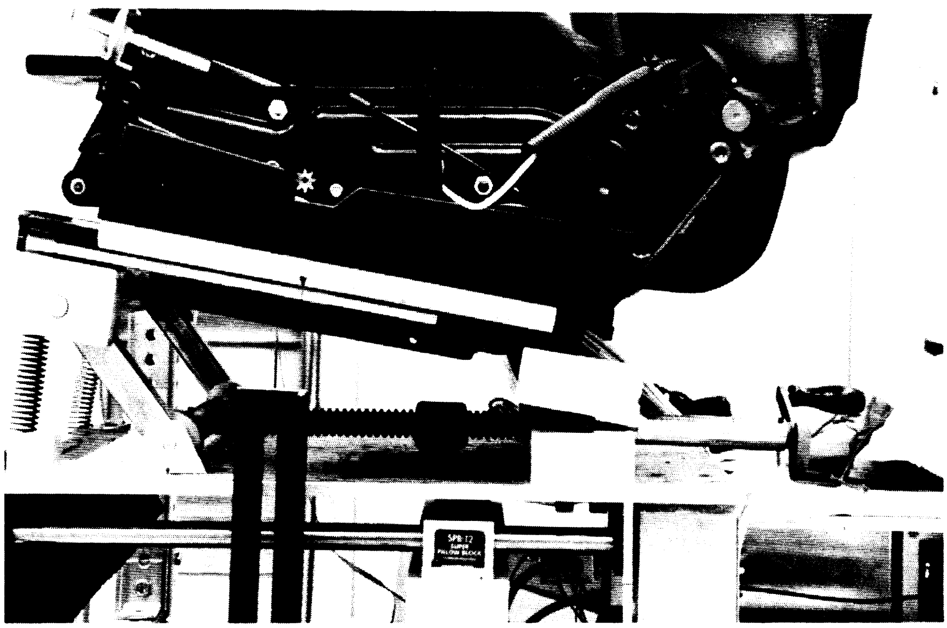


Figure 10b. Seat track tilt mechanism.

configurations, 4 degrees for MID seat height configurations, and 0 degrees for HIGH height configurations, based on general industry practice. Positions of the front and back power seat risers are compensated accordingly to achieve the desired seatpan angles for each seat height.

The two pedal force levels are achieved by using two interchangeable accelerator pedal assemblies and different extension springs on the throttle linkage at the carburetor. One pedal linkage is used as it is designed for production vehicles. The other was modified by inserting Delrin spacers between the pedal linkage and the pivot housing and replacing the production linkage pivot rod with a bolt and locknut, as shown in Figure 11. By tightening or loosening the bolt, changes in both the opening force and the hysteresis force can be achieved.

To measure and calibrate the force-displacement characteristics of the two pedal assemblies, a protractor is attached to the pedal linkage at the linkage pivot point. The pedal is displaced in 1 degree increments of the protractor by pushing a spring force gauge at the center of the pedal. At each increment, the force required to depress the pedal and the force level at which the pedal begins to move back when the force is slowly decreased are recorded. This procedure was used to establish the two force-displacement curves shown in Figure 12. Pedal characteristics were adjusted by tightening the bolt on the Delrin spacer and using different springs on the carburetor linkage. Calibration of the force-displacement curve was repeated regularly during testing to ensure that the force and hysteresis levels remained relatively constant.

The completed seating buck includes an interactive simulated road-scene display to provide a more realistic driving environment while subjects selected their seat position and body orientation for each set of test conditions. Speed and direction of the road scene are controlled though operation of the accelerator and steering wheel by means of rotary potentiometers installed on the steering wheel shaft and on the accelerator pedal linkage at the carburetor assembly. Simulator braking is accomplished by a signal from a load cell mounted in series with the brake pedal linkage. A relatively simple road tracking task is used so that the subjects would not be unduly distracted from the primary task of selecting their preferred position and posture.

In the completed buck, black cloth was draped over most of the hardware and instrumentation to reduce subject distraction. Also, a stairway was constructed for subject entry and exit from the buck seat.

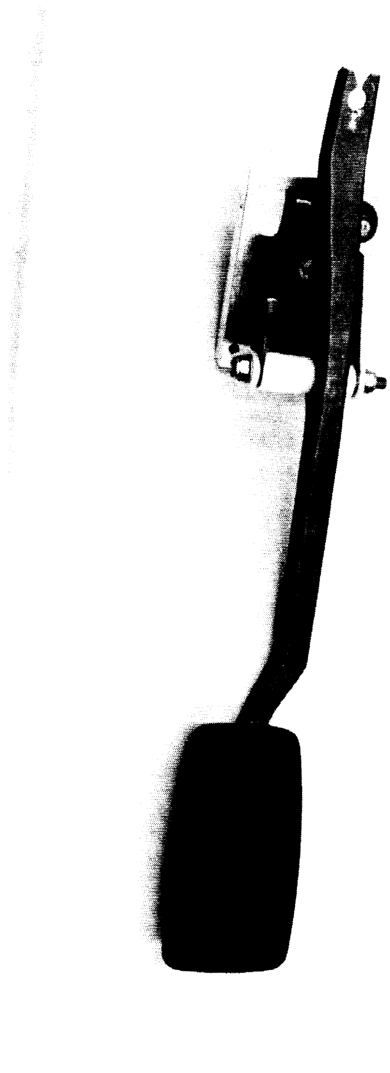


Figure 11. Modified pedal linkage.

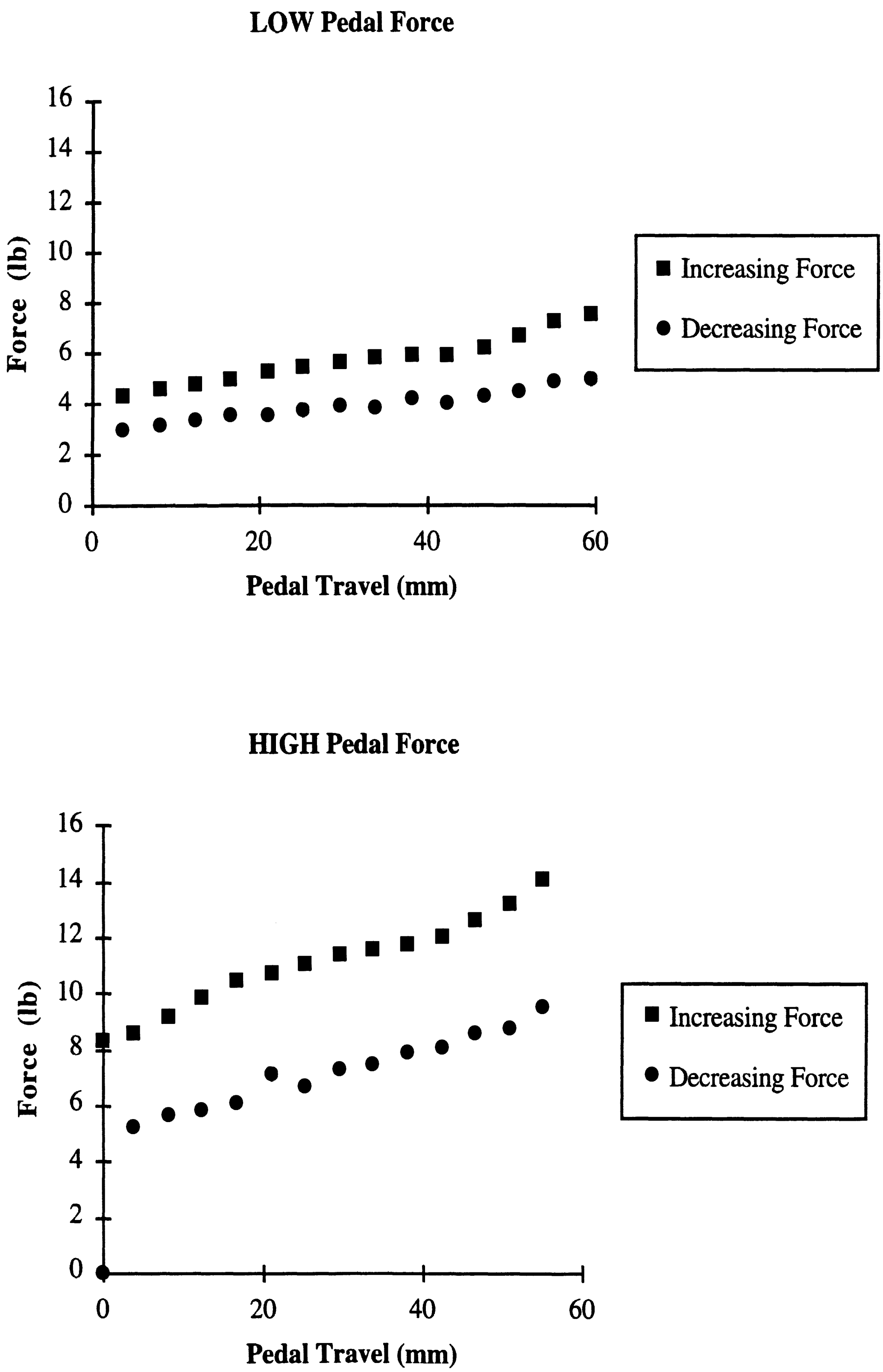


Figure 12. Force-displacement curves for the two pedal linkages.

2.4.2 Instrumentation and Measurement Equipment

The seating buck was equipped with instrumentation, devices, and readout scales required to measure the desired dependent variables during subject testing. Subject selected front/back seat position was measured using a millimeter scale attached to the Mercedes seat base, as shown in Figure 8. Seatback angle was measured using an inclinometer fastened to the back of the seatback frame, as shown in Figure 13. Inclinometer readings for subject-selected seatback angles were converted to values relative to the manikin back angle reading in the design position for each test configuration. Subject-selected seat position readings were converted to distances from BOF based on the H-point-to-BOF distance in the design H-point location at 100 mm forward of the full rearward seat position. The calculations involved in these translations are described in Sections D1 and D2 of Appendix D.

The position of the subject's right heel was determined by noting its location on X-Y coordinate grid lines marked at centimeter intervals on the heel surface of the buck. Figure 14 shows the device used to measure pitch and rotation angles of the subject's right foot while it was positioned on the undepressed accelerator pedal. As shown in Figure 15, the base plate of the device was placed on the heel surface with the longitudinal axis aligned in the buck X direction (i.e., front to back). While maintaining this alignment, the base plate was moved and the two pivoting plates were adjusted so that the right side edge of the right-most plate was aligned against the bottom of the subject's foot (i.e., at the top of the shoe sole). Sections D3 and D4 of Appendix D present further illustrations and more detailed descriptions of heel location and foot orientation measurements.

Subject leg angle was measured using an inclinometer as shown in Figure 16. Figure 17 further illustrates the foot orientation angles and leg angle. Thigh angle was also measured using an inclinometer, as shown in Figure 18, while knee angle was measured by visually aligning two straight edges with the leg and thigh, respectively, as shown in Figure 19. The knee angle was read from the scale of the protractor attached to the device.

During pedal displacement testing (see below), a Penny and Giles goniometer, shown in Figure 20, was used to measure the changes in the subject's right ankle extension/flexion angle. As shown in Figure 21, one end of the goniometer was connected to the subject's right leg just above the ankle by means of medical tape. The other end was connected to the outside of the subject's standard shoe (see Section D7) by means of Velcro.

Figure 13. Incinometer on Mercedes seat used to measure seatback angle.

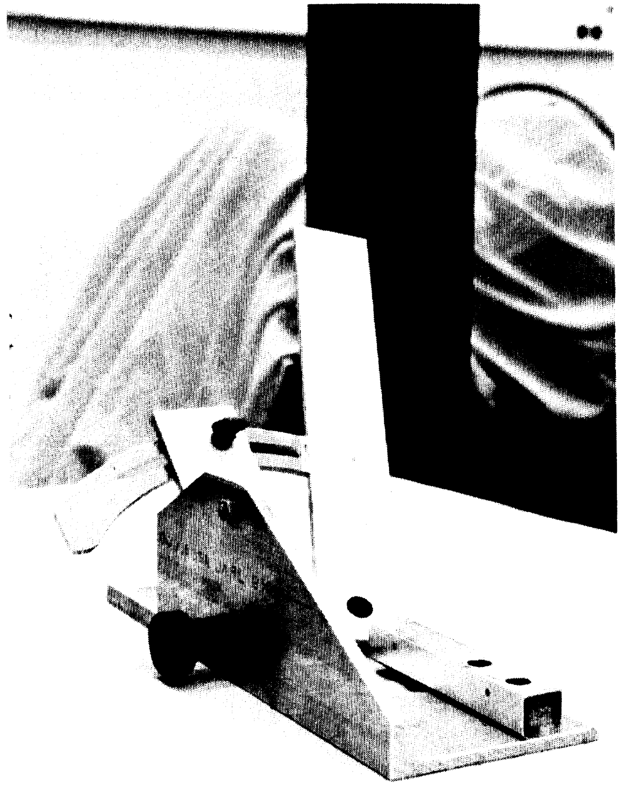


Figure 14. Foot angle measuring device.

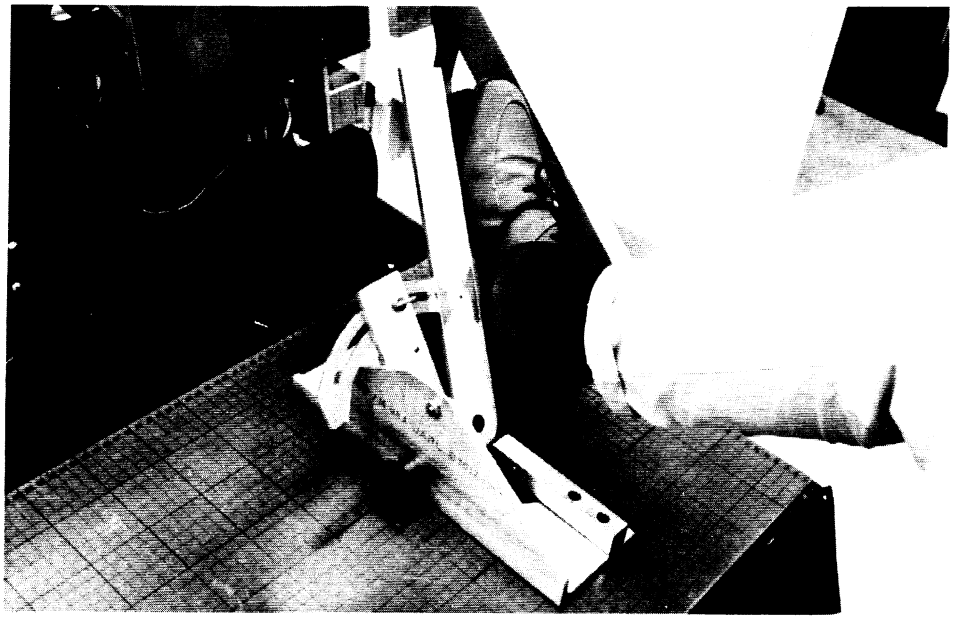


Figure 15. Foot pitch and rotation angle measurement.

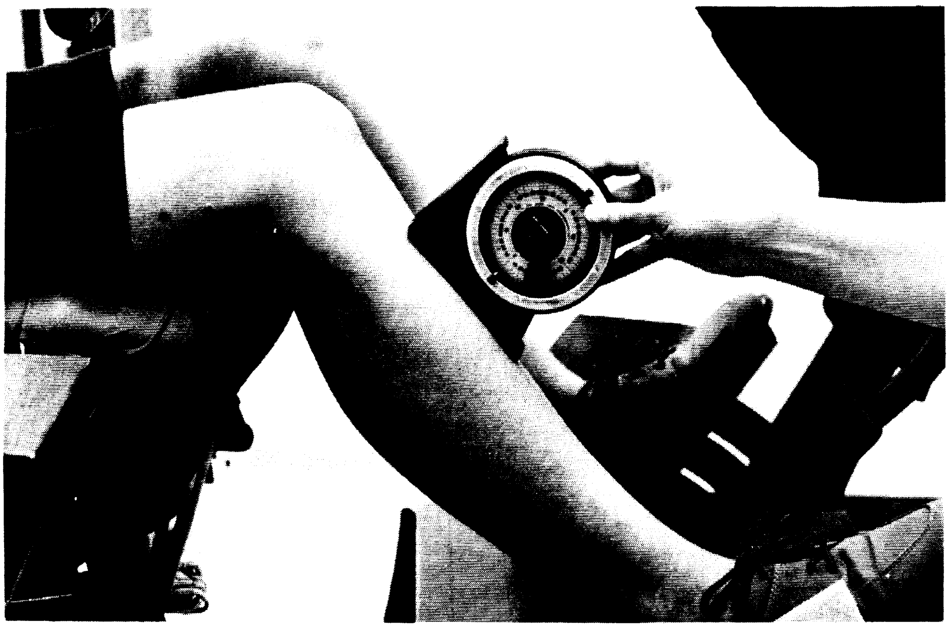


Figure 16. Leg angle measurement.

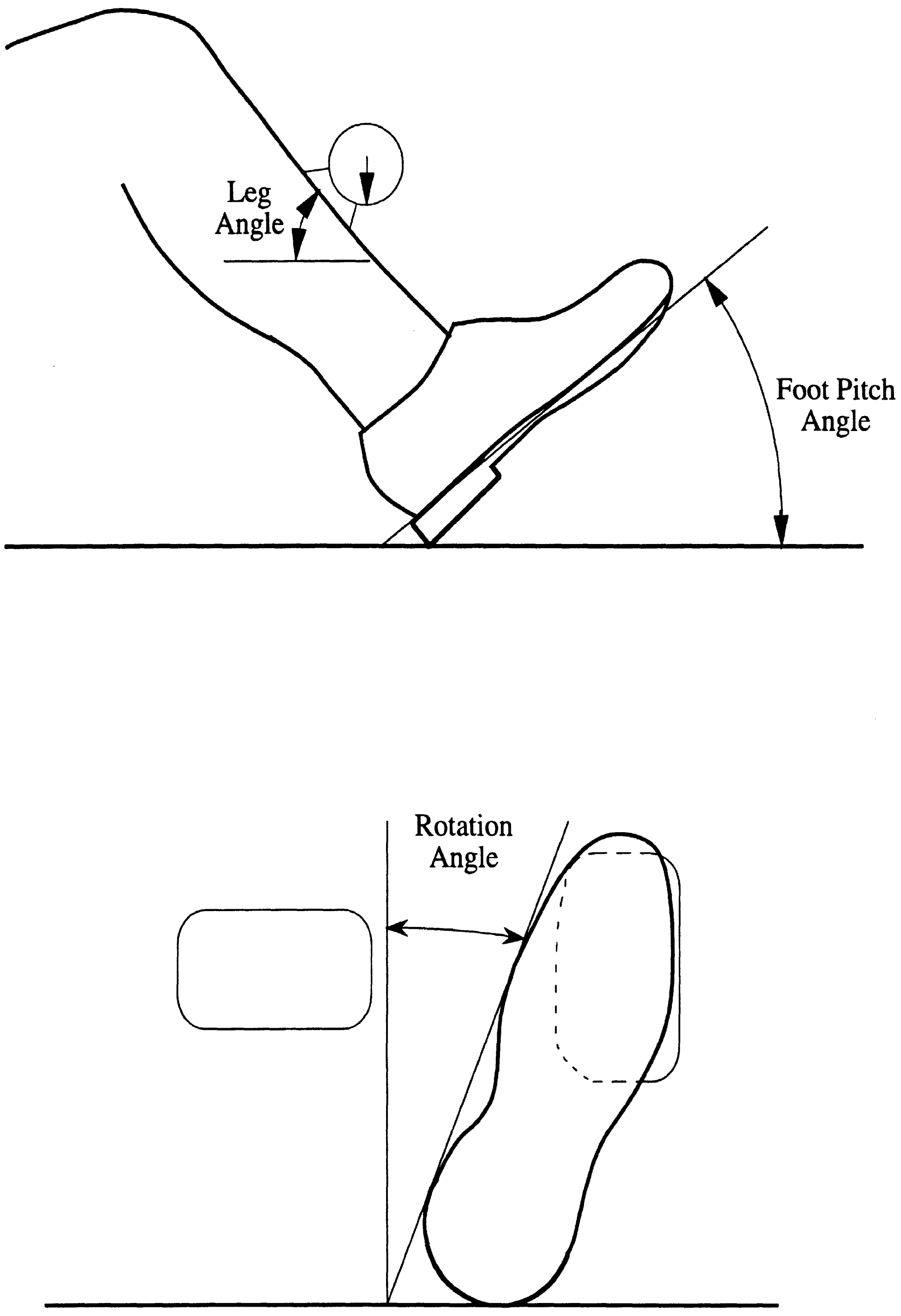


Figure 17. Illustration of foot and leg angles.

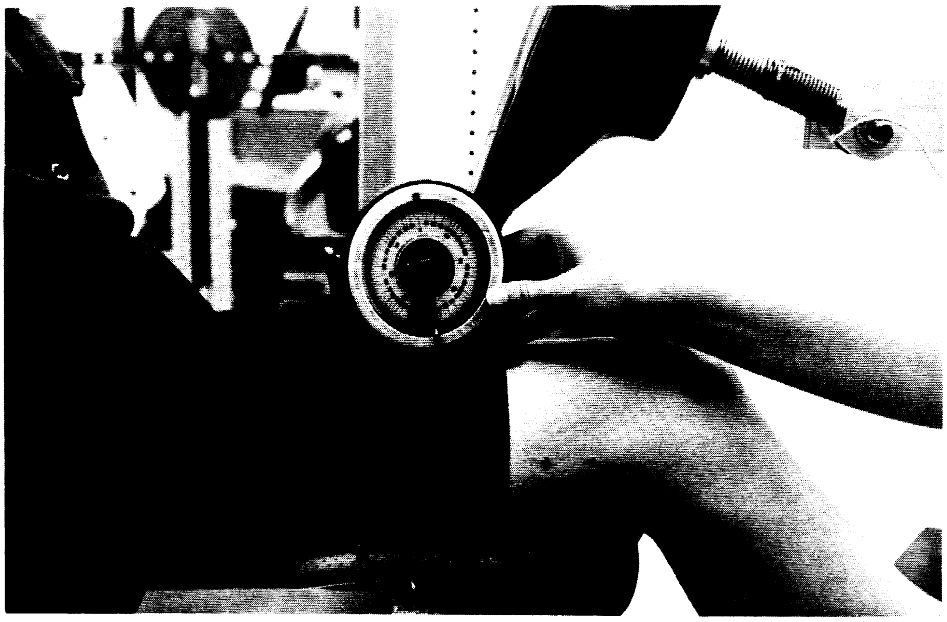


Figure 18. Thigh angle measurement.

Figure 19. Knee angle measurement.

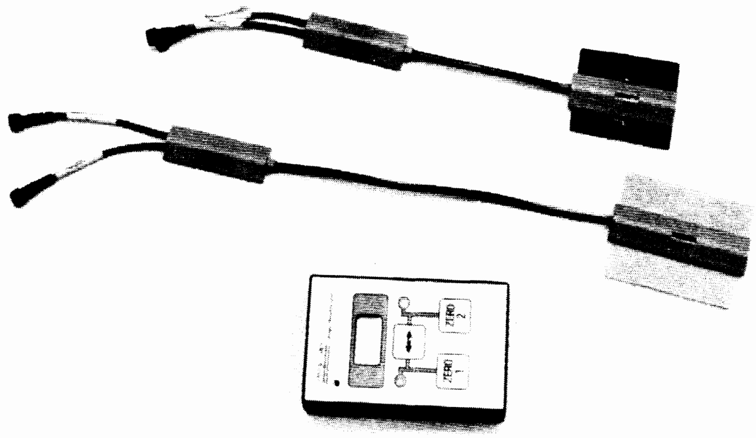


Figure 20. Penny & Giles goniometer and angle display unit.

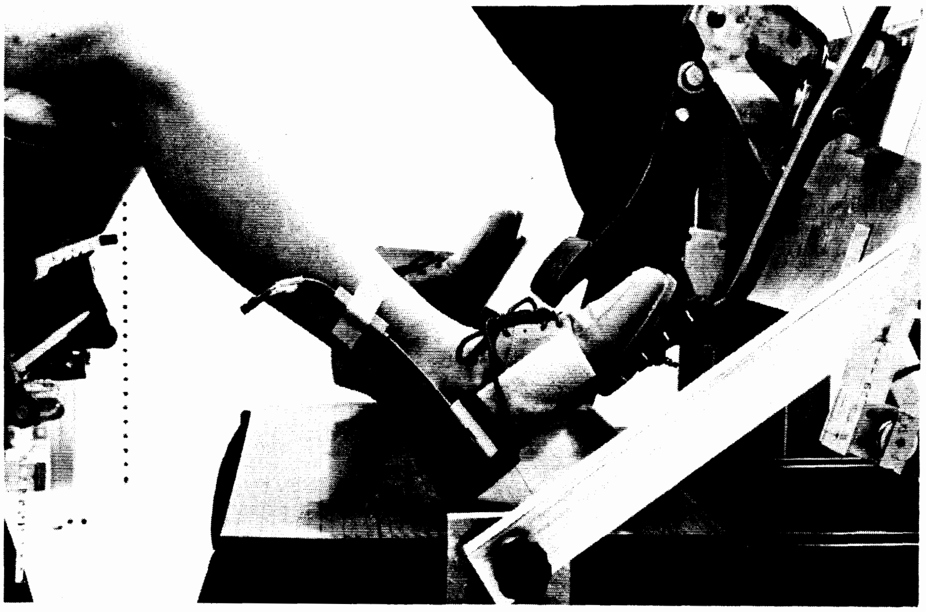


Figure 21. Goniometer attachment to subject's shoe and leg to measure ankle flexion/extension angle.

Measurement of accelerator pedal displacement was accomplished by a string potentiometer mounted to the pedal assembly support plate. The string potentiometer was hooked to the back of the pedal pad, as shown in Figure 22. Pedal displacement measurements were used to calculate the equivalent change in manikin foot angle based on the initial angle for both a 95th-percentile population and 50th-percentile male seat position and manikin leg lengths. Sections D8 and D9 of Appendix D describe the calculations for these conversions.

Downward thigh displacement during MCPD testing was determined using a standard anthropometer to measure the height of the top of the knee with the foot on the undepressed accelerator pedal and with the pedal displaced to the maximum-comfortable position as shown in Figure 23. Thigh pressure applied to the front of the seat cushion during these tests was measured by two force sensing resistors (FSRs) taped to the right of the seat centerline just behind the front edge of the seat, with one FSR behind the other. Sections D5 and D6 in Appendix D contain illustrations and calculations for thigh pressure and thigh displacement.

The force applied by the subject's foot on the accelerator pedal with the ankle and leg relaxed was measured by a cantilever-beam type strain-gauge load cell attached to the back side of the pedal support plate. As illustrated in Figure 24, when the load cell is in position for testing, a bolt threaded through the free end of the cantilevered beam makes contact with the pedal linkage, thereby preventing movement of the pedal and linkage from its undepressed position. During application of force to the pedal, the load cell measures the reactive force at the bolt location on the pedal linkage. By knowing the distance from this point to the pedal linkage pivot point, the applied moment to the pedal linkage can be calculated. Using the distance from the pedal linkage pivot to the point of application of the subject's foot on the pad and to the center of the pad, the measured moment was used to calculate the resting foot force applied by the subject to the pedal and the equivalent resting foot force applied to the center of the pedal pad, respectively. Section D10 of Appendix D describes these force calculations.

Strain gage and load cell output signals were amplified by a set of UMTRI-built instrumentation amplifiers placed under the base platform of the seating buck. The goniometer signal was processed through a Penny and Giles signal conditioning module and the output signal was connected to a signal-conditioning unit that enabled zeroing of the output signal with the foot on the undepressed pedal. All transducer signals were input to a Soltec Model TA200-938 strip chart recorder for subsequent hand analysis to determine values for the dependent test variables.

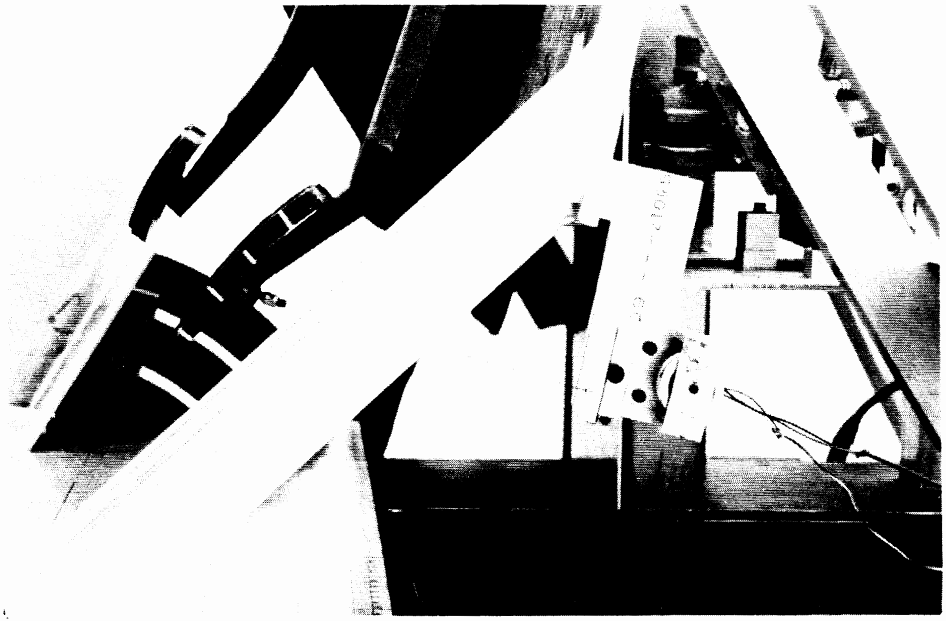


Figure 22. String potentiometer used to measure pedal displacement.

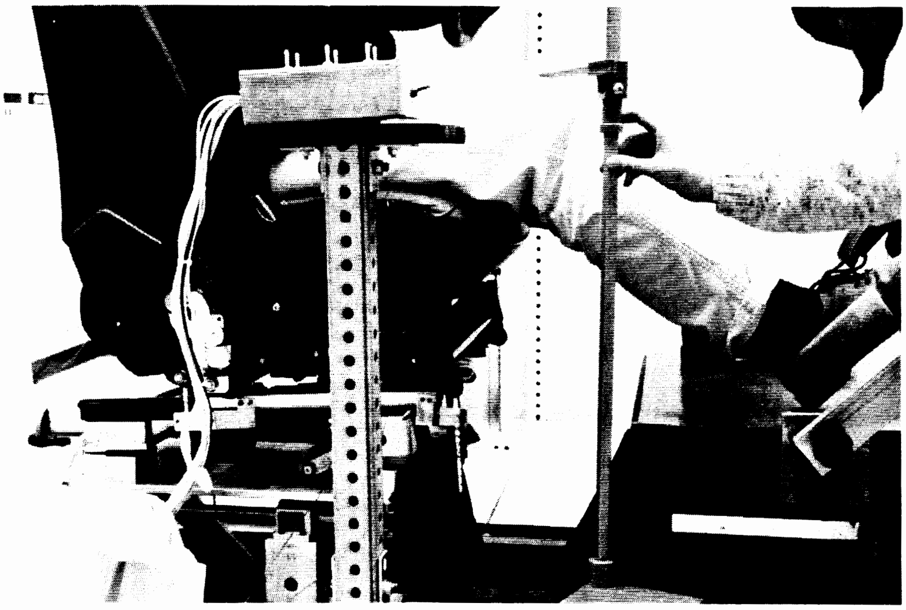


Figure 23. Measured downward thigh displacement.

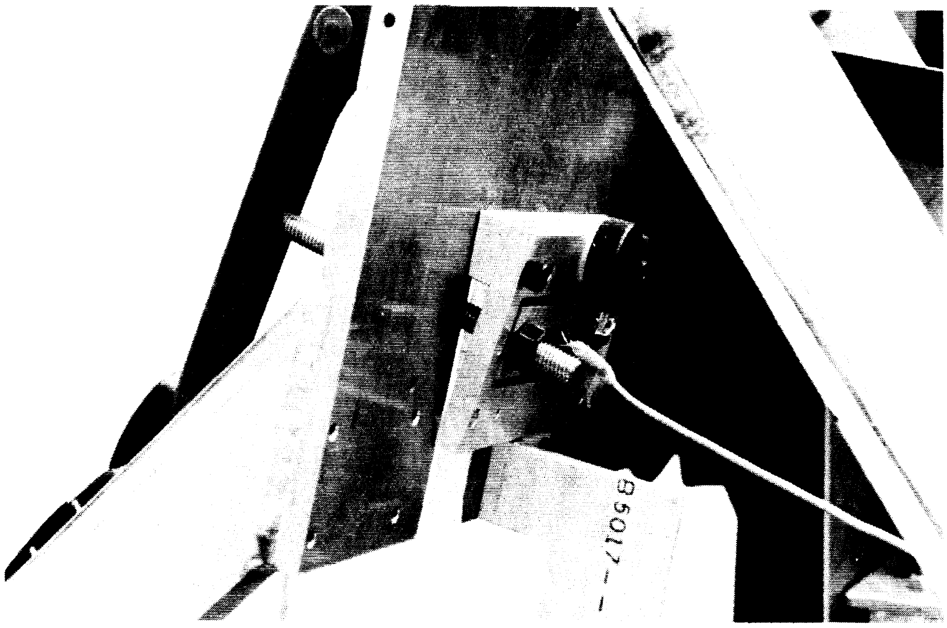


Figure 24. Load cell to measure resting foot force.

2.4.3 H-point Calibrations and Pedal Package Design

Tables 5a and 5b summarize the scale settings and resulting buck, pedal package, and steering wheel dimensions for the vehicle package and seat conditions used in the study. For each seat height, the desired pedal angles are based on examination of Ford package drawings for vehicles spanning the range of test seat heights. Because of the fixed relationship between the brake and accelerator pedals for all test conditions, some compromise to the angles of the brake and accelerator pedal pads at each seat height was necessary. The angle of the curved accelerator pad is defined as the angle of the chord connecting the ends of the top surface of the pad, as shown in Figure 25. Figure 26 illustrates the pedal assembly and its dimensions.

The desired design H-point-to-AHP distances were established for each combination of seat height, cushion angle, and cushion length (12 conditions in all) using the standard J826 procedures and manikin. With the power seat track set at the design position 100 mm forward of full rear, the pedals oriented for the selected seat height, and the seat cushion angle and seat cushion length set to one of the test conditions, the height and front/back

Table 5a
Scale Settings and Resulting Buck Dimensions

Seat Condition	Front Riser Scale	Rear Riser Scale	Seat Platform X Scale	Seat Platform Z Scale	Cushion Length Scale	Resulting Seatpan Angle	Resulting H-Point to AHP Distance		Resulting Cushion Length
							X	Z	
LOW	7	58	72	39	3	9	909	180	460
	0	58	75	29	43	9	901	181	500
	9	0	123	79	3	18	906	182	460
	54	58	66	64	43	18	898	182	500
MID	36	58	171	63	3	9	857	265	460
	0	26	205	70	43	9	857	271	500
	25	0	222	103	3	16	862	273	460
	16	0	227	95	43	16	856	268	500
HIGH	53	58	260	140	3	9	770	357	460
	45	58	263	128	43	9	775	360	500
	27	0	312	173	3	14	781	360	460
	18	0	317	166	43	14	774	359	500

Table 5b
Pedal Package and Steering Wheel Measurements*

Measurement**	Seat Height Low	Seat Height Mid	Seat Height High
Accelerator			
Pedal Pad Angle re Hor.	58.0	49.0	39.5
AHP Plane to Bottom of Pedal Height - H_{ab}	133	113	98
AHP Plane to Center of Pedal Height - H_{ac}	181	167	142
Brake			
Pedal Pad Angle re Hor.	67.0	60.5	48.0
AHP Plane to Bottom of Pedal Height - H_{bb}	168	162	146
AHP Plane to Center of Pedal Height - H_{bc}	209	202	183
Step-over Height (Accelerator to Brake)	61	59	57
Steering Wheel			
Angle re Vertical	22	22	22
Center to AHP Horizontal Distance	531	455	370
Center to AHP Vertical Distance	568	645	727

*All dimensions in mm or degrees
**See Figure 26 for illustration of measurements

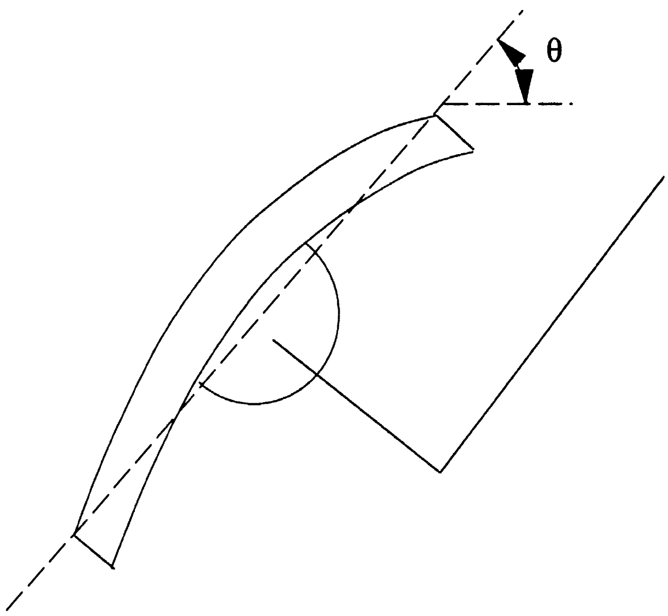


Figure 25. Accelerator pedal angle for curved pad.

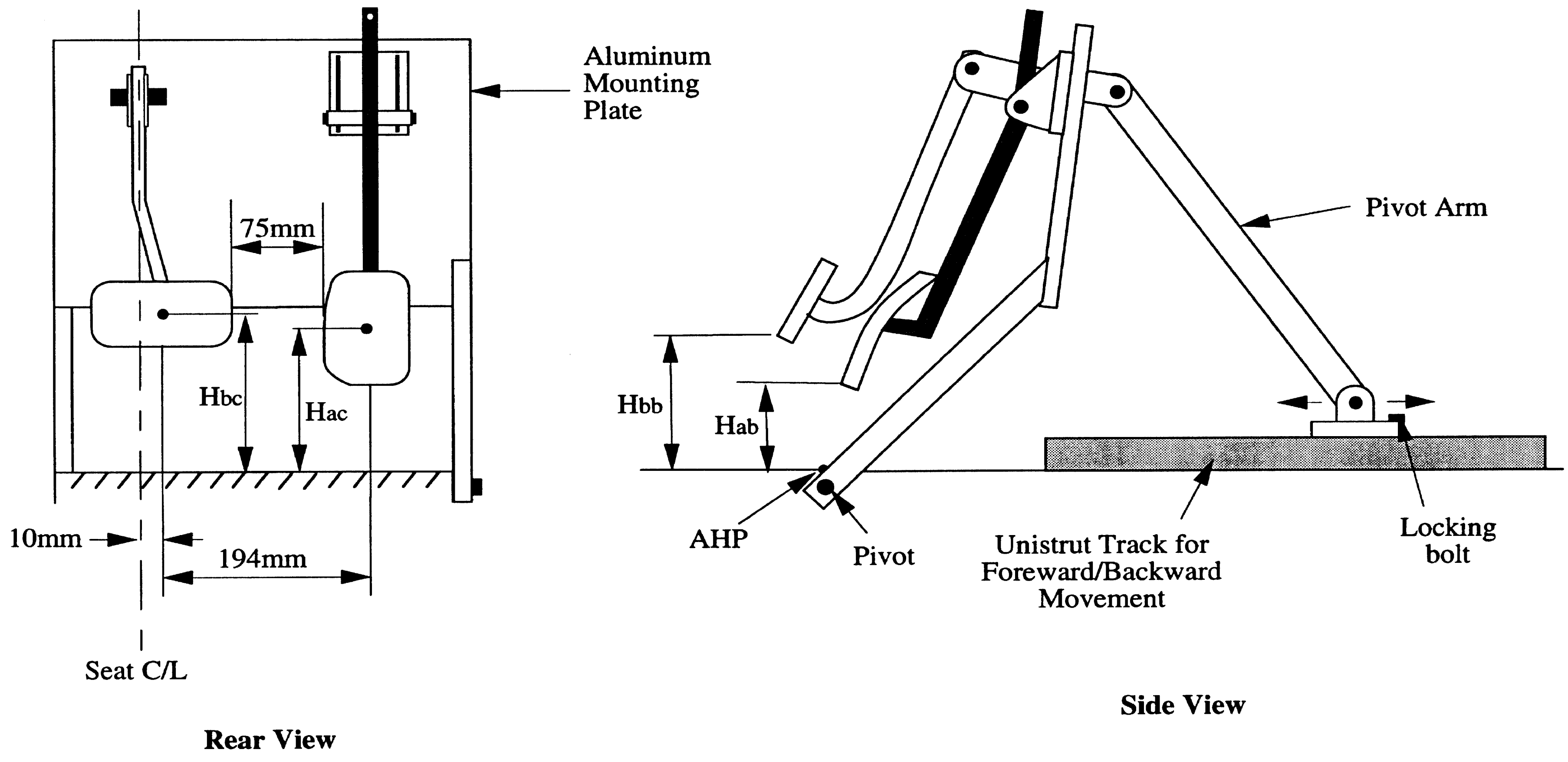


Figure 26. Schematic of the pedal assembly and support structure showing distances in Table 5b.

position of the seat assembly were adjusted to estimated SgRP-to-AHP vertical and horizontal distances using the scissors-jack and front/back adjustment mechanism. After setting the seatback angle to an estimate of the desired design angle (see Table 4), a manikin drop was performed using J826 procedures. The horizontal and vertical distances from the manikin H-point to AHP were then measured and the manikin back angle, hip angle, and knee angle were recorded. Based on differences of SgRP-to-AHP distances from desired, the seat assembly was moved up or down and front or back, and the seatback was adjusted with the manikin in place until distances closer to the desired measures were obtained. The manikin was then removed, the seat was allowed sufficient time to recover to its unloaded contour, and another manikin drop was performed starting with the settings just established. This process was repeated until the desired H-point-to-AHP distances were established. The scale settings on the scissors-jack assembly were then recorded, the seat and pedals were adjusted to another configuration in the test matrix, and the calibration process was repeated. Table 4 and Appendix B present the final results of these calibrations and the corresponding scale settings.

2.5 TEST PROTOCOL

2.5.1 Subject Recruitment, Instructions, and Measurement

Subjects with at least four years of driving experience were recruited through ads in the local newspaper and by word of mouth. Subjects were questioned in a phone interview to determine if they would potentially qualify for one of the unfilled subject groups.

Upon arriving at UMTRI, the subject's stature was measured to confirm his/her original stature estimate. If qualified, the subject was instructed to fill out three forms including a standard consent form explaining the purpose and general nature of the testing, a standard health questionnaire, and an information sheet. Examples of these forms are included in Appendix A. After reviewing the subject's completed forms, the anthropometric measurements listed in Table 6 were taken to provide further information on the subject's body size and proportions.

2.5.2 Selection of Preferred Seat Position and Posture

After completing these measurements, the subject was instructed to select an appropriate size pair of "standardized" shoes to wear during subject testing. A decision to use a standard

Table 6
<u>Anthropometric Measurements</u>

Stature w/o shoes
Weight
Erect sitting height
Shoulder height (sitting erect)
Shoulder breadth
Elbow-hand length
Shoulder-elbow length
Knee height
Buttock-knee length
Buttock-popliteal length
Trochanter-lateral femoral condyle length
Foot Length
Shoe weight
Shoe heel height

walking shoe for all subjects, rather than the subject's own shoes, was based mainly on a need to facilitate attachment of the goniometer transducer across the ankle joint. A strip of Velcro was glued to the outside of the right shoe as shown in Figure 27 so that one end of the goniometer could be easily and securely attached to the shoe. Use of the standard shoes also potentially reduces measurement variability due to shoe and heel characteristics, thereby enhancing the effects of vehicle and seat factors on dependent measures.

After attaching the goniometer to the subject's right leg and shoe, the subject was instructed to enter the seating buck, which had been previously configured to the first, randomly selected set of test conditions with the seat and seatback angle in their design positions, and the accelerator pedal connected to the throttle assembly so that pedal travel was similar to that of a Taurus vehicle (approximately 53 mm). The subject was instructed on how to make adjustments in the seat front/back position and seatback angle using two toggle switches on the control panel to the right of the seat. To prevent the subject from inadvertently altering the seat cushion length or seat cushion angle, other toggle switches on the control box were covered with a foam pad as shown in Figure 28.

The driving simulator display was turned on and the subject was instructed to follow the road and to maintain a speed of approximately 55 mph while adjusting the seat and seatback angle to his/her preferred positions. Figure 29 shows a subject seated in the buck with the simulator display turned on. Each subject was encouraged to make many adjustments and to try positions forward and rearward of acceptable locations before selecting his/her preferred

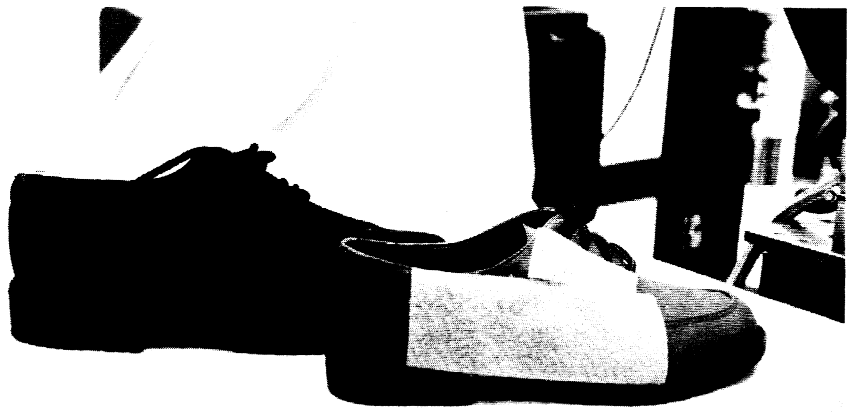


Figure 27. “Standardized” shoe worn by subjects during testing

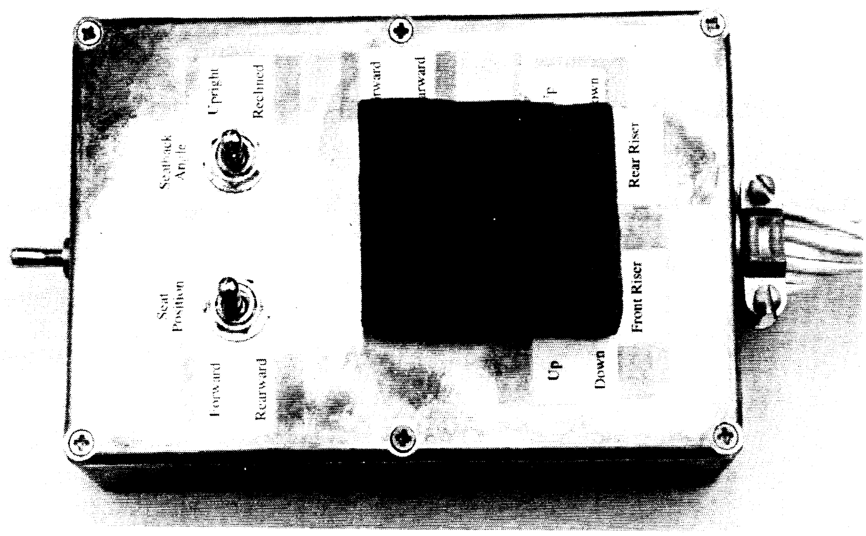


Figure 28. Control module for Mercedes seat with foam pad to prevent subject adjustment of cushion angle and cushion length.

Figure 29. Subject in seating buck with interactive driving display.

positions. The subject was also encouraged and reminded to assume a relaxed and normal driving posture with his/her feet and legs positioned as he/she would do when actually driving a vehicle.

When the subject indicated that the seat and seatback angle were appropriately located for the test configuration, the simulator display was turned off and the subject was instructed to maintain his/her driving posture and feet positions while the measurements listed in Table 7 were taken. The X and Y grid coordinates of the subject's right heel were noted and marked with self-adhesive labels for future reference.

Table 7
Body Position and Posture Measurements

Measurement	Measurement Technique
Seat Position - front/back	Scale on seat track
Seatback angle	Inclinometer on seatback
Right heel location	Grid on heel surface
Foot pitch angle	Foot angle measuring device
Foot rotation angle	Foot angle measuring device
Leg angle	Inclinometer
Knee angle	Adjustable protractor
Thigh angle	Inclinometer

With the subject maintaining this position and posture, measurements of maximum-comfortable pedal displacement and resting foot force were made using the procedures described in Sections D9 and D10 of Appendix D.

2.5.3 Testing for Maximum-Comfortable Pedal Displacement (MCPD)

For this phase of testing, the accelerator throttle cable was disconnected from the top of the pedal linkage and replaced by a spring attached to an eye bolt on the mounting plate, as shown in Figure 30. The spring replicated the force in either the LOW or HIGH pedal condition, as appropriate, but this setup allowed the accelerator pedal to be depressed significantly beyond the production limit of the throttle assembly. In this way, maximum-comfortable pedal excursions could be studied without the limitation of current vehicle designs.

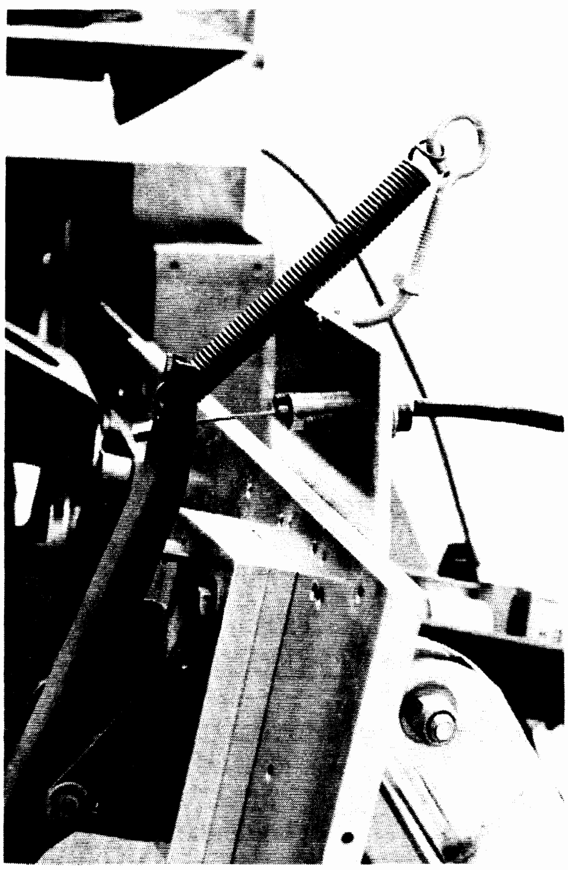


Figure 30. Spring attachment allowing extended pedal travel.

Prior to collecting data on maximum-comfortable pedal displacements (MCPDs), the subject was instructed to operate the accelerator pedal through a maximum pedal displacement (MPD) in order to provide a reference for the subject prior to performing maximum-comfortable pedal displacements. The subject was told to depress the pedal as far as possible using extension of the ankle while keeping the heel on the floor, and was instructed not to consciously extend the knee joint or to use any upper body effort in operating the pedal.

After practicing this motion a few times, the subject performed one MPD test while the output signals from the goniometer, the two FSR units on the seat, and the string potentiometer connected to the back of the pedal pad were recorded on strip chart paper.

The subject was next instructed to operate the accelerator through the maximum displacement that he/she considered comfortable using the same general guidelines as for the MPD (i.e., heel stays on floor, no knee extension, etc.). After the subject practiced this movement a few times, three repetitions were performed while transducer signals were recorded on strip chart paper. Immediately after completing these three maximum-comfortable pedal displacement, an additional repetition of this test was performed by the subject while the investigator manually measured the downward thigh displacement and change in knee angle. The investigator also visually observed and recorded the distance that the right heel slid on the grid.

2.5.4 Testing for Resting Foot Force

After completing the MCPD tests, the spring was removed from the top of the pedal linkage and the load cell was installed on the back of the pedal mounting plate as previously described. With the subject's foot still removed from the accelerator pedal, the no-load output voltage from the load cell was recorded on the strip chart. The subject was then instructed to position his/her right heel at the position chosen during the drive simulation, to lift his/her foot off the pedal pad slightly, and then to relax the leg and ankle muscles allowing the foot to make contact with the pedal pad surface. With the foot relaxed on the pedal, the voltage from the load cell was recorded on the strip chart. The effective resting foot force applied at the center of the accelerator pedal pad was computed from the difference in force reading with the pedal unloaded and the steady-state force after foot contact, and the location of primary shoe contact with the pedal. Section D10 of Appendix D describes and illustrates these calculations.

After completing resting foot force measurements, the goniometer cable was disconnected and the subject was instructed to exit the seating buck. While the subject was distracted and relaxing with reading materials, the investigator reconfigured the seating buck to the next randomly selected set of test conditions in the test session. The subject then reentered the buck, the simulator display was turned on, and the process was repeated.

2.6 DATA PROCESSING AND ANALYSIS

As indicated in the protocol above, data were collected during subject testing using manual readout of scales (e.g., seat position, seatback angle, heel location) and strip chart recordings of transducer signals (e.g., FSR pressure sensors, load cell, goniometer signals). The latter were manually processed soon after a subject was tested to determine peak values for the dependent variables. These results were combined in a computer file with the manually recorded data to provide a complete data set for each subject. Values for repeated measures of pedal displacement, ankle extension angle, etc. were averaged and results of these and other measures were used to compute values for other dependent variables as documented in Appendix D.

3. RESULTS

As indicated in Section 1, the primary goal of this study was to measure resting foot force (RFF) and maximum-comfortable (accelerator) pedal displacements (MCPDs) under simulated driving conditions for a population of subjects that spans 95 percent of U.S. male and female drivers by stature. This section presents and compares RFF and MCPD results obtained by testing the sample population of 48 male and female subjects at three different seat heights, two seatpan angles, two cushion lengths, and two accelerator pedal force levels. Prior to presenting these results, however, the anthropometric characteristics of the subject populations and the results for driver-selected seat, foot, and leg positioning are described.

Appendix E contains tables and bar graphs that compare the mean values, standard deviations, and ranges of all dependent variables for each of the 24 test conditions, including those calculated from measured data. Prior to using analysis of variance (ANOVA) and cross-correlation techniques to examine the relationships between dependent and independent variables, comparisons are made between the overall mean values of dependent variables for the different levels of an independent variable (e.g., 3 levels of seat height, 2 levels of seatpan angle, etc.). In these cases, the term ***overall*** is used to imply that the data have been averaged for all subjects and all test configurations containing a particular level of the independent variable.

For example, to examine the effect of seat height on resting foot force, each subject's mean resting foot force value for the three trials at each test configuration was first calculated. These average subject values for the 24 subjects tested at each of the eight test configurations with LOW, MID, and HIGH seat heights, respectively, were then averaged to give *overall* mean values of RFF at LOW, MID, and HIGH seat heights. For example, RFF results for conditions A1-A4 and B1-B4 (see Table 2) were averaged to obtain the LOW-seat-height *overall* mean value. Note that the number of data points used to determine the *overall* mean value at each seat height is 192 (24 subjects x 8 test configurations at each seat height), but for the other independent variables it is 288 (e.g., since there are only two levels of seatpan angle, the sample size for the *overall* mean is 24 subjects x 12 test configurations at each seatpan angle level).

In all bar graphs presented in this report, the height of each bar is the mean or overall mean value and the bracket on each bar shows ± 1 standard deviation about the mean (not the standard error). The value of the mean is also printed at the top of each bracket.

3.1 ANTHROPOMETRY OF THE SAMPLE POPULATIONS

Table 8 presents the mean values and standard deviations of the anthropometric measurements for each stature/gender group, all females, all males, and all subjects combined. Figure 31a through 31c show bar plots of these results for stature and weight, while Figures C1-C15 show bar plots of all the measurements. Subject age ranges between 20 and 70 years, with an overall mean age of 41.8 years. Individual subject anthropometry is given in Appendix C. Appendix C also contains a list of vehicles owned or operated by each subject at the time of the study.

As previously noted, half of the subjects in each stature/gender group completed the A test conditions and half completed the B test conditions. Comparison of the mean anthropometric values for group A subjects to those of group B subjects is presented in Table 9. Although significant differences exist for some of the measures and some of the groups when compared by subject group (n=4), the results are generally in excellent agreement when compared by all males or all females (n=12), or all subjects (n=24), indicating that Group A and Group B subject populations are anthropometrically the same. Figure 32 compares the distributions of stature for Group A and Group B subjects. It will be noted that there is some difference in the shapes of the stature distributions of Group A and Group B subjects, but these differences are not considered significant with regard to the results of the primary dependent measurements.

3.2 SEAT POSITIONS AND SEATBACK ANGLE

3.2.1 Distributions and Results by Stature

Figures 33a and 33b show distribution histograms of H-Point-to-BOF distance from all subjects and all test conditions at each seat height (n = 192) and each seatpan angle (n = 288), respectively. The seat position distributions are seen to be censored at the front end of the track in spite of the relatively large amount of track travel provided by the Mercedes seat (i.e., 188 mm forward of SgRP and 100 mm rearward of SgRP). In spite of this one-sided censoring in the seat position results, the differences between the mean and median seat positions are minimal, as shown in Table 10. It is also noted that, as expected, the distributions and mean seat position values shift rearward with lower seat heights.

Figure 34 contains plots of overall mean H-Point-to-BOF distance for the six different stature/gender groups (n = 192/6 = 32 for each group) at each seat height. As expected, the mean distance increases with the mean stature of the group.

Table 8: Subject Anthropometry Summary

Group	n	Stature without Shoes (mm)		Stature with Shoes (mm)		Weight (lbs)		Forearm Length (mm)		Arm Length (mm)	
		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1	8	1524	27	1548	27	124	26	421	11	335	17
2	8	1604	24	1629	25	151	16	436	14	350	9
3	8	1689	17	1713	19	162	31	462	14	371	11
All Females	24	1605	72	1630	72	146	29	439	21	352	19
4	8	1646	12	1669	15	156	11	453	12	347	11
5	8	1749	22	1776	20	179	22	498	23	385	19
6	8	1833	38	1859	34	190	13	508	9	395	13
All Males	24	1743	82	1768	83	175	21	486	29	376	26
All Subjects	48	1674	103	1699	104	160	29	463	34	364	25

Group	n	Erect Sitting Height (mm)		Erect Shoulder Height (mm)		Shoulder Breadth (mm)		Knee Height (mm)		Buttock-Knee Length (mm)	
		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1	8	806	26	539	16	391	22	471	19	553	20
2	8	846	23	574	19	404	12	497	12	587	24
3	8	871	28	597	26	416	23	535	11	618	20
All Females	24	841	37	570	31	403	21	501	30	586	34
4	8	863	22	586	20	439	17	515	19	586	17
5	8	880	27	602	22	437	16	551	15	635	14
6	8	945	38	644	26	461	19	574	20	645	16
All Males	24	896	46	610	33	446	20	547	31	622	30
All Subjects	48	868	50	590	38	425	30	524	38	604	37

Group	n	Trochanter-Lateral Femoral Condyle Length (mm)		Buttock-Popliteal Length (mm)		Foot Length (mm)		Shoe Weight (gm)		Age (yrs)	
		mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1	8	379	19	455	20	232	7	312	85	48	19
2	8	397	26	486	20	240	9	255	113	42	16
3	8	429	17	507	25	253	4	340	85	36	13
All Females	24	401	29	483	30	242	11	284	85	42	16
4	8	400	23	473	23	256	7	397	142	40	19
5	8	433	22	517	15	273	9	482	227	52	18
6	8	438	21	523	20	278	8	539	227	35	15
All Males	24	424	27	505	30	269	12	482	198	42	18
All Subjects	48	413	30	494	32	255	18	397	170	42	17

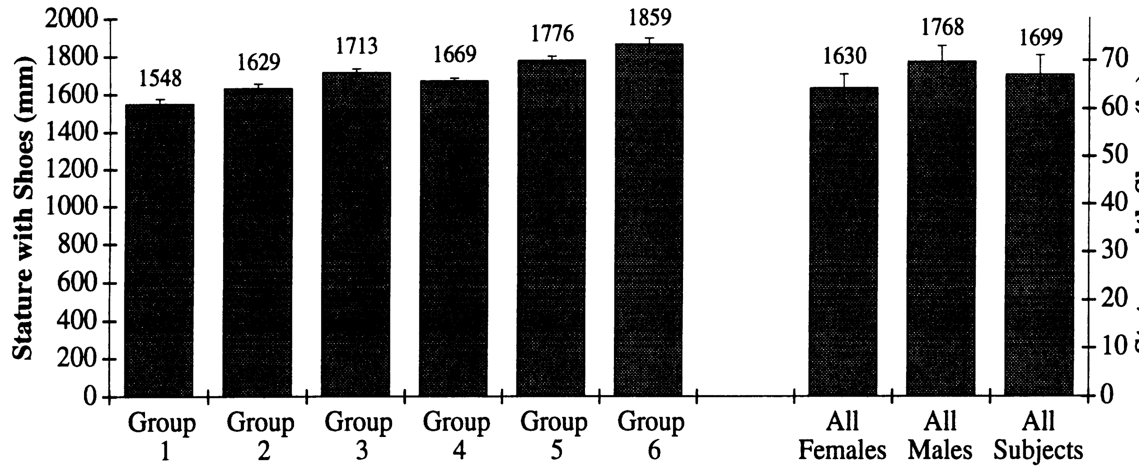


Figure 31a. Mean values and standard deviations of stature with shoes by subject group.

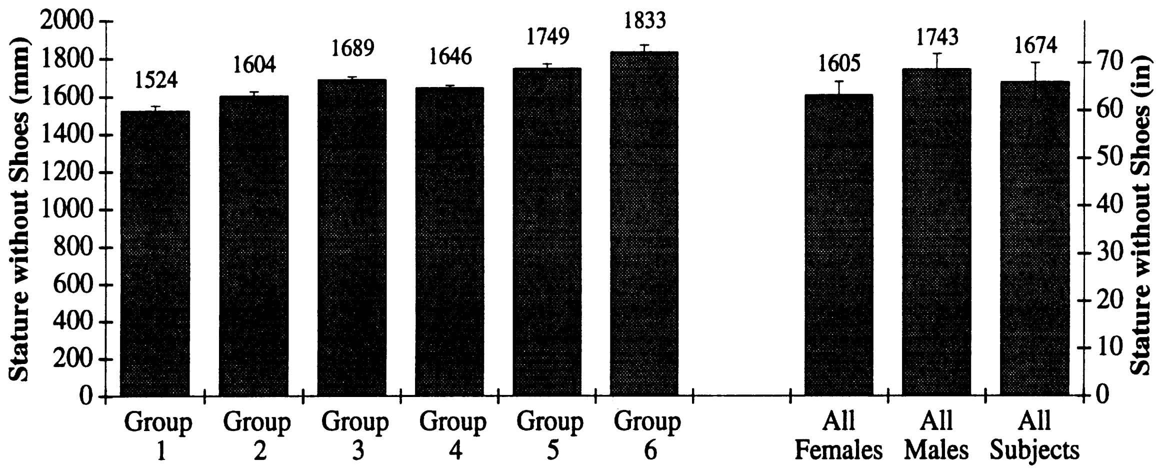


Figure 31b. Mean values and standard deviations of stature without shoes by subject group.

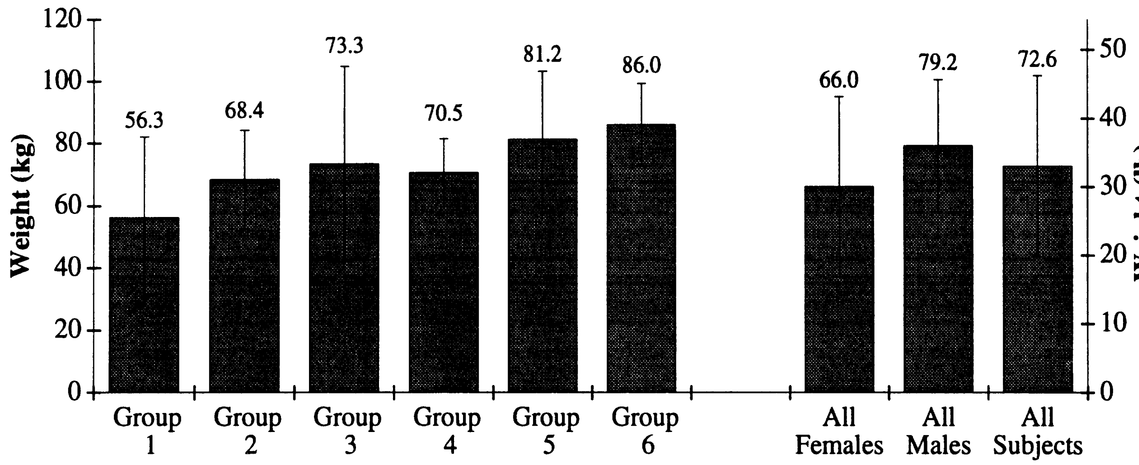


Figure 31c. Mean values and standard deviations of weight by subject group.

Table 9
Comparison of Group A and B Anthropometry Mean Values

Group	n	Stature w/ Shoes (mm)			Stature w/o Shoes (mm)			Weight (lbs)		
		A	B	diff	A	B	diff	A	B	diff
1	4	1551	1545	-6	1529	1519	-10	136	112	-25
2	4	1640	1618	-22	1614	1593	-21	151	151	0
3	4	1705	1720	15	1681	1697	16	170	153	-17
All Females	12	1632	1628	-5	1608	1603	-5	152	139	-14
4	4	1664	1673	9	1645	1647	2	155	156	2
5	4	1773	1779	5	1747	1752	5	190	169	-21
6	4	1859	1859	-1	1832	1834	2	193	186	-7
All Males	12	1765	1770	5	1741	1744	3	179	170	-9
All Subjects	24	1699	1699	0	1675	1674	-1	166	154	-11

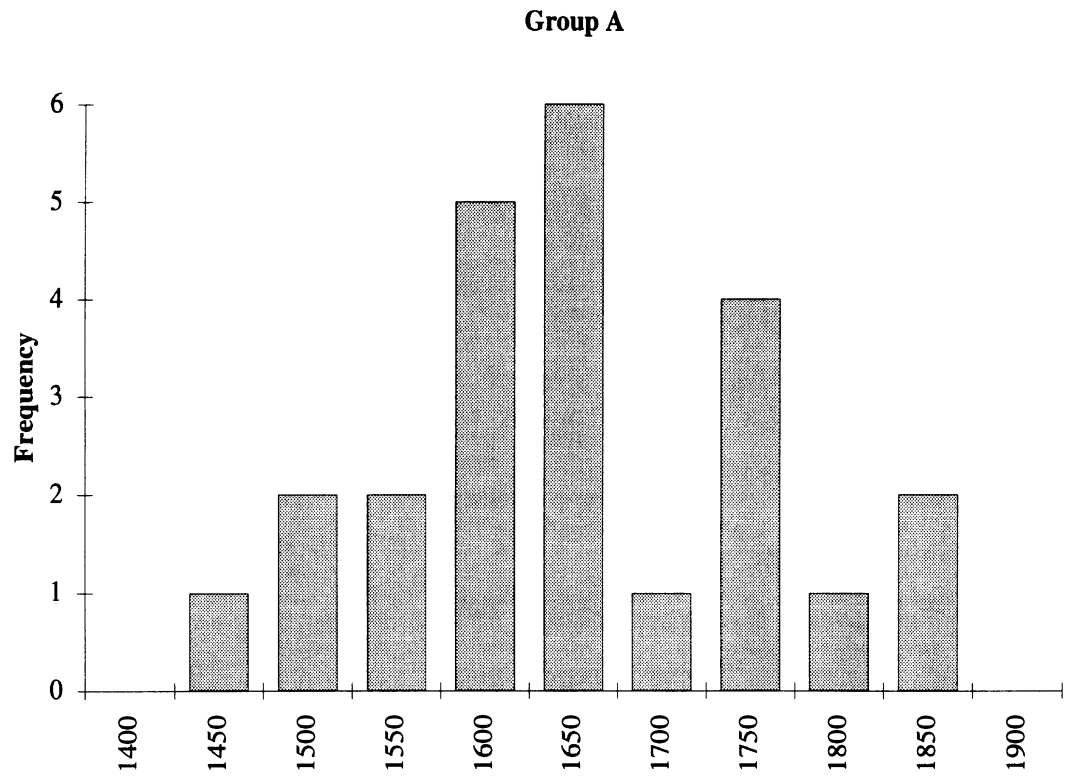
Group	n	Forearm Length (mm)			Arm Length (mm)			Erect Sitting Height (mm)		
		A	B	diff	A	B	diff	A	B	diff
1	4	415	428	13	327	344	17	806	788	-18
2	4	437	434	-4	352	348	-5	846	851	5
3	4	465	459	-6	371	372	2	871	879	8
All Females	12	439	440	1	350	354	5	841	839	-2
4	4	453	453	0	351	343	-8	863	868	5
5	4	487	508	21	384	385	1	880	869	-10
6	4	513	503	-10	396	395	-2	945	951	6
All Males	12	484	488	4	377	374	-3	896	896	0
All Subjects	24	462	464	3	363	364	1	868	868	-1

Group	n	Erect Shoulder Height (mm)			Shoulder Breadth (mm)			Knee Height (mm)		
		A	B	diff	A	B	diff	A	B	diff
1	4	546	532	-15	399	384	-15	463	479	16
2	4	571	577	6	396	411	16	503	492	-11
3	4	595	599	4	421	410	-11	537	534	-3
All Females	12	571	569	-2	405	402	-3	501	502	1
4	4	586	587	1	428	450	22	517	513	-4
5	4	612	591	-22	437	437	-1	545	558	13
6	4	639	649	10	455	467	13	580	568	-12
All Males	12	612	609	-3	440	451	12	547	546	-1
All Subjects	24	591	589	-3	423	427	4	524	524	0

Table 9 (cont'd)
Comparison of Group A and B Anthropometry Mean Values

Group	n	Buttock-Knee Length (mm)			Buttock-Popliteal Length (mm)			Trochanter-Lateral Femoral Condyle Length (mm)		
		A	B	diff	A	B	diff	A	B	diff
1	4	552	554	2	453	456	3	368	390	22
2	4	594	580	-14	496	476	-20	399	395	-4
3	4	624	613	-10	511	503	-8	421	437	15
All Females	12	590	582	-8	487	478	-8	396	407	11
4	4	591	582	-10	470	476	6	409	391	-18
5	4	635	634	-1	516	518	2	437	430	-7
6	4	648	643	-5	522	525	2	453	424	-29
All Males	12	625	619	-5	503	506	3	433	415	-18
All Subjects	24	607	601	-6	495	492	-3	414	411	-4

Group	n	Foot Length (mm)			Shoe Weight (gm)			Age (yrs)		
		A	B	diff	A	B	diff	A	B	diff
1	4	231	234	4	284	340	56	10	12	2
2	4	242	238	-4	170	312	142	6	11	6
3	4	253	254	1	312	340	28	11	12	1
All Females	12	242	242	0	255	340	85	9	12	3
4	4	254	258	4	340	454	114	12	16	4
5	4	269	278	9	537	425	-112	19	15	-3
6	4	280	275	-5	537	567	30	19	20	1
All Males	12	268	270	3	454	482	28	16	17	1
All Subjects	24	255	256	1	369	397	28	13	14	2



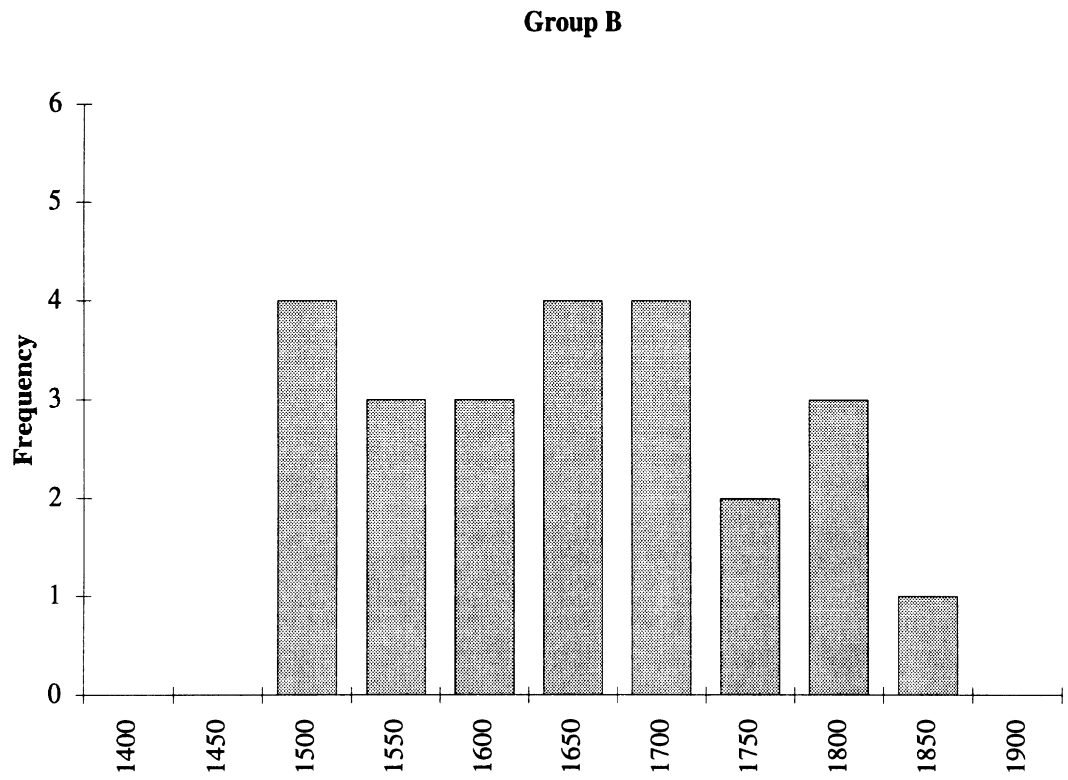
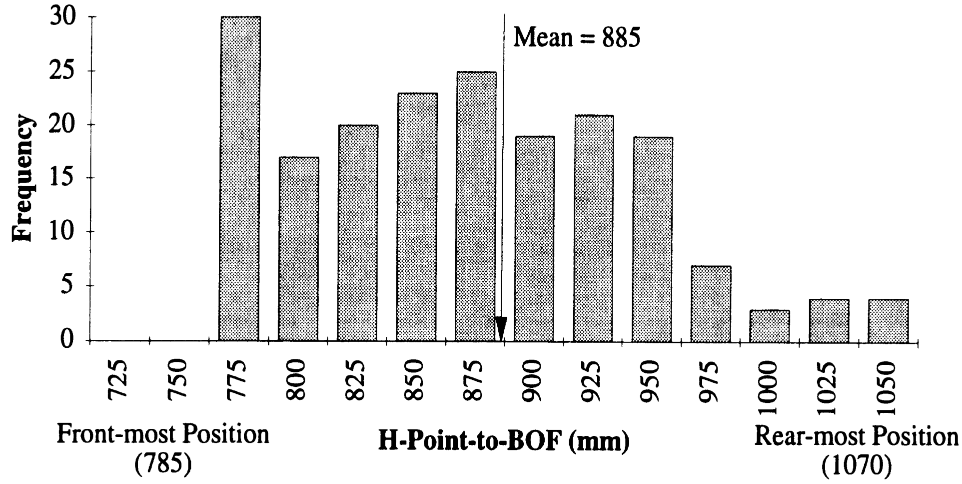
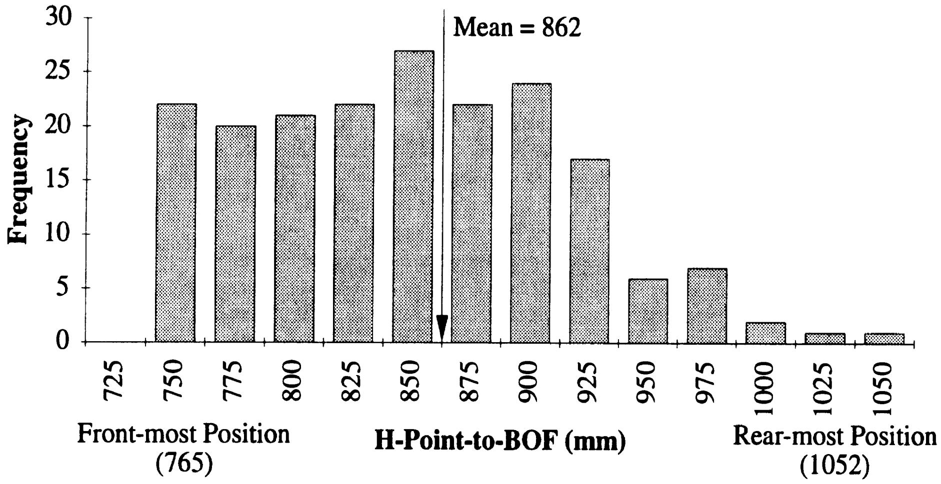


Figure 32. Stature distributions for group A and group B subjects.

LOW Seat Height



MID Seat Height



HIGH Seat Height

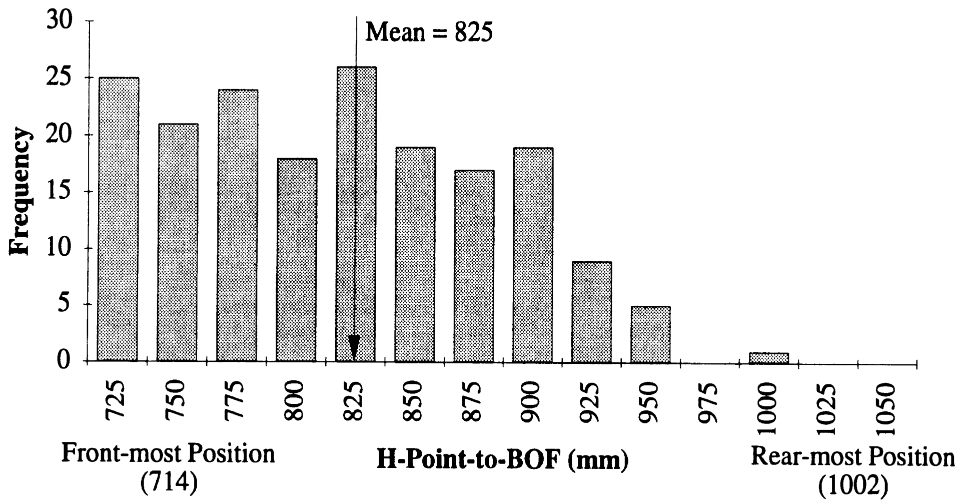
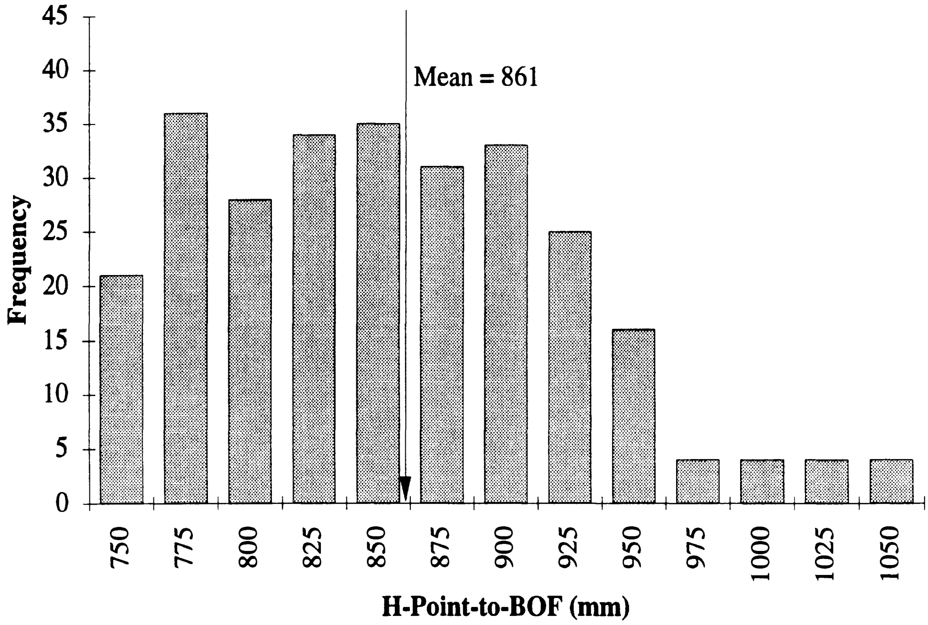


Figure 33a. H-point-to-BOF histograms by seat height.
(n=192)

LOW Seatpan Angle



HIGH Pan Angle

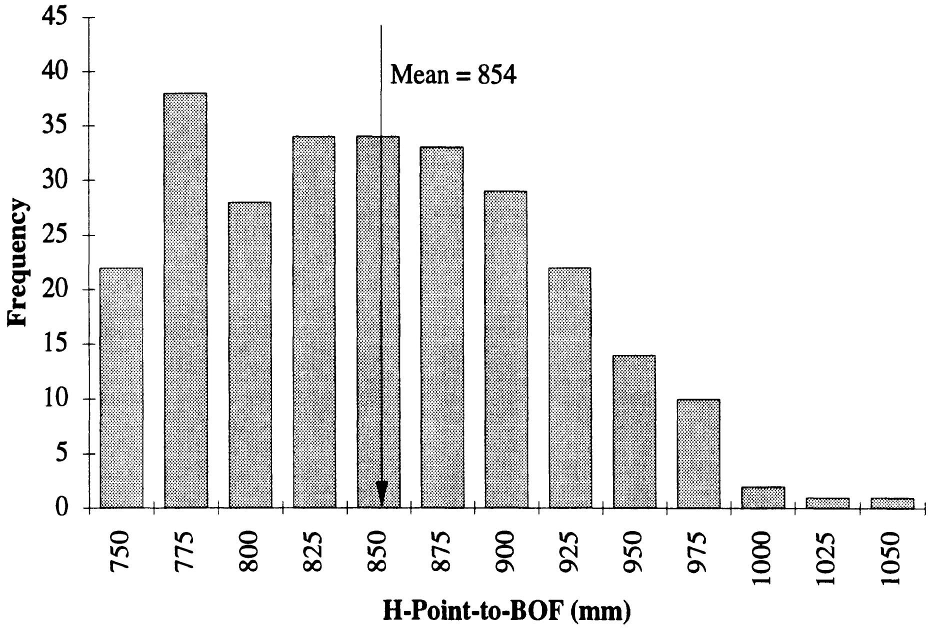
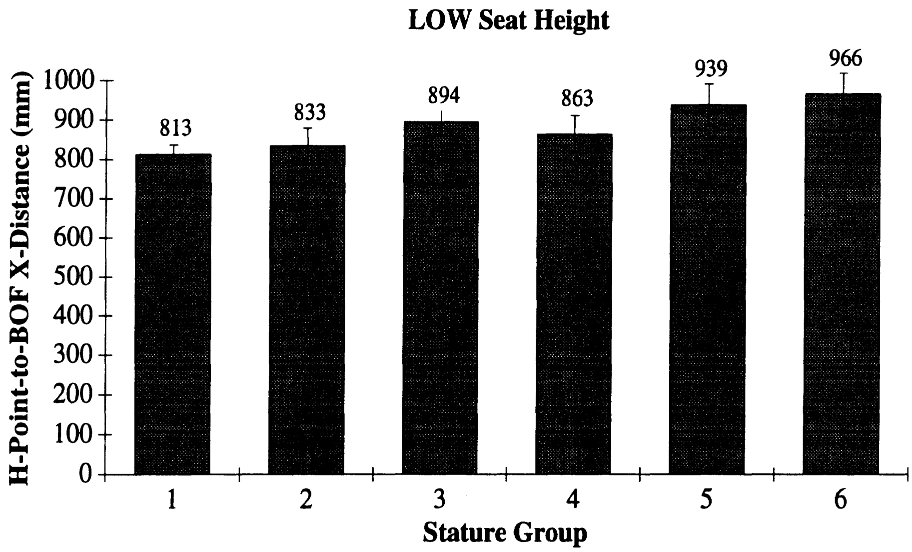
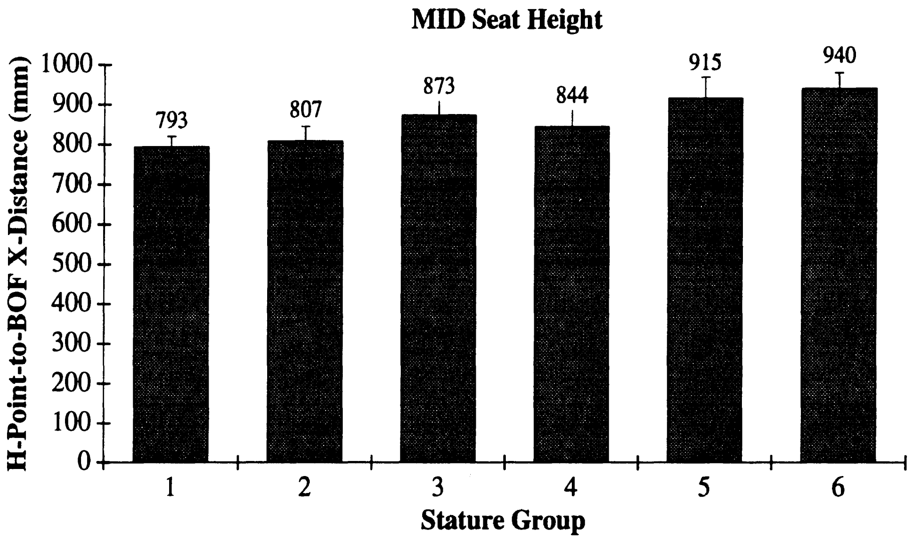


Figure 33b. H-point-to-BOF histograms by seatpan angle.
(n=288)





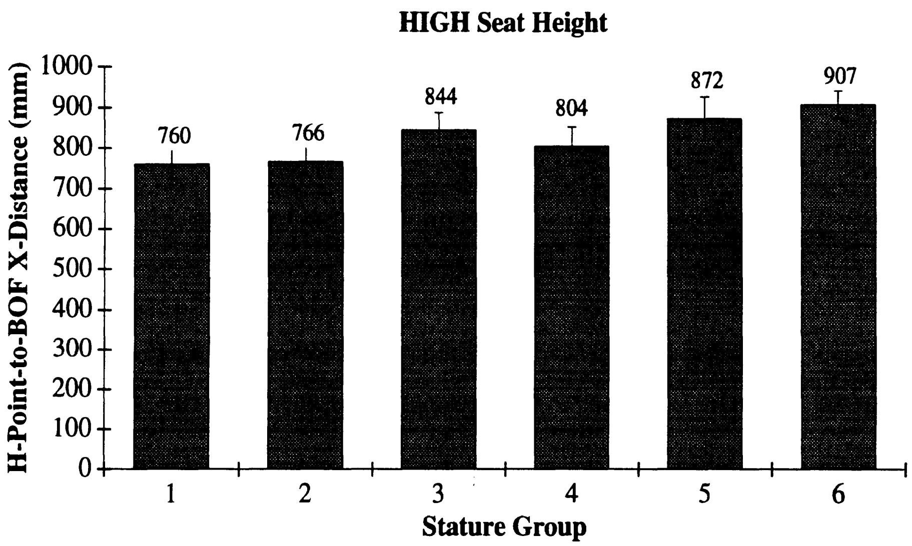


Figure 34. H-point-to-BOF x-distance by stature group for each seat height. (n=192)

Table 10
Comparisons of Overall Mean and Median Seat Positions re BOF

Condition	Mean	Median	Difference
LOW H30	878	885	7
MID H30	859	862	3
HIGH H30	826	825	1
LOW seatpan angle	857	861	4
HIGH seatpan angle	851	854	3

Figures 35a and 35b show distributions of subject-selected seatback angles for all test conditions at each seat height and each seatpan angle, respectively. Unlike the histograms of Figures 33a and 33b for seat position, these distributions are normally distributed without censoring. The distributions and mean seat positions are seen to shift to lower values (i.e., more upright seatback angles) with higher seat heights, but show little or no change with seatpan angle.

Figure 36 shows plots of overall mean seatback angle for each of the six stature/gender groups for each seat height. While differences in overall mean values exist between some of the groups, there is no consistent pattern to these differences with either gender or stature.

3.2.2 Differences with Test Conditions

Table E-1 and Figures E-1 and E-2 in Appendix E summarize selected seat position results, represented by H-Point-to-BOF distance, and seatback angle results by test condition, and present the means, standard deviations, and ranges of these data. Table 11 and Figure 37 give the overall mean values of H-Point-to-BOF distance for each level of the four independent variables, while Table 12 and Figure 38 shows the overall mean values for seatback angle. It is again seen that seat height (H30) has the largest effect on both the H-Point-to-BOF distance and seatback angle with subjects sitting further forward and with more upright seatback angles at the higher seat heights. Neither seat position nor seatback angle appear to be influenced by seat cushion length or pedal force level.

In contrast to results of other recent studies, which show that the effect of seatpan angle on seat position can be as much as 4 to 6 mm/degree, the effect of seatpan angle on seat position in this study is quite small, with mean effects of 1, 1.5, and .4 mm/degree for LOW, MID, and HIGH seat heights, respectively.

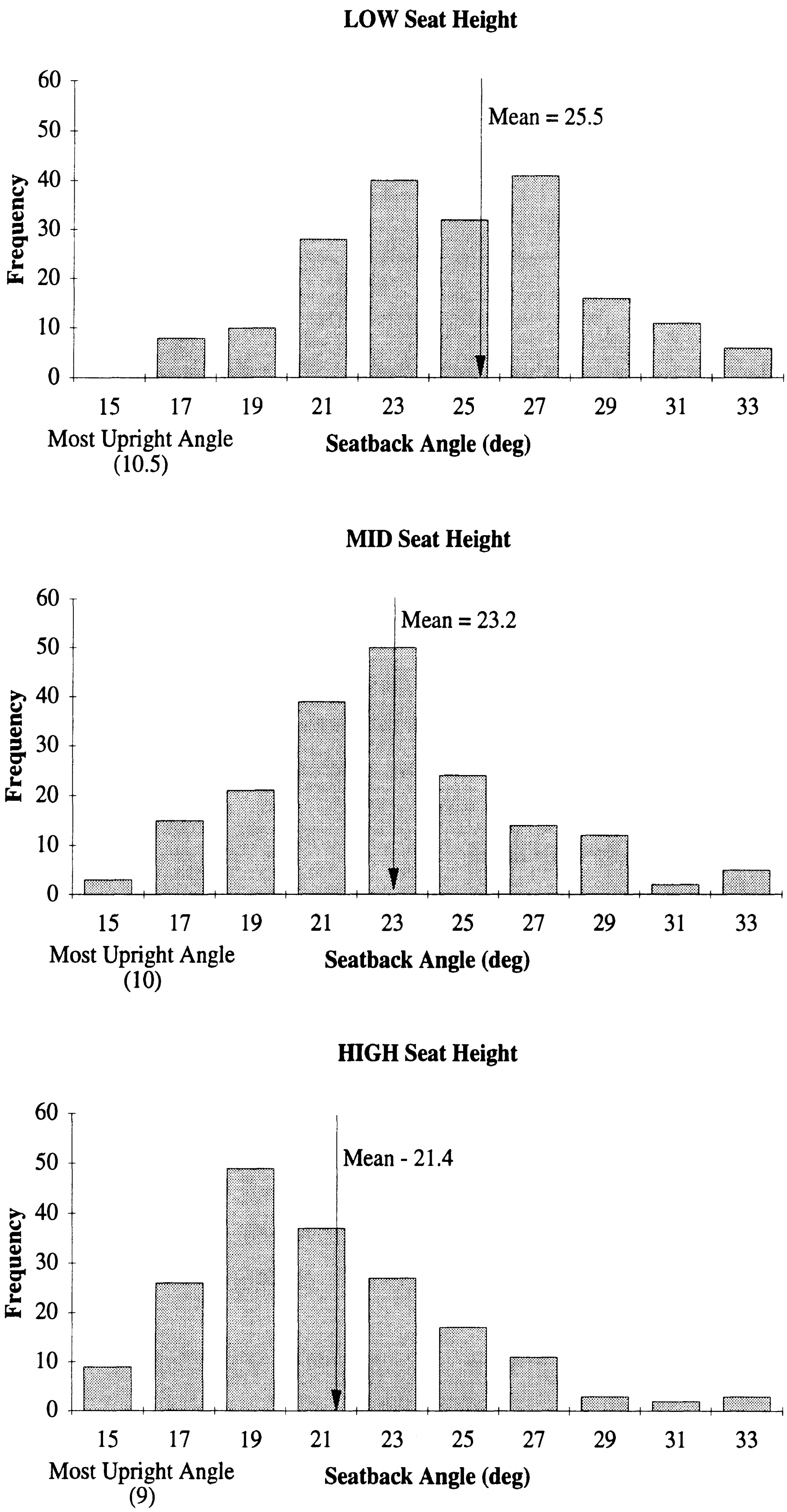
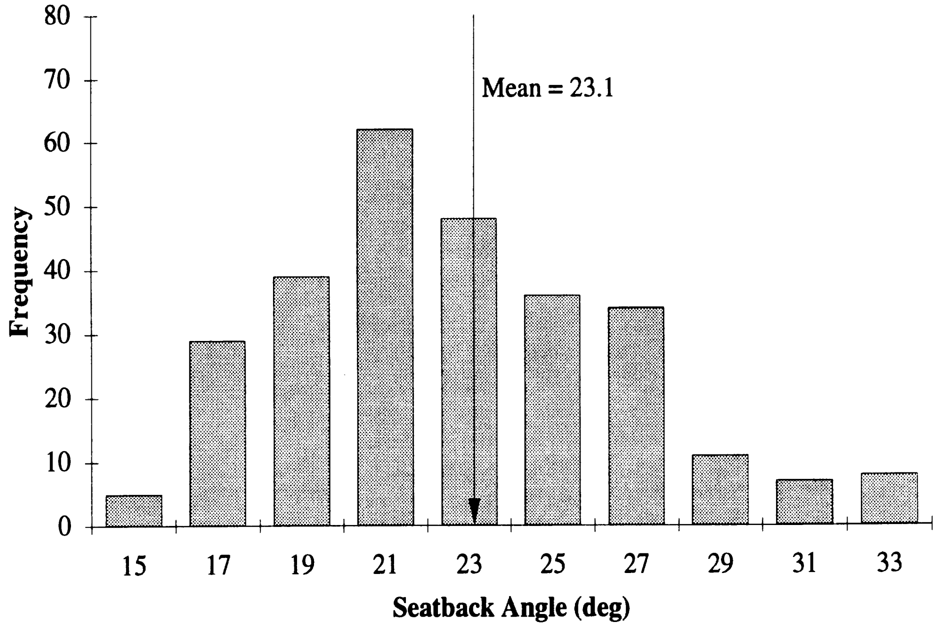


Figure 35a. Seatback angle histograms by seat height.
(n=192)

LOW Seatpan Angle



HIGH Pan Angle

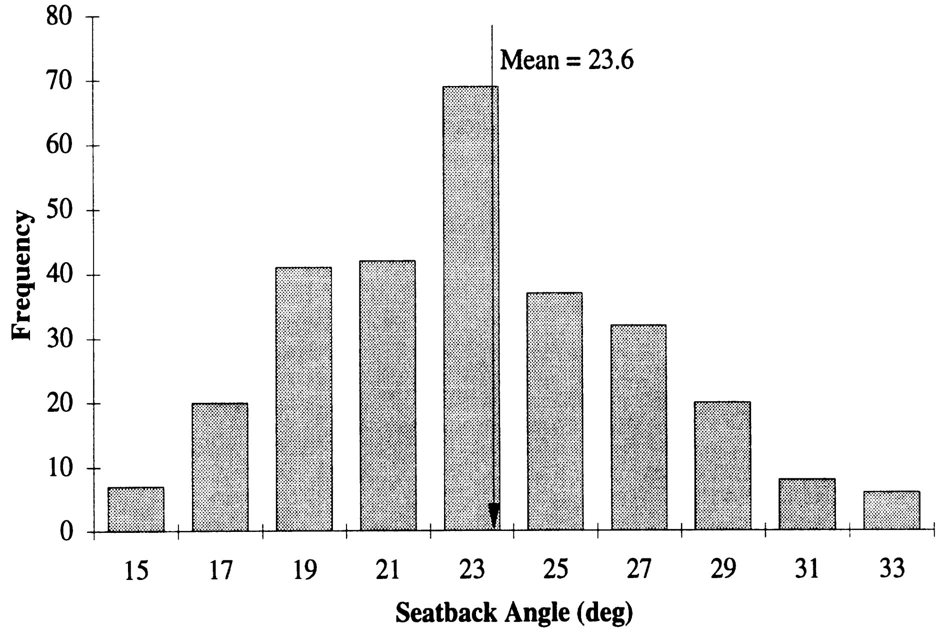


Figure 35b. Seatback angle histograms by seatpan angle.
(n=288)

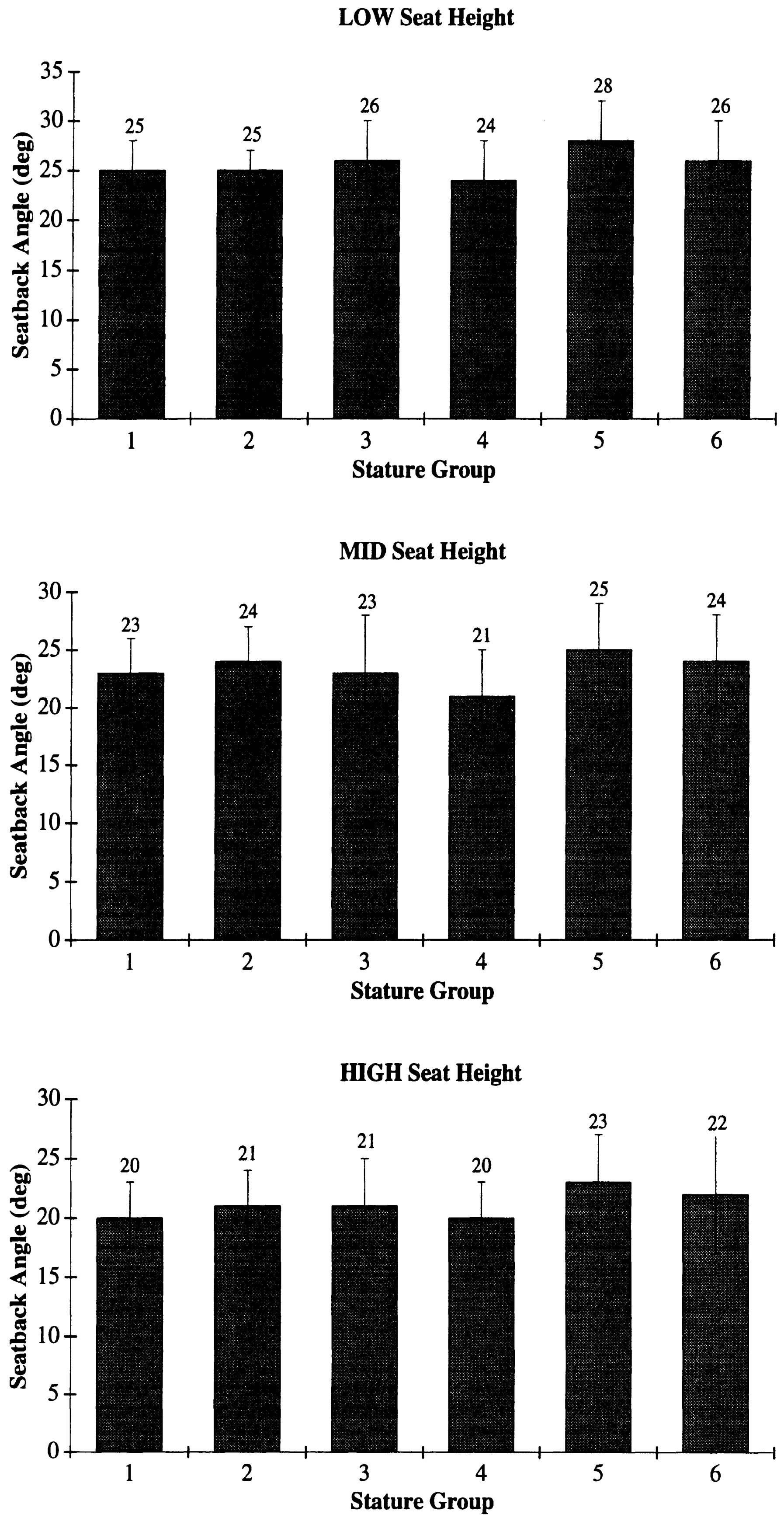


Figure 36. Seatback angle by stature group for each seat height.
(n=192)

Table 11
Overall Mean H-Point to BOF X-Distance by Independent Variables (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	885	70.37
Mid Seat Height	192	862	66.72
High Seat Height	192	825	68.28
Low Pan Angle	288	861	73.56
High Pan Angle	288	854	71.56
Short Cushion	288	857	72.71
Long Cushion	288	857	72.6
Low Pedal Force	288	859	73.77
High Pedal Force	288	856	71.49

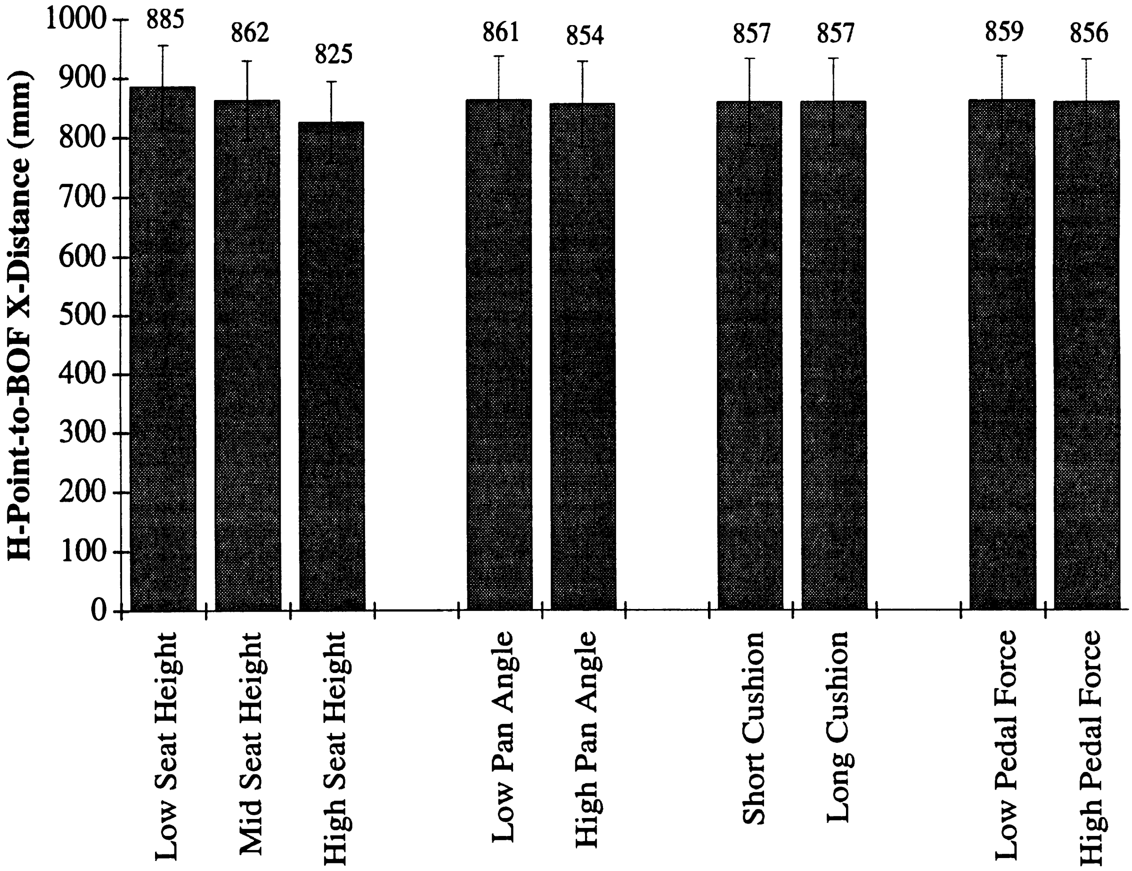


Figure 37. Overall mean H-point-to-BOF x-distance by independent variable.

Table 12
Overall Mean Seatback Angle by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	25.5	3.77
Mid Seat Height	192	23.2	4.16
High Seat Height	192	21.4	4.05
Low Pan Angle	288	23.1	4.42
High Pan Angle	288	23.6	4.24
Short Cushion	288	23.5	4.28
Long Cushion	288	23.2	4.39
Low Pedal Force	288	23.4	4.49
High Pedal Force	288	23.3	4.18

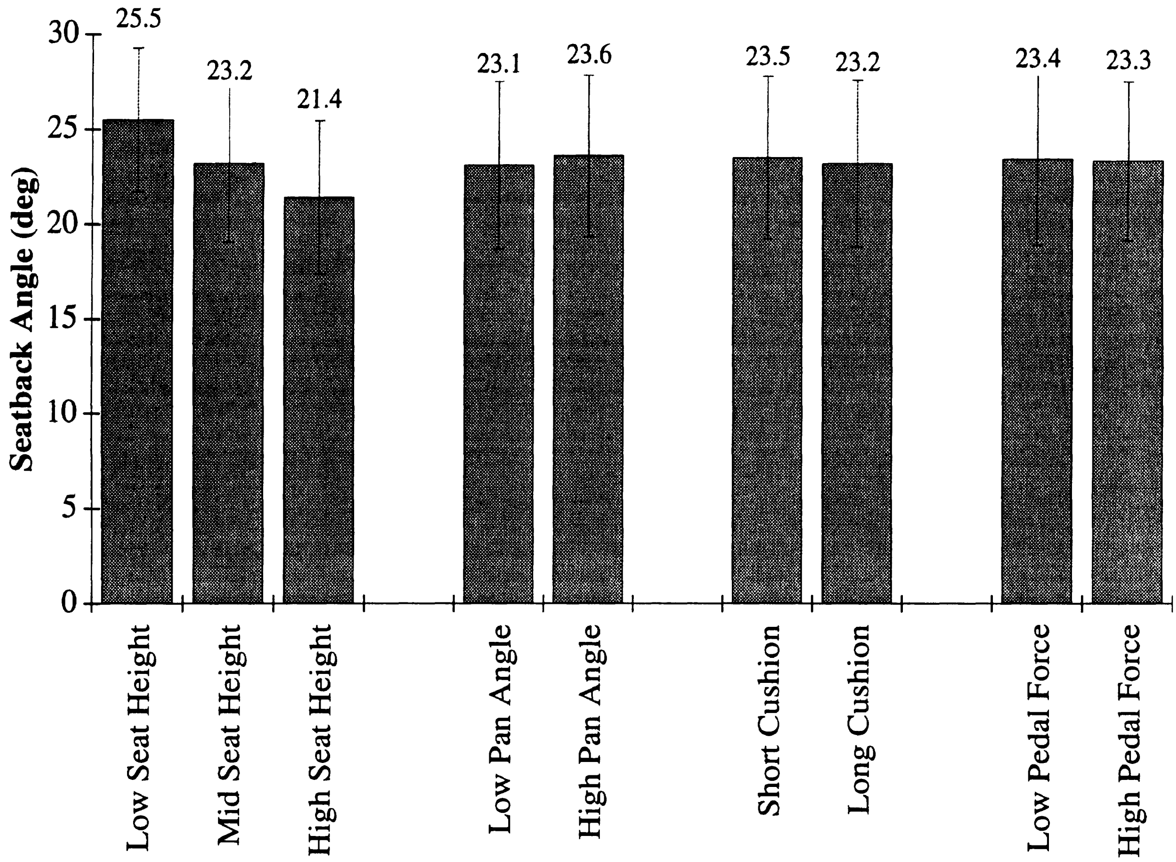


Figure 38. Overall mean seatback angle by independent variables.

Figure 39 shows scatter plots of differences in subject seat position for tests conducted at LOW and HIGH seatpan angle, where the difference is computed by subtracting overall mean seat positions for HIGH seatpan angle tests from overall mean seat positions for LOW seatpan angles tests at each seat height for each subject. This gives a positive difference if the seat position at LOW seatpan angle is rearward of the seat position at HIGH seatpan angle. As indicated, a number of subjects at each seat height positioned the seat more rearward (i.e., negative difference) for the HIGH seatpan angle conditions than they did for the LOW seatpan angle conditions, especially at the high seat height. The reason for this result with some subjects is unexplained, but these wrong-way subjects reduce the overall mean effect of seatpan angle on seat position from what it would be if all subjects had positioned the seat further forward for HIGH seatpan angles, as has been found in other studies.

3.2.3 Comparison of Empirical Seat Position Results to SAE J1517 Seating Accommodation Model Predictions

Because of the nonrepresentative sampling strategy used in this study, it is not possible to compute population percentiles of seat position relative to BOF from the empirical data for direct comparison to SAE J1517 predictions. In order to provide general comparisons of the seat position results of the study at each seat height, it was assumed that stature percentile corresponds to seat-position percentile. Other studies have shown relatively high correlations between stature and seat position (50 percent or more of seat position variability is explained by stature), indicating that this is not an unreasonable assumption.

Figure 40 makes these comparisons for each of the three seat heights. In each plot, the population percentile corresponding to each subject's stature was calculated based on data from the HANES II national survey (Abraham). The H-Point-to-BOF distance for each subject was plotted versus the subject's stature percentile using a linear scale on the left vertical axis of each plot. Statures corresponding to selected percentiles appear on the right side of the graph for reference. Because stature percentile is not a linear function of stature in a normal distribution, simple interpolation does not produce correct values for points between those given. Rather, interpolation of a normal distribution would be required.

These comparisons indicate that the distributions of seat positions selected in the seating buck are in general agreement with model predictions and are, therefore, similar to what one would expect in actual vehicles.

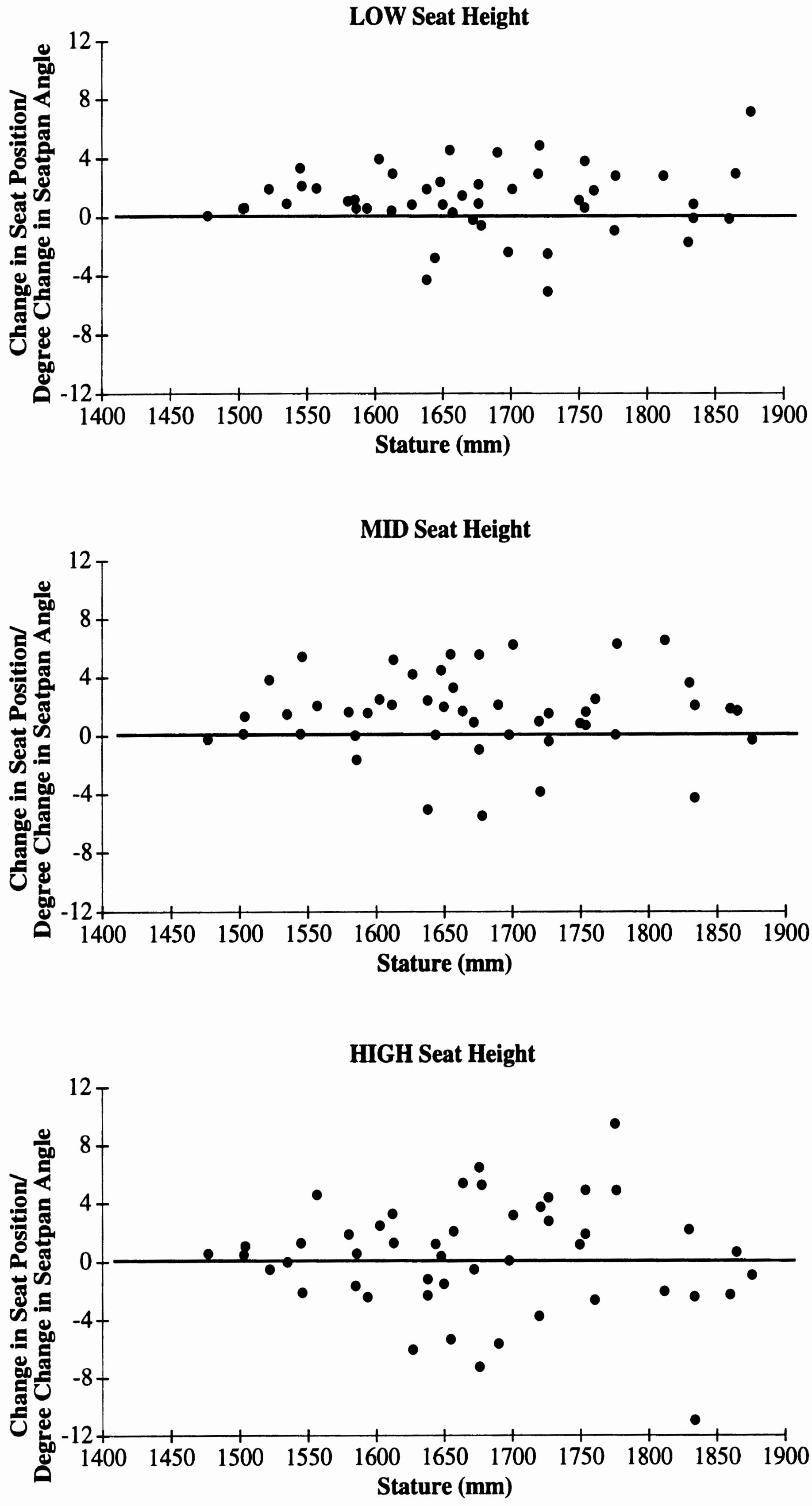


Figure 39. Difference in overall mean seat position for HIGH seatpan angle minus LOW seatpan angle (positive value indicates subject sat more rearward for LOW seatpan angle).

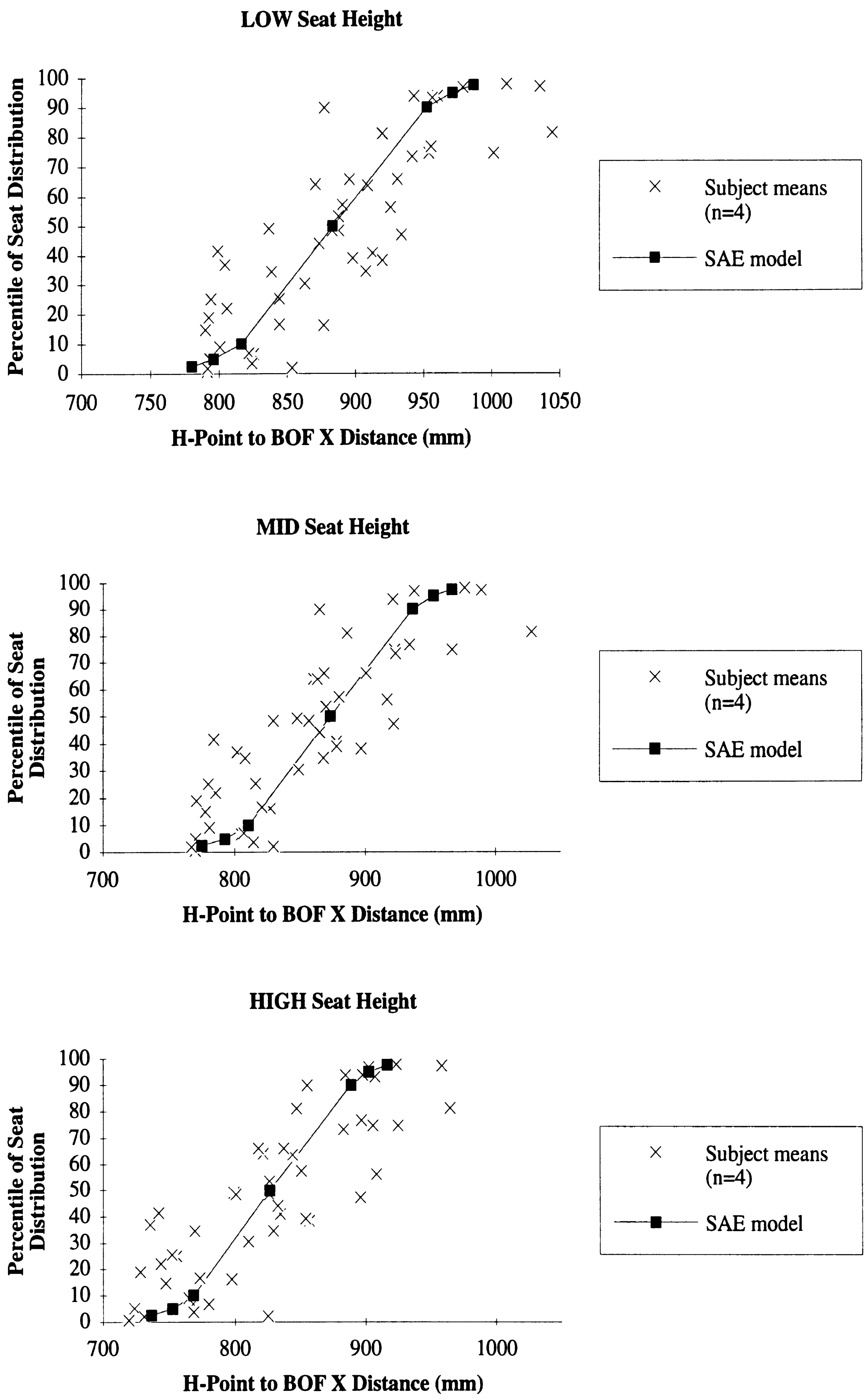


Figure 40. Subject-selected seat position compared to the SAE J1517 model by seat height.

3.3 RIGHT HEEL LOCATIONS AND FOOT ORIENTATIONS

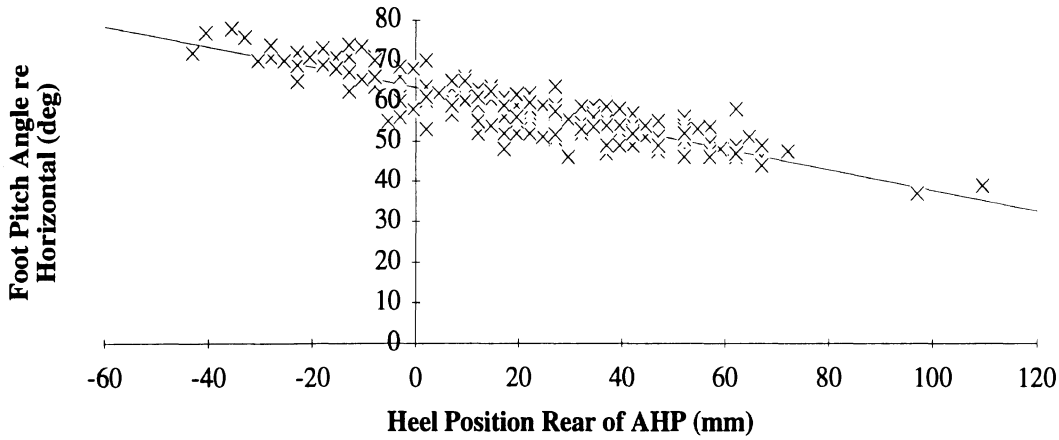
Tables E-2 and E-3 and Figures E-3 through E-6 of Appendix E summarize subject right heel locations and foot angles by test condition, and present the mean locations, standard deviations, and ranges of these variables. As shown in the scatter plots of Figure 41, there is a strong correlation between fore/aft heel location and foot pitch angle, such that the more horizontal the pitch angle, the more rearward of AHP the heel is placed. Very few subjects placed their heel at or forward of the AHP. There is also a strong correlation between lateral heel position and foot rotation angle, as shown in Figure 42, such that the greater the rotation angle, the further left the heel is placed.

Table 13 and Figure 43 show overall mean values for heel position rear of AHP for each level of the independent variables. Table 14 and Figure 44 show overall mean foot pitch angles for the independent variables. Fore/aft heel location relative to the AHP and foot pitch angle are influenced most by seat height and seatpan angle. As expected, with higher seat heights, the mean driver foot pitch angle becomes more horizontal. However, the mean distance of heel position rearward of AHP decreases with increasing seat height (i.e., with a more horizontal foot angle). This somewhat unexpected result is due to the relationship between manikin foot angle, which determines AHP, and subject shoe angle. At higher seat heights, the difference between manikin foot angle and mean subject foot angle is smaller, resulting in a mean heel position that is less rearward relative to the AHP (see Table 15 and discussion below). Pedal force and cushion length have little or no effect on fore/aft heel position and foot pitch angle.

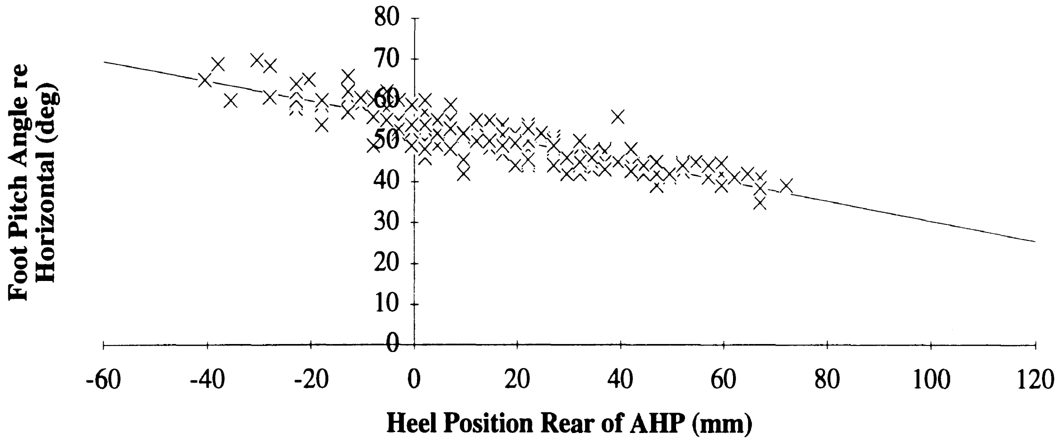
As shown in the histograms of Figure 45, foot pitch angle has a relatively normal distribution at each seat height. Figure 46 shows overall mean foot pitch angles and heel locations rearward of AHP for male and female subjects separately. There are no significant or consistent differences in front/back heel positioning with gender.

In order to compare these measured foot angles with the manikin foot angle, an adjustment to the measured bottom of foot pitch angle was made, as illustrated in Figure 47, to account for the difference in the angle of the bottom of the foot versus the bottom of the shoe. For female subjects, the angle adjustment used was 4.25 degrees, while for male subjects an angle adjustment of 4.75 degrees was used. These values are based on measurements taken from the standard shoes used in the study. Note in Table 15 that the mean values of shoe pitch angle at each seat height are more horizontal than foot angles calculated from J1516 for the 95th-percentile manikin. At higher seat heights, the mean pitch angle is closer to the

LOW Seat Height



MID Seat Height



HIGH Seat Height

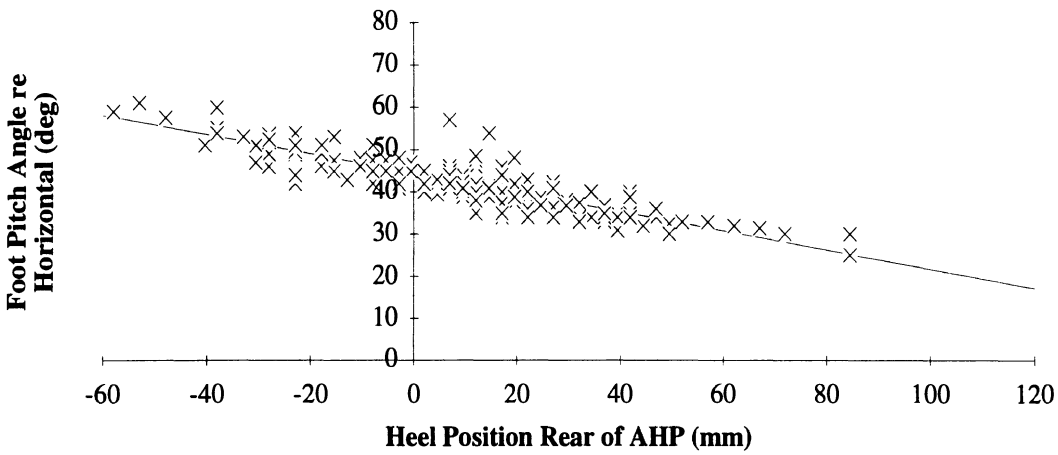
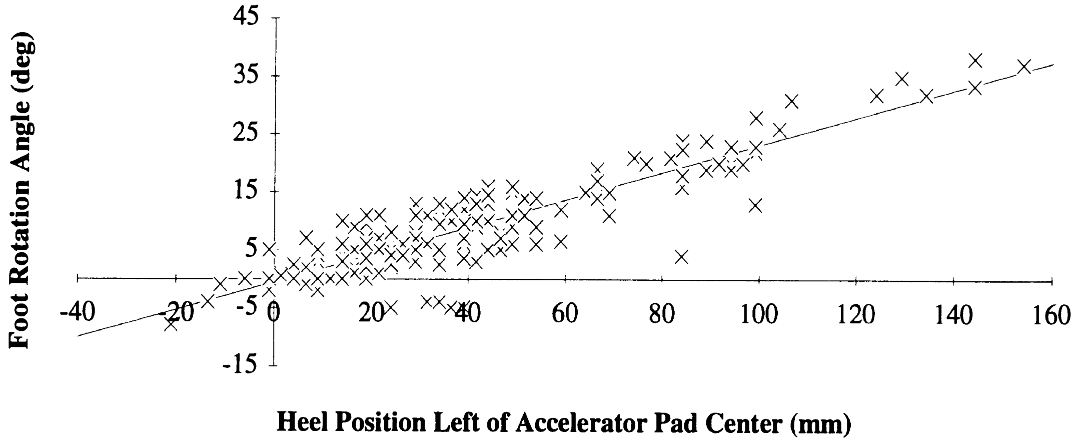
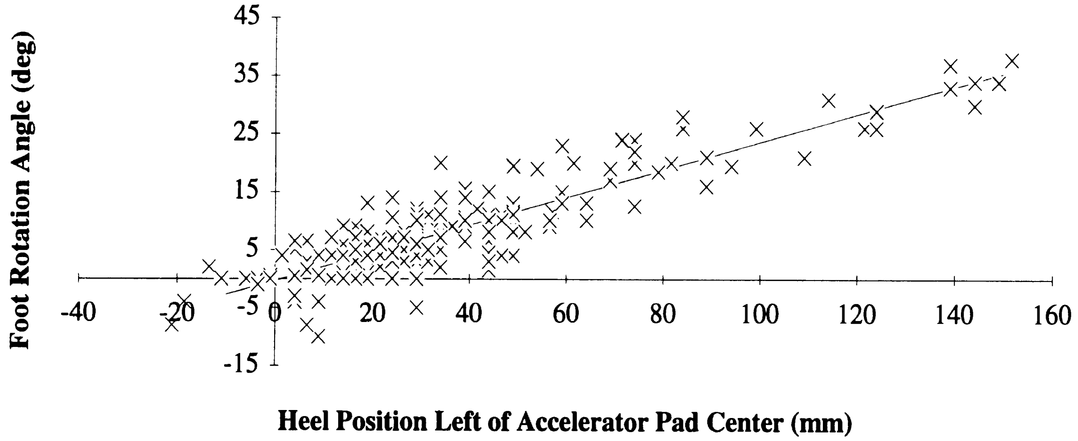


Figure 41. Foot pitch angle vs heel position rear of AHP for each seat height.
(n = 192)

LOW Seat Height



MID Seat Height



HIGH Seat Height

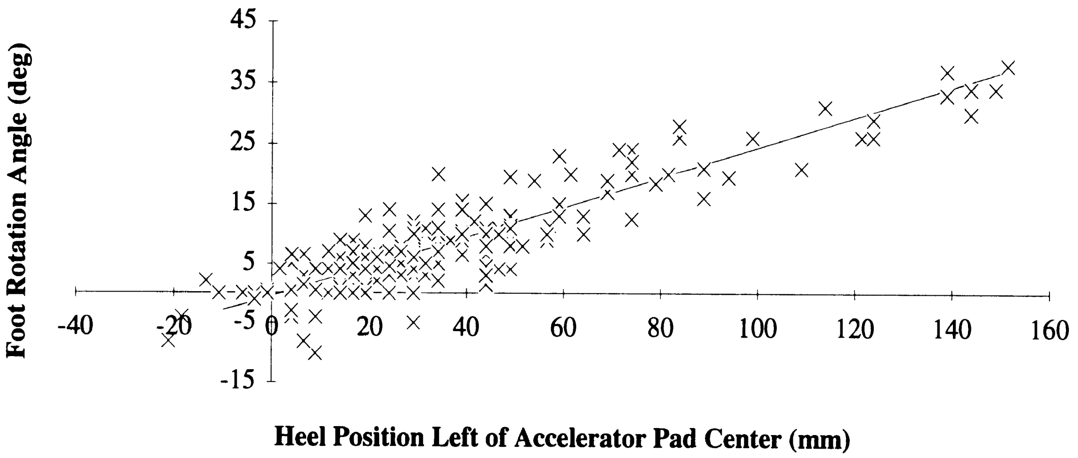


Figure 42. Foot rotation angle vs heel position left of accelerator for each seat height. (n = 192)

Table 13
Overall Mean Heel Position Rearward of AHP by Independent Variable (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	21	26.36
Mid Seat Height	192	17	23.14
High Seat Height	192	10	24.58
Low Pan Angle	288	13	24.48
High Pan Angle	288	20	25.23
Short Cushion	288	17	24.44
Long Cushion	288	16	25.74
Low Pedal Force	288	18	25.94
High Pedal Force	288	15	24.10

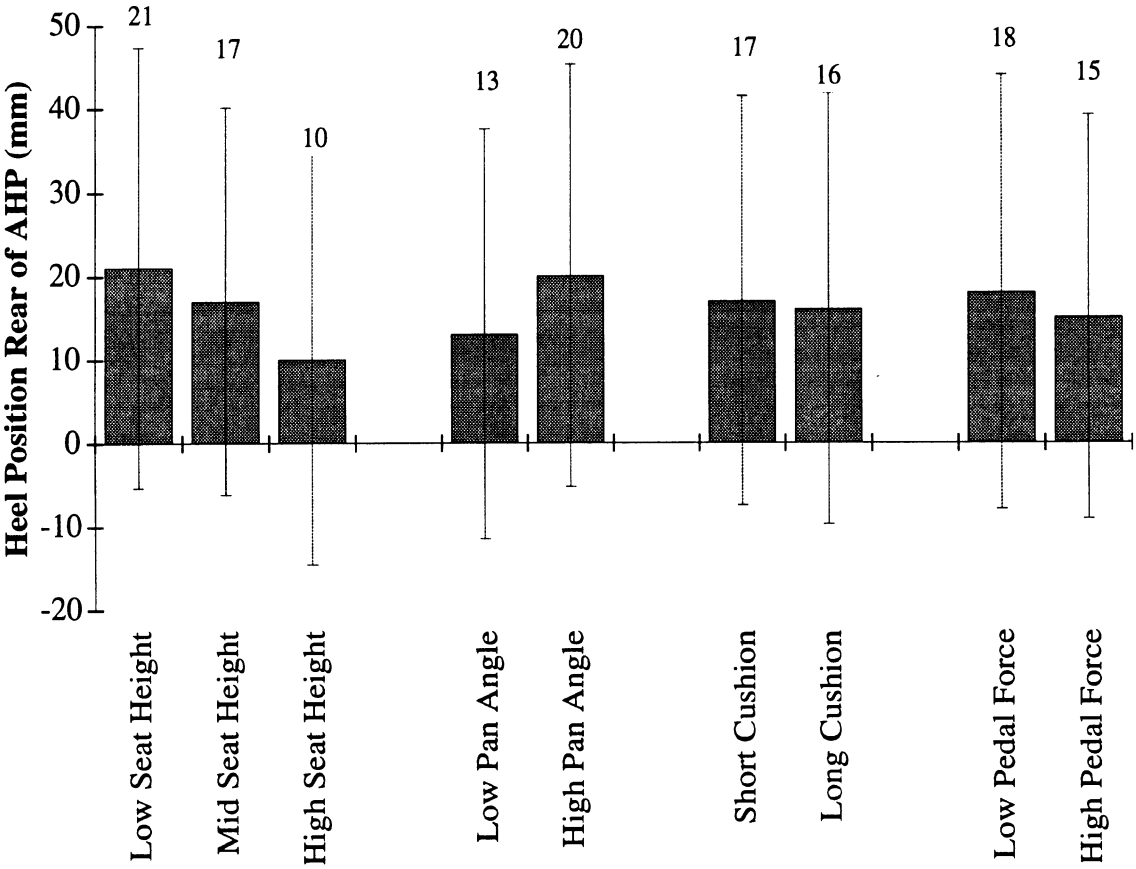


Figure 43. Overall mean heel position rearward of AHP by independent variables.

Table 14
Overall Mean Foot Pitch Angle by Independent Variable (deg re Horizontal)

	N	Mean	Standard Deviation
Low Seat Height	192	57.9	7.67
Mid Seat Height	192	50.6	6.54
High Seat Height	192	42.1	6.33
Low Pan Angle	288	51.3	9.57
High Pan Angle	288	49.2	9.15
Short Cushion	288	50.2	9.72
Long Cushion	288	50.2	9.12
Low Pedal Force	288	50.8	9.38
High Pedal Force	288	49.7	9.43

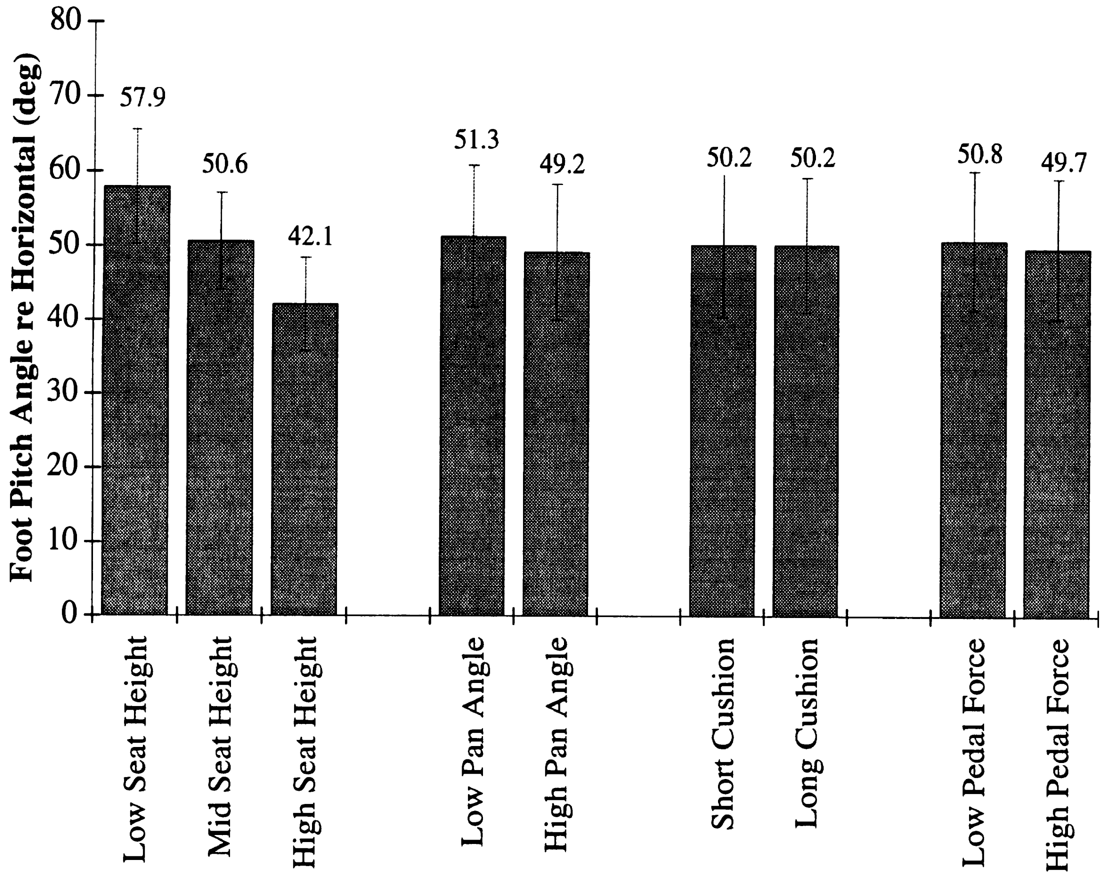
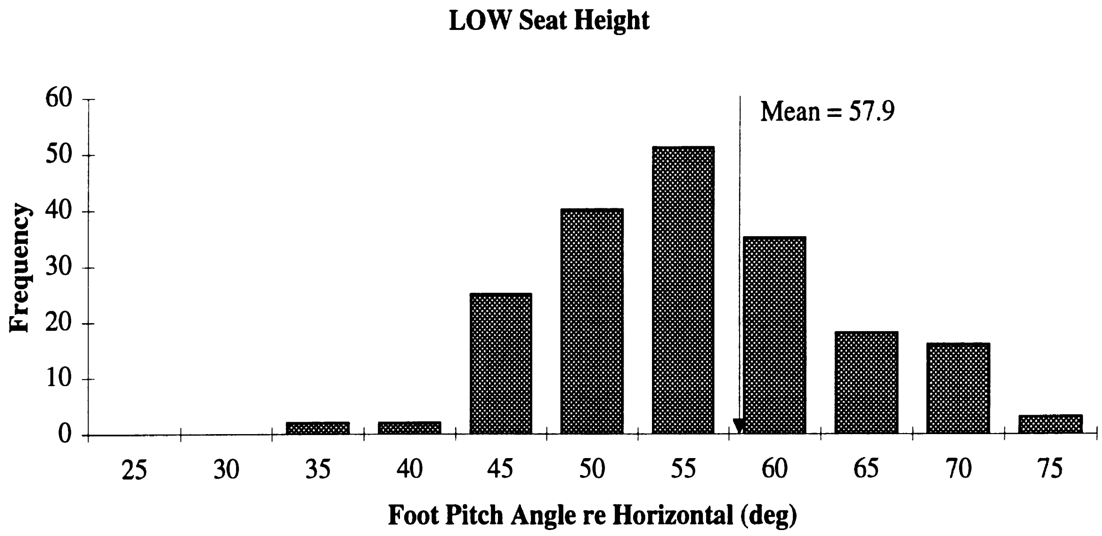
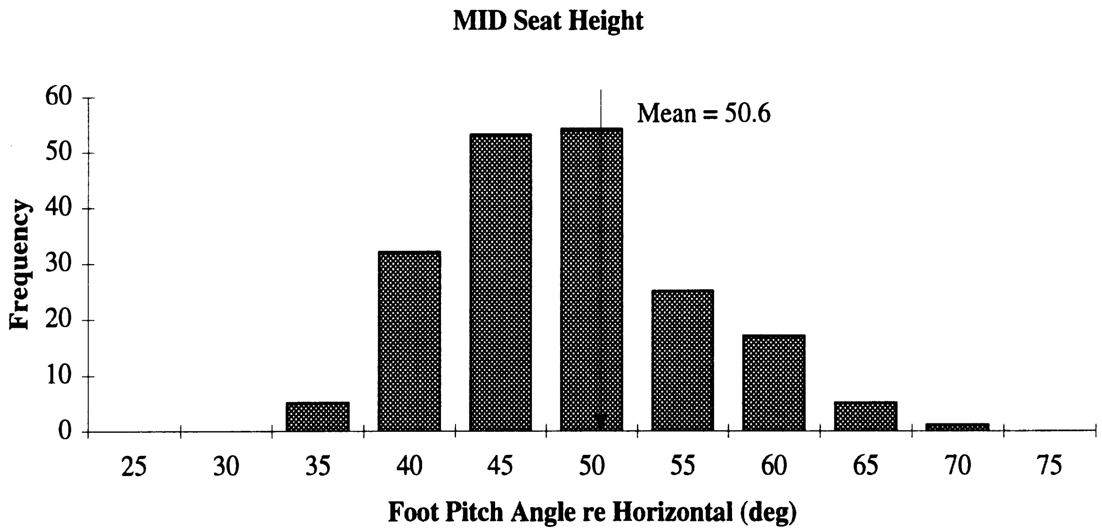


Figure 44. Overall mean foot pitch angle by independent variables.





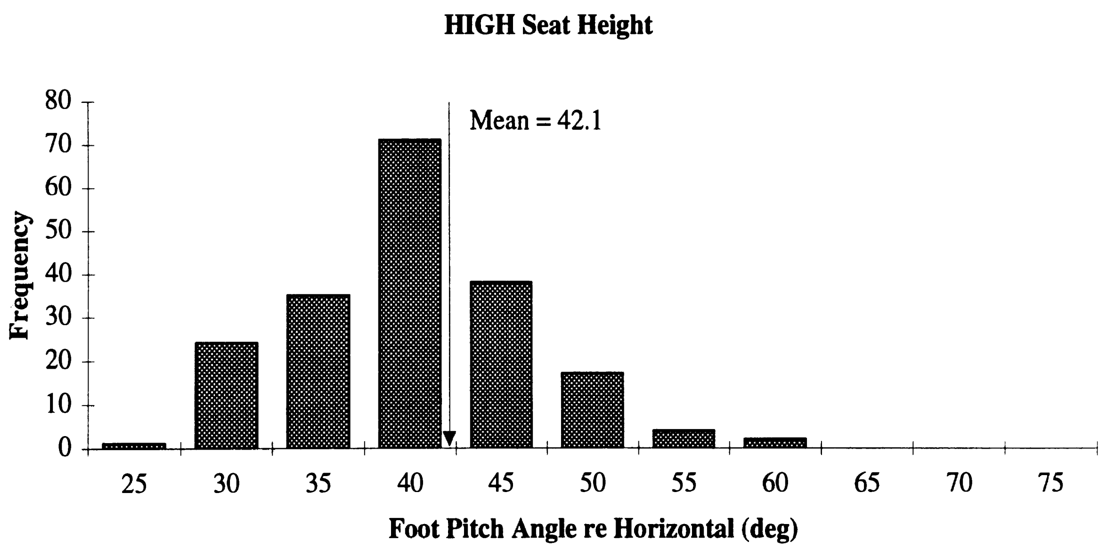


Figure 45. Foot pitch angle histograms by seat height.
(n = 192)

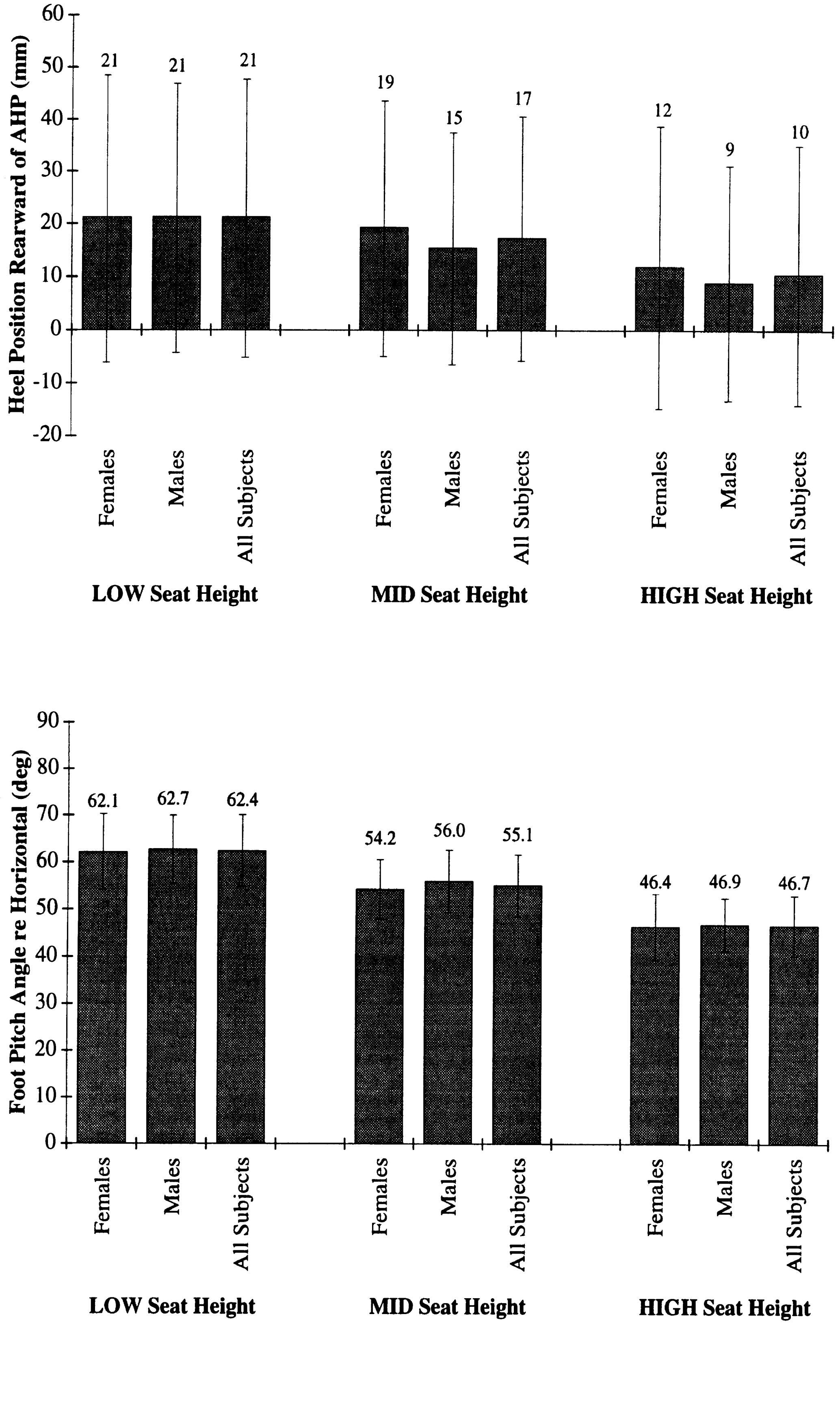


Figure 46. Overall mean front/back heel positioning by gender.

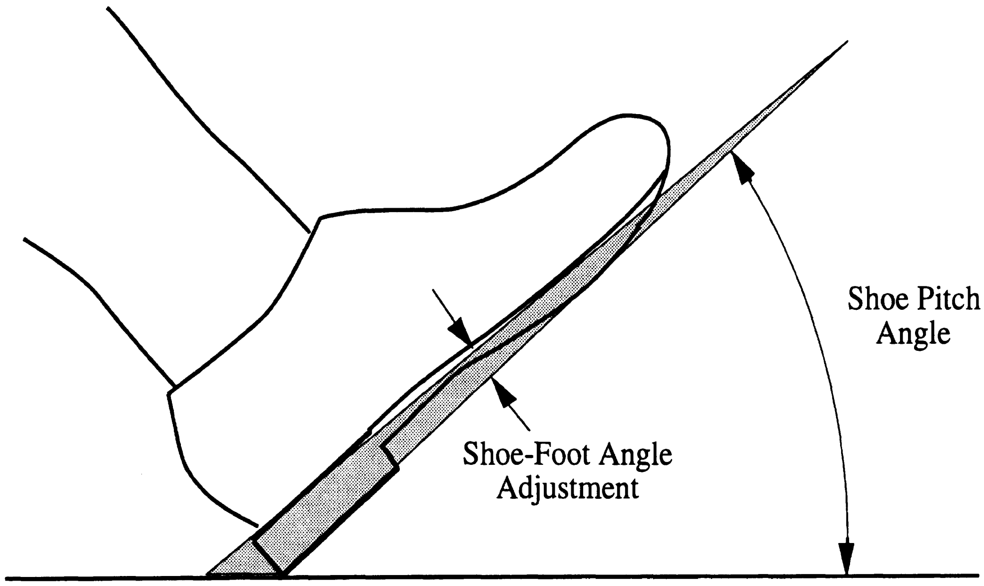


Figure 47. Shoe pitch angle and angle adjustment.

Table 15
Comparison of Manikin and Subject Shoe Pitch Angles

Seat Height (mm)	Manikin Foot Angle from J1516 (deg re horizontal)	Subject Overall Mean Shoe Pitch Angle (deg re horizontal)	Difference (deg)
180	71	62	9
270	62	55	7
360	51	47	3

angle of the manikin foot, i.e., the difference between the two angles is smaller. This corresponds to the subjects placing their heels closer to the AHP, as stated above.

Table 16 and Figures 48 give the overall mean values of lateral heel position for each level of the independent variables. Table 17 and Figure 49 give the overall mean foot rotation angles for the independent variables. None of the four vehicle factors significantly influence lateral heel position or foot rotation angle. Figure 50 compares foot rotation angles and heel position left of the accelerator pad center by gender for each of the seat heights. As illustrated, female subjects tend to place their heels about 30 mm closer to the center of the accelerator, and this corresponds to approximately 10 degrees less foot rotation than for male subjects.

3.4 INITIAL KNEE, LEG, AND THIGH ANGLES

Table E-4 and Figures E-7 through E-9 in Appendix E summarize results for subject right leg orientations, including the overall subject means, standard deviations, and ranges of knee, leg, and thigh angles by test condition. Tables 18, 19, and 20 and Figures 51, 52, and 53 give the overall mean values for each level of the independent variables.

As expected, leg and thigh angles are influenced by seat height such that leg angle (relative to the horizontal) increases for higher seat heights, and thigh angle (relative to the horizontal) decreases with higher seat height. Knee angle is seen to increase with decreasing seat height, ranging from an overall mean of 120 degrees at the high seat height to 129 degrees at the low seat height. Seatpan angle, cushion length, and pedal force have relatively little influence on leg, thigh, and knee angles. Stick-figure diagrams in Figure 54a through 54d further illustrate these differences in leg and knee angles for the different independent variables.

3.5 PEDAL CONTACT ZONES AND INITIAL ANKLE ANGLES

Table E-5 and Figure E-10 show results for pedal contact zone by test condition, while Table 21 and Figure 55 give the overall mean values for each level of the independent variables. Overall, subjects tended to position their feet in contact with the lower part of the pedal pad, in zone 4 (see Figure D10-4 of Appendix D). Subjects tended to position their feet somewhat higher on the pedal (lower zone value) for the higher pedal force conditions, but the change is relatively small and insignificant. Figure 56 shows mean pedal contact zone by subject group

Table 16
Overall Mean Heel Position Left of Accelerator Pad Center by Independent Variable (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	38.0	34.48
Mid Seat Height	192	37.0	32.65
High Seat Height	192	36.4	28.91
Low Pan Angle	288	38.1	32.30
High Pan Angle	288	36.2	31.87
Short Cushion	288	37.2	32.52
Long Cushion	288	37.1	31.66
Low Pedal Force	288	38.0	33.70
High Pedal Force	288	36.3	30.34

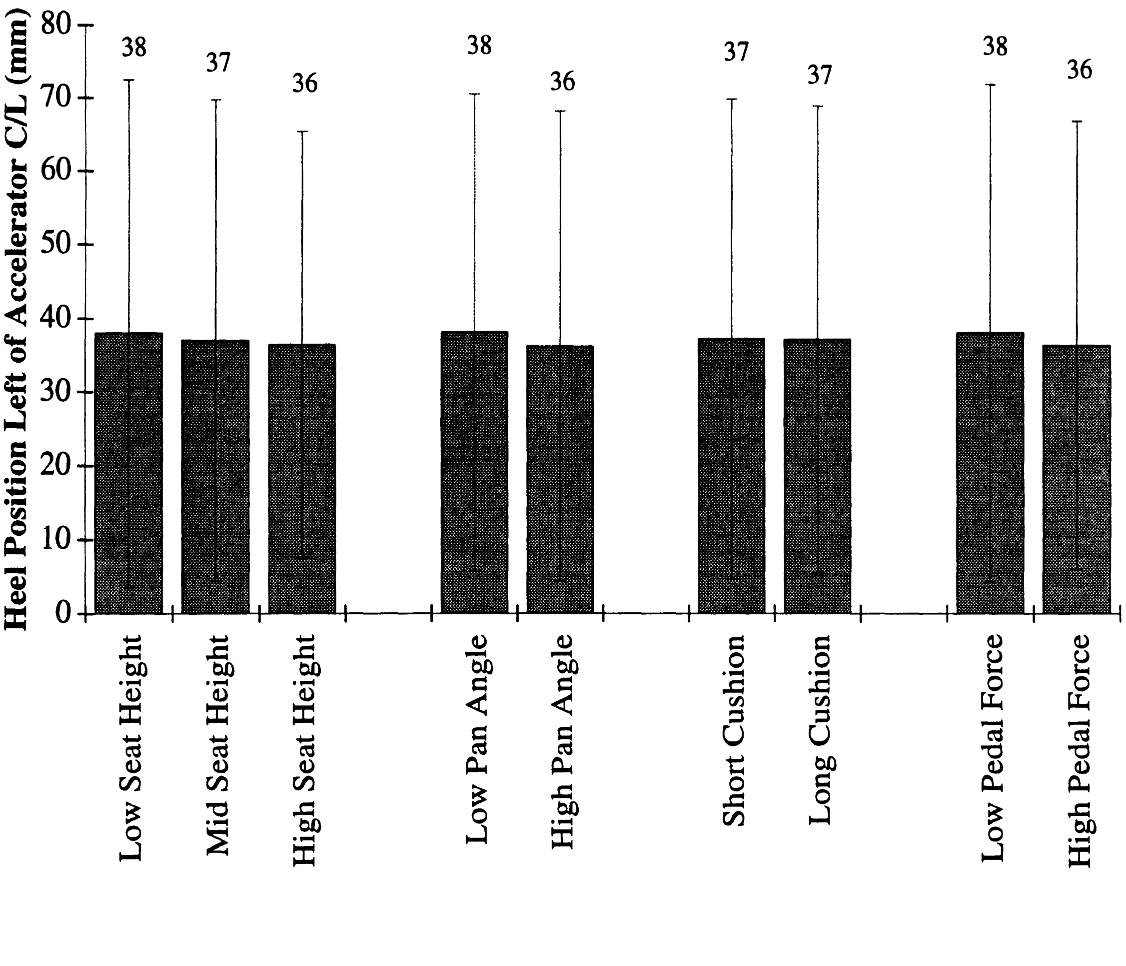


Figure 48. Overall mean heel position left of accelerator pad center by independent variables.

Table 17
Overall Mean Foot Rotation Angle by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	8.4	8.60
Mid Seat Height	192	8.6	8.71
High Seat Height	192	8.6	8.01
Low Pan Angle	288	8.6	8.70
High Pan Angle	288	8.4	8.17
Short Cushion	288	8.4	8.40
Long Cushion	288	8.6	8.48
Low Pedal Force	288	8.5	8.74
High Pedal Force	288	8.6	8.13

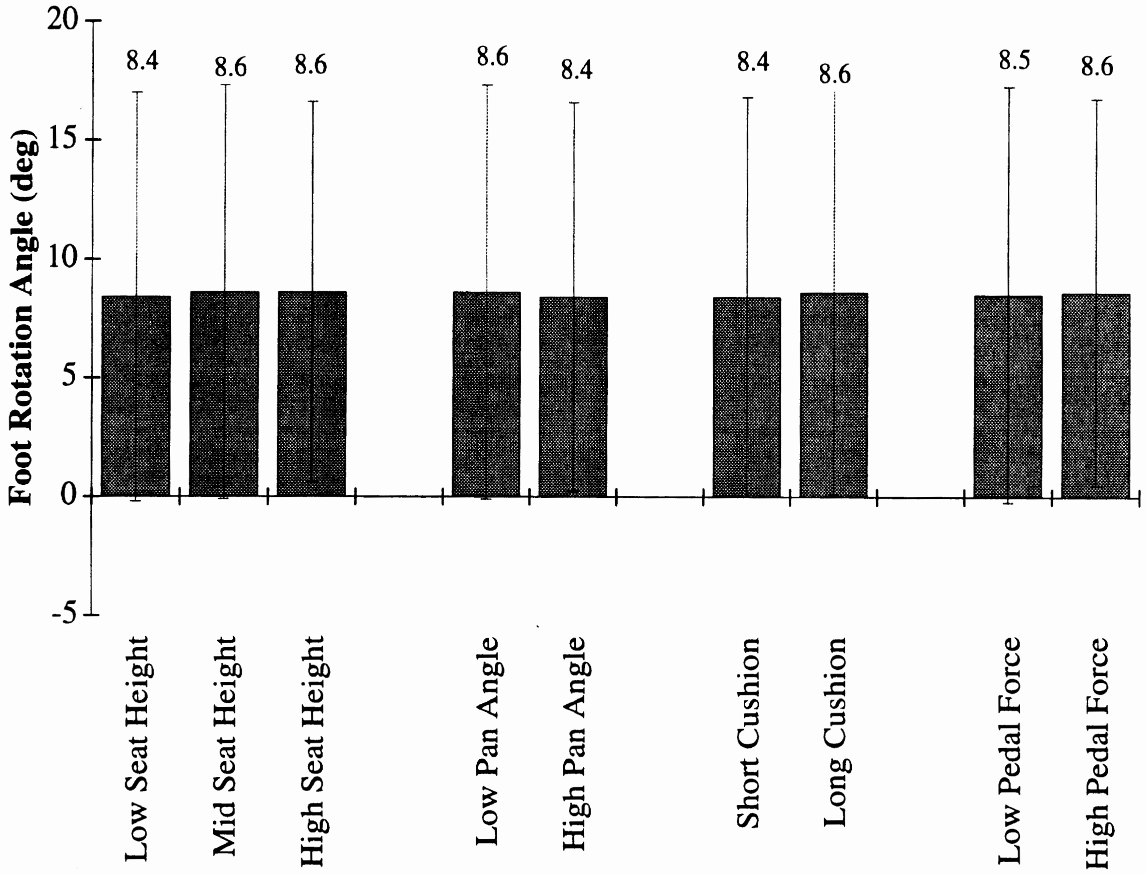


Figure 49. Overall mean foot rotation angle by independent variable.

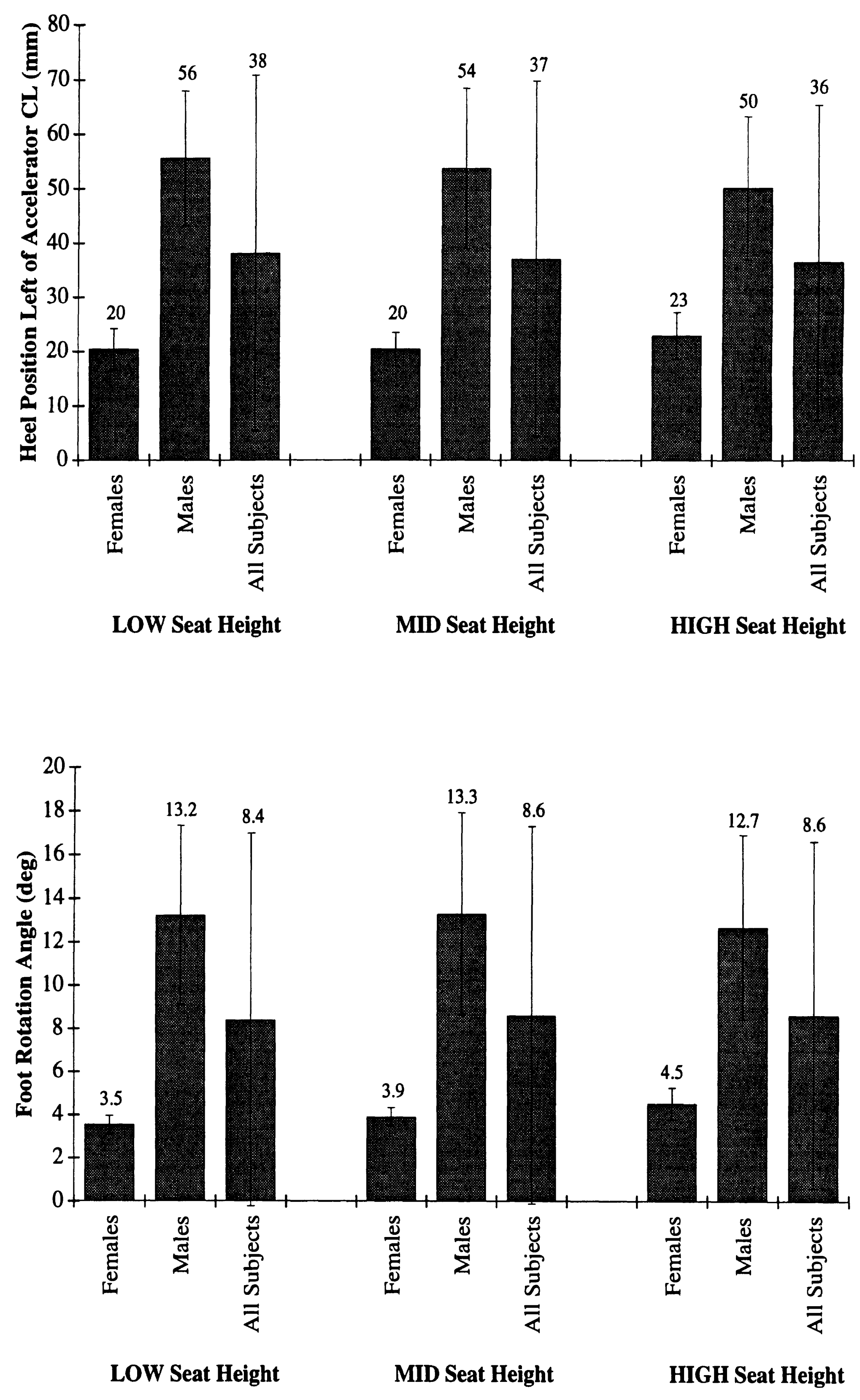


Figure 50. Overall mean lateral heel positioning and foot rotation angle by gender.

Table 18
Overall Mean Knee Angle re Horizontal by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	128.5	10.73
Mid Seat Height	192	124.8	8.33
High Seat Height	192	119.9	7.21
Low Pan Angle	288	125.5	10.34
High Pan Angle	288	123.3	8.52
Short Cushion	288	124.6	9.38
Long Cushion	288	124.2	9.69
Low Pedal Force	288	124.0	9.41
High Pedal Force	288	124.8	9.65

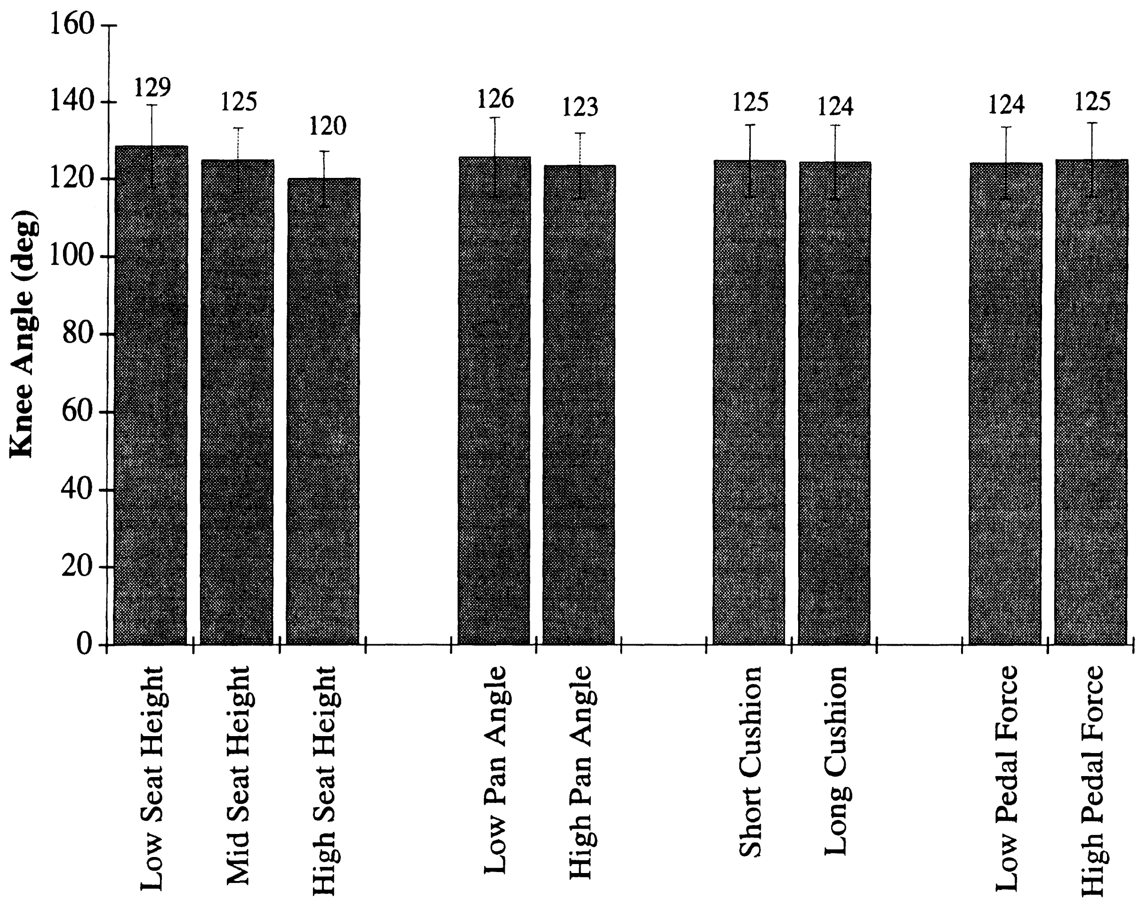


Figure 51. Overall mean knee angle by independent variables.

Table 19
Overall Mean Leg Angle re Horizontal by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	36.2	6.59
Mid Seat Height	192	45.0	5.72
High Seat Height	192	54.9	5.53
Low Pan Angle	288	44.2	10.17
High Pan Angle	288	46.5	9.12
Short Cushion	288	45.2	9.70
Long Cushion	288	45.6	9.74
Low Pedal Force	288	45.5	9.68
High Pedal Force	288	45.3	9.77

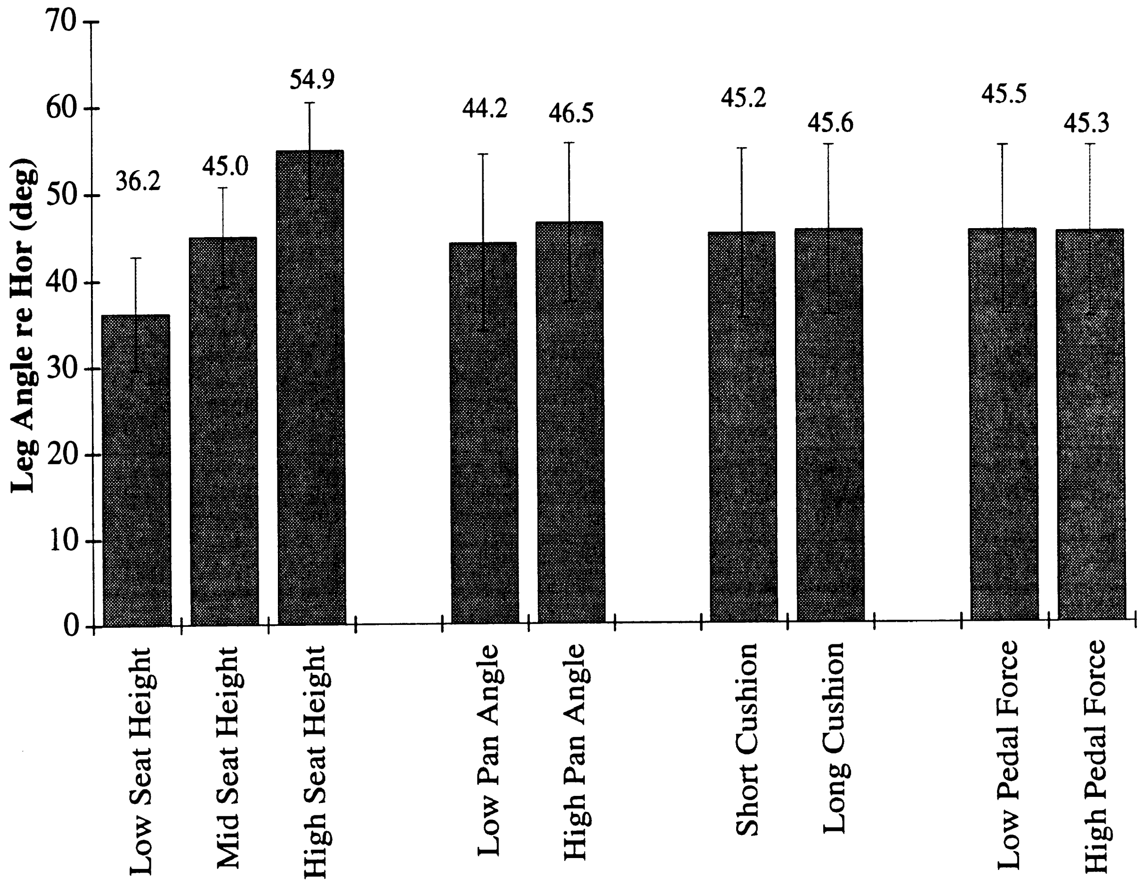


Figure 52. Overall mean leg angle by independent variables.

Table 20
Overall Mean Thigh Angle re Horizontal by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	14.7	6.74
Mid Seat Height	192	10.2	5.41
High Seat Height	192	5.3	4.92
Low Pan Angle	288	9.9	7.16
High Pan Angle	288	10.3	6.66
Short Cushion	288	9.8	6.96
Long Cushion	288	10.3	6.87
Low Pedal Force	288	10.2	6.87
High Pedal Force	288	9.9	6.97

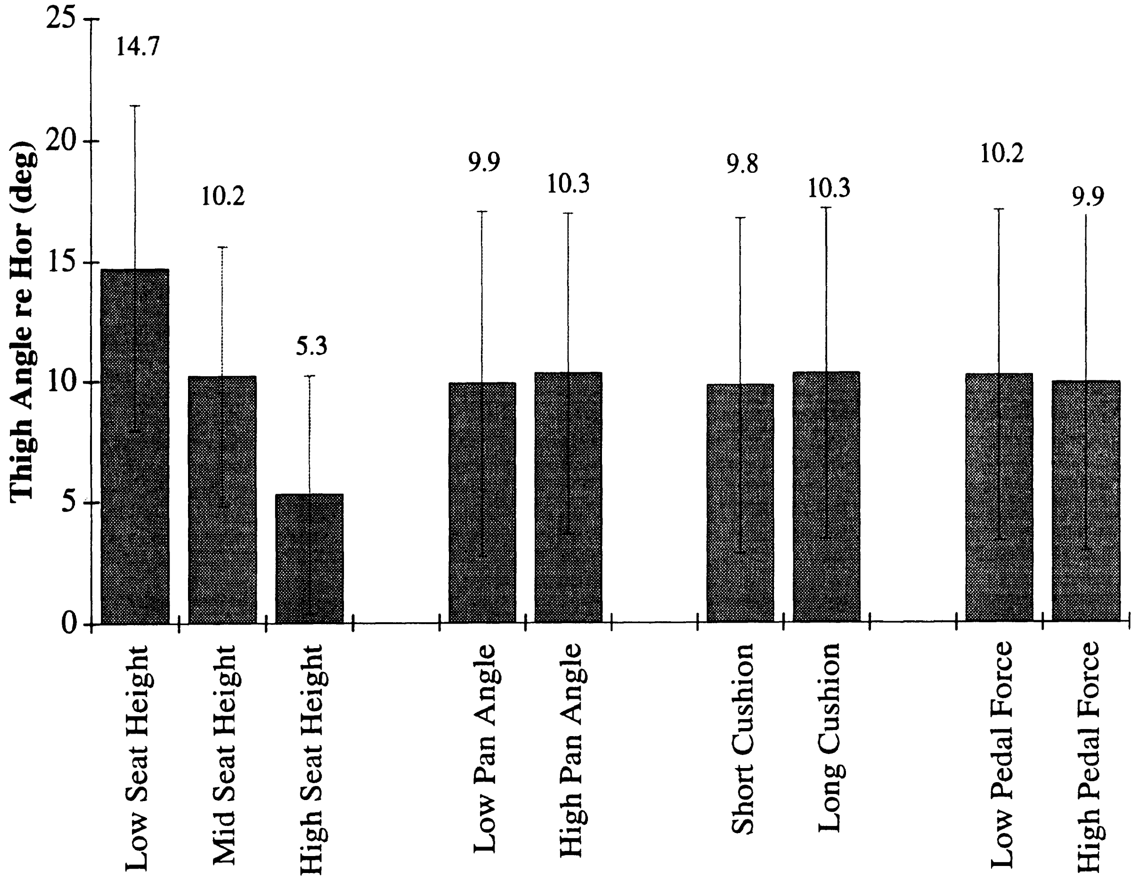


Figure 53. Overall mean thigh angle by independent variables.

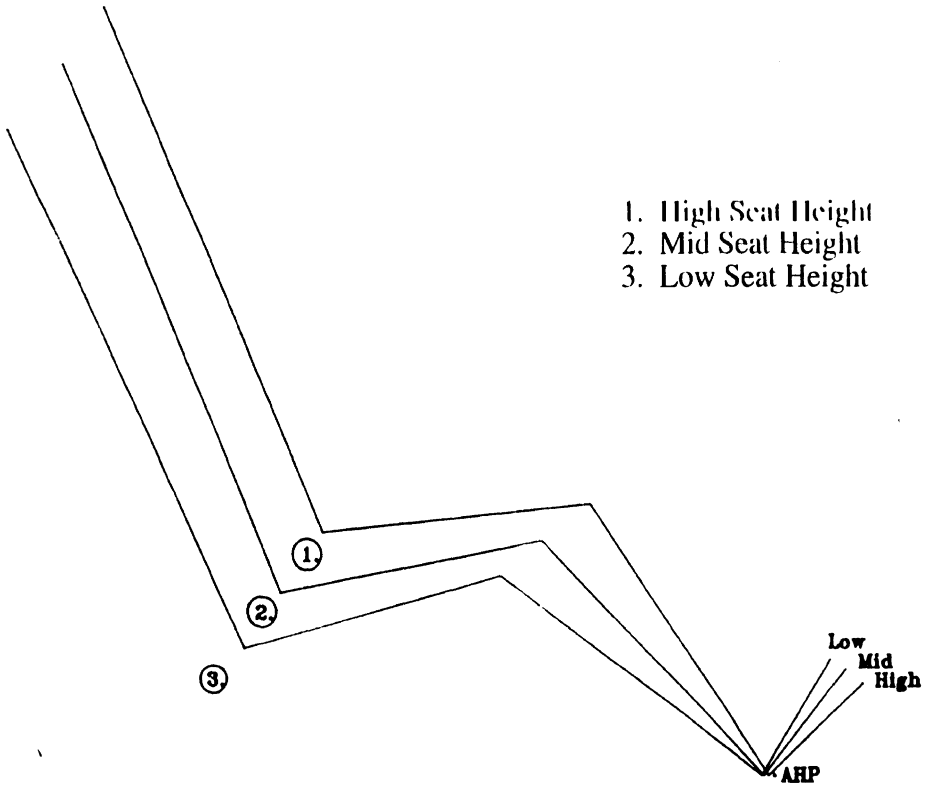


Figure 54a. Stick-figure drawings using overall mean seatback angles, thigh angles, leg angles, and foot angles at low, mid, and high seat heights.

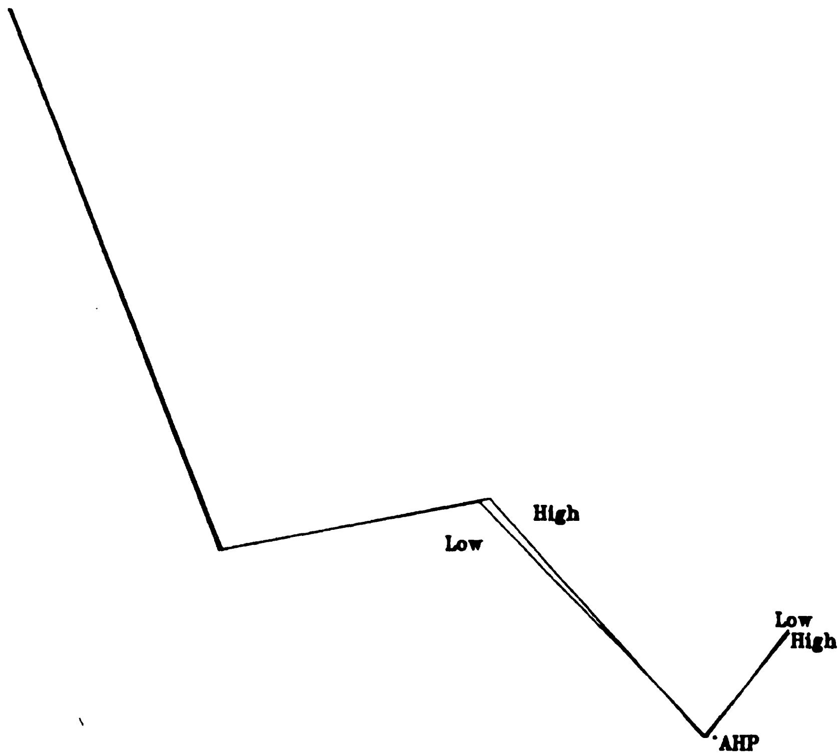


Figure 54b. Stick-figure drawings using overall mean seatback angles, thigh angles, leg angles, and foot angles at low and high seatpan angles.

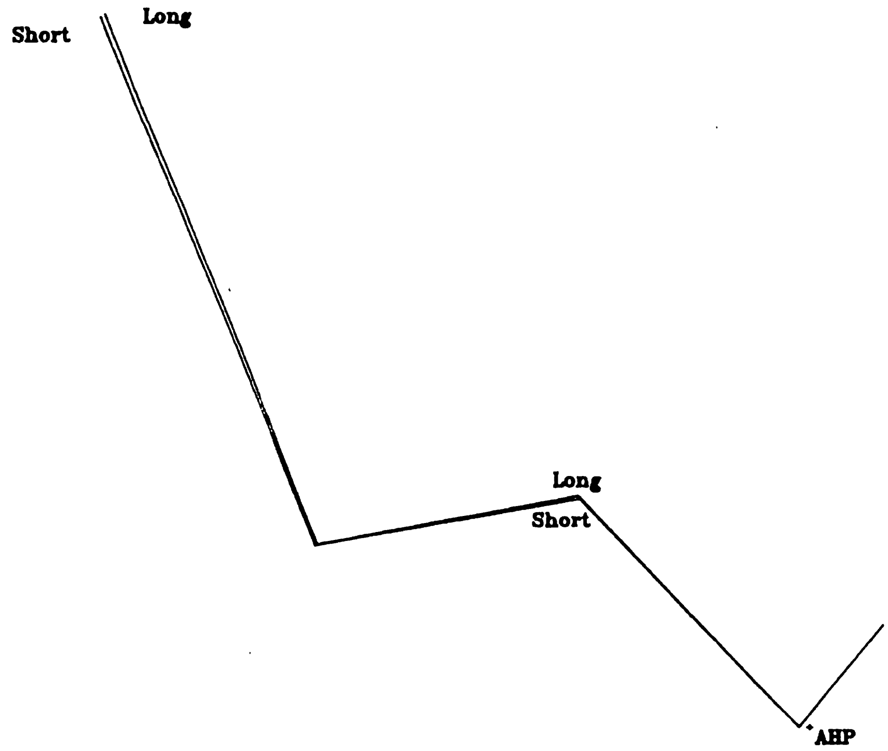


Figure 54c. Stick-figure drawings using overall mean seatback angles, thigh angles, leg angles, and foot angles at short and long cushion length values.

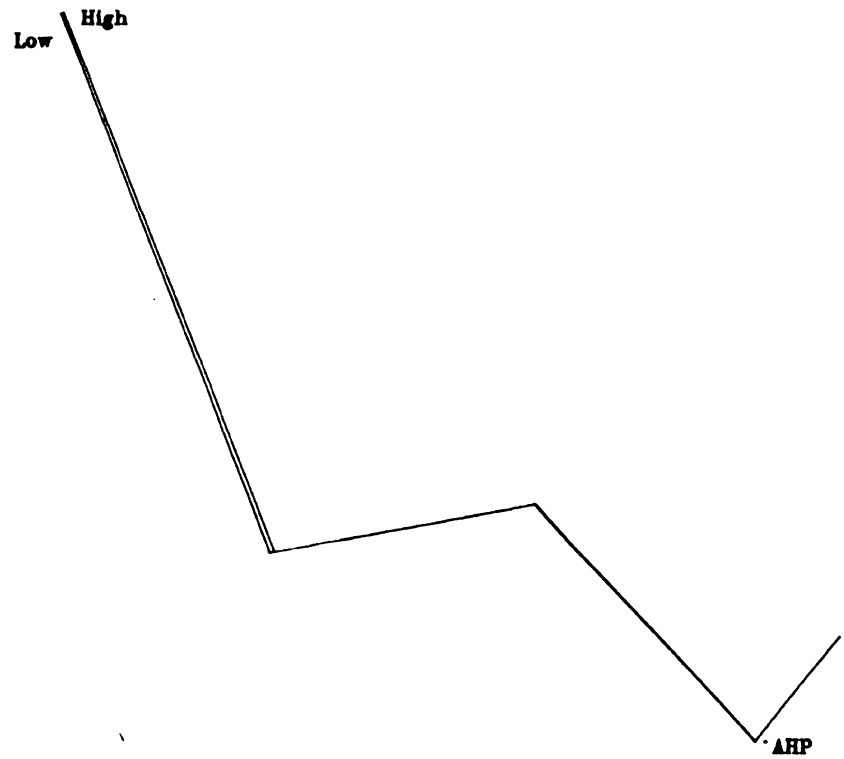


Figure 54d. Stick-figure drawings using overall mean seatback angles, thigh angles, leg angles, and foot angles at low and high pedal force values.

Table 21
Overall Mean Foot/Pedal Contact Zone by Independent Variable

	N	Mean	Standard Deviation
Low Seat Height	192	4.2	0.51
Mid Seat Height	192	4.3	0.50
High Seat Height	192	4.4	0.49
Low Pan Angle	288	4.3	0.51
High Pan Angle	288	4.3	0.51
Short Cushion	288	4.3	0.50
Long Cushion	288	4.3	0.52
Low Pedal Force	288	4.5	0.53
High Pedal Force	288	4.1	0.41

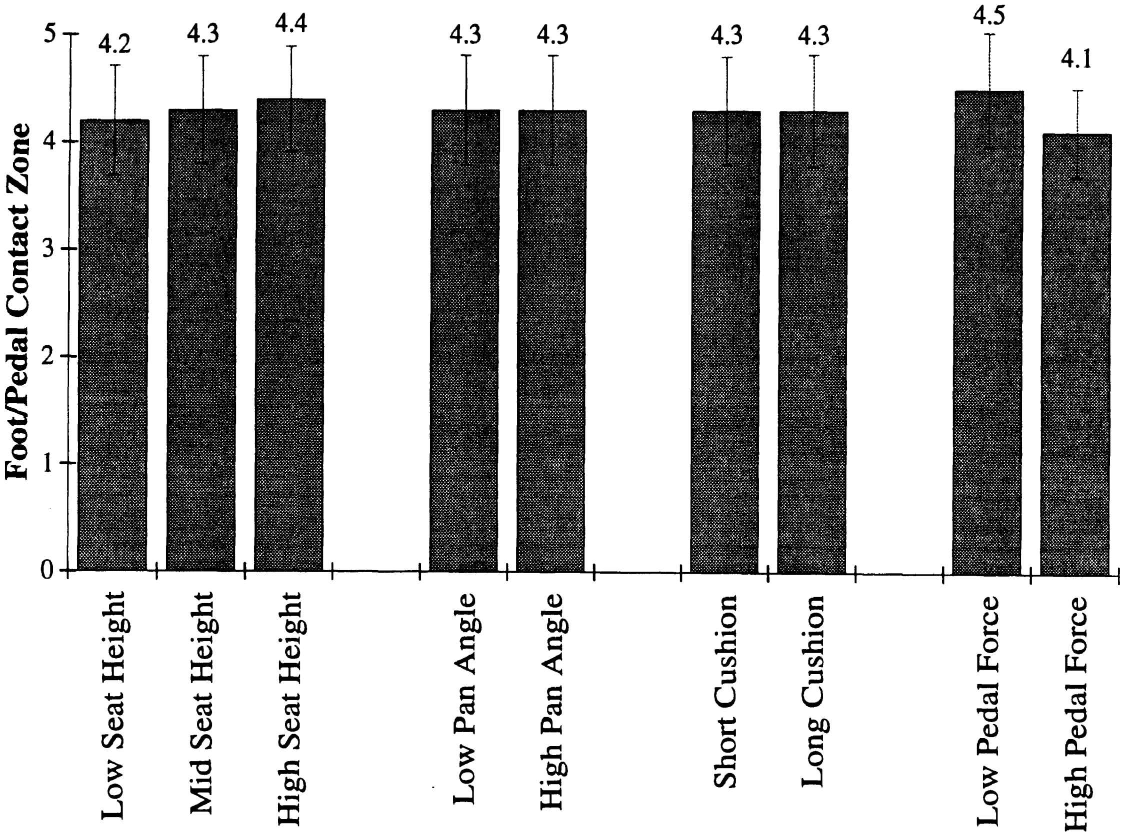


Figure 55. Overall mean foot/pedal contact zone by independent variable.
(See Figure D10-3 on page 183 for an illustration of pedal zones).

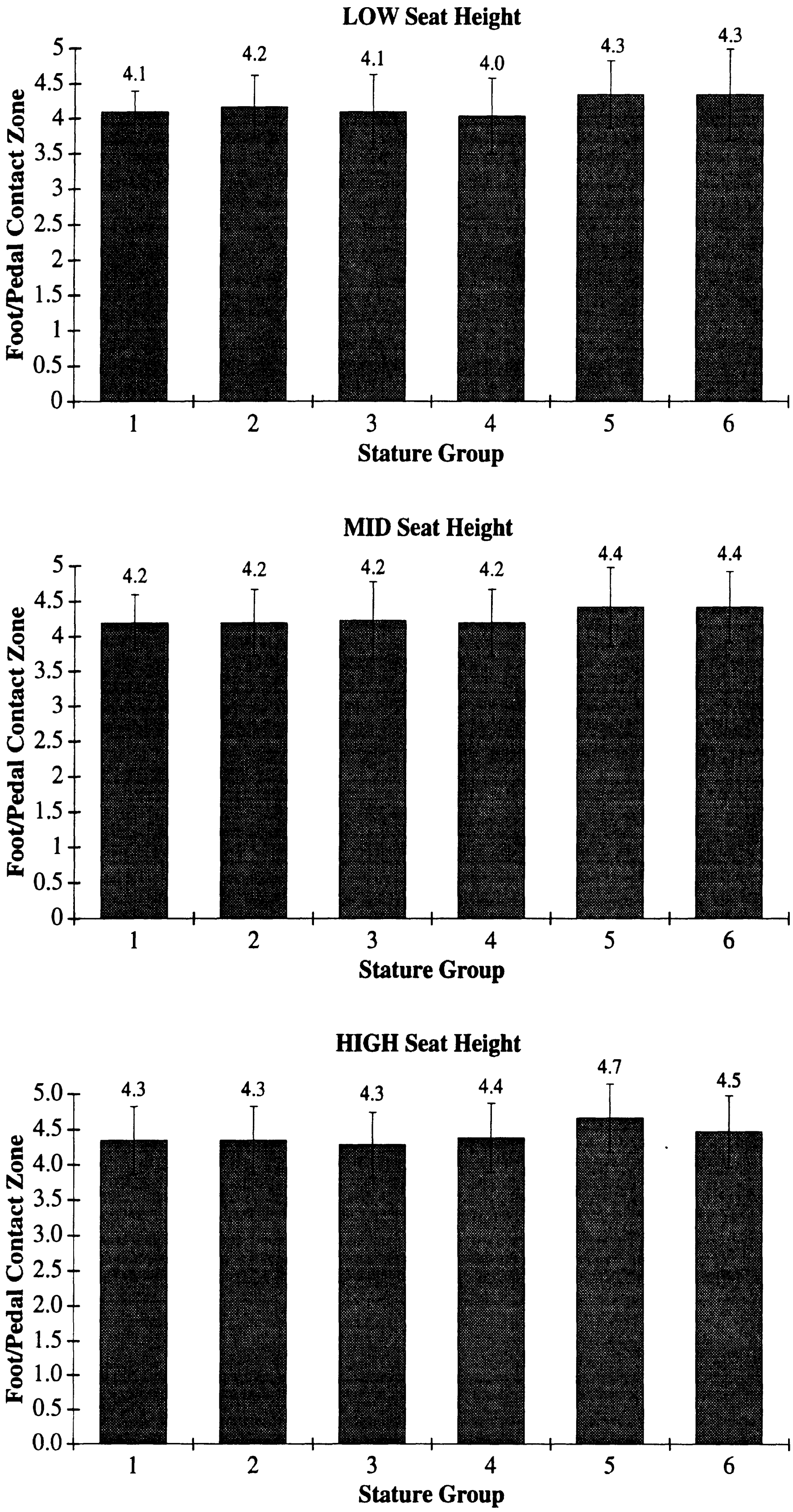


Figure 56. Foot/pedal contact zone by stature group by seat height.
(See Figure D10-3 on page 183 for an illustration of the pedal zones).
(n=192)

for each seat height. There are no significant differences in pedal contact zone by subject size and gender.

Table E-5 and Figure E-11 show results for initial ankle angle by test condition, which was calculated by subtracting initial leg angle plus initial foot pitch angle from 180 degrees. In this calculation, measured leg angle was corrected by 2.5 degrees to account for the difference in placing the inclinometer directly on top of the leg, rather than measuring the angle of the line connecting the knee joint and the ankle joint, as illustrated in Figure 57.

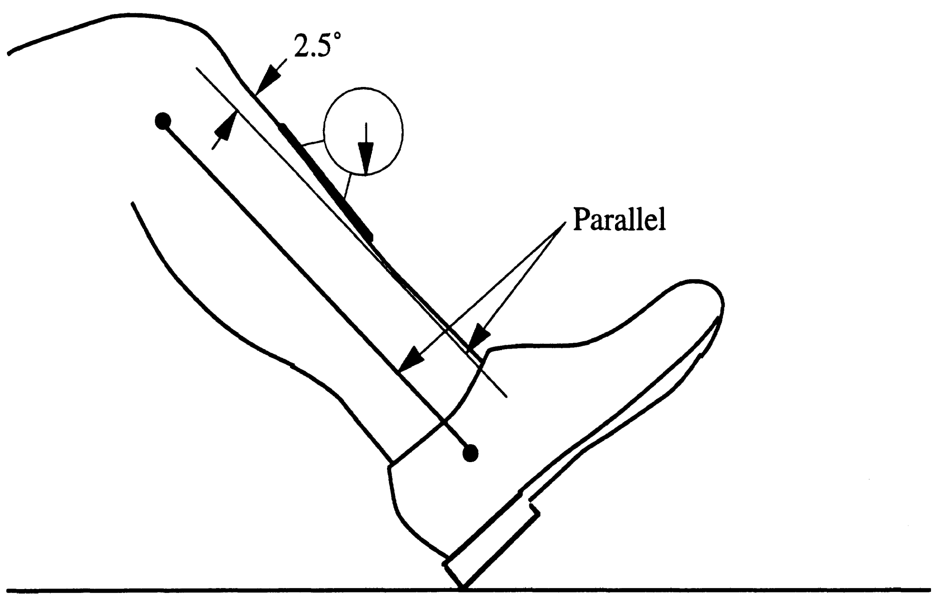


Figure 57. Leg angle adjustment.

Table 22 and Figure 58 give the overall mean values of initial ankle angle for each level of the independent variables. As shown, initial ankle angle is relatively constant, with means ranging from 86.1 to 88.8 degrees, and an overall mean of 87.3 degrees for all conditions. This agrees extremely well with the initial manikin "foot" angle setting of 87 degrees from SAE J826, which is the angle between the leg line connecting the knee joint and the ankle joint and the manikin "bare foot flesh line." As indicated in Figure 59, there is no relationship between initial ankle angle and stature group.

Table 22
Overall Mean Initial Ankle Angle by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	88.8	9.08
Mid Seat Height	192	86.9	7.38
High Seat Height	192	86.1	9.06
Low Pan Angle	288	87.0	8.09
High Pan Angle	288	87.5	9.10
Short Cushion	288	87.4	8.63
Long Cushion	288	87.1	8.59
Low Pedal Force	288	86.4	8.30
High Pedal Force	288	88.1	8.83

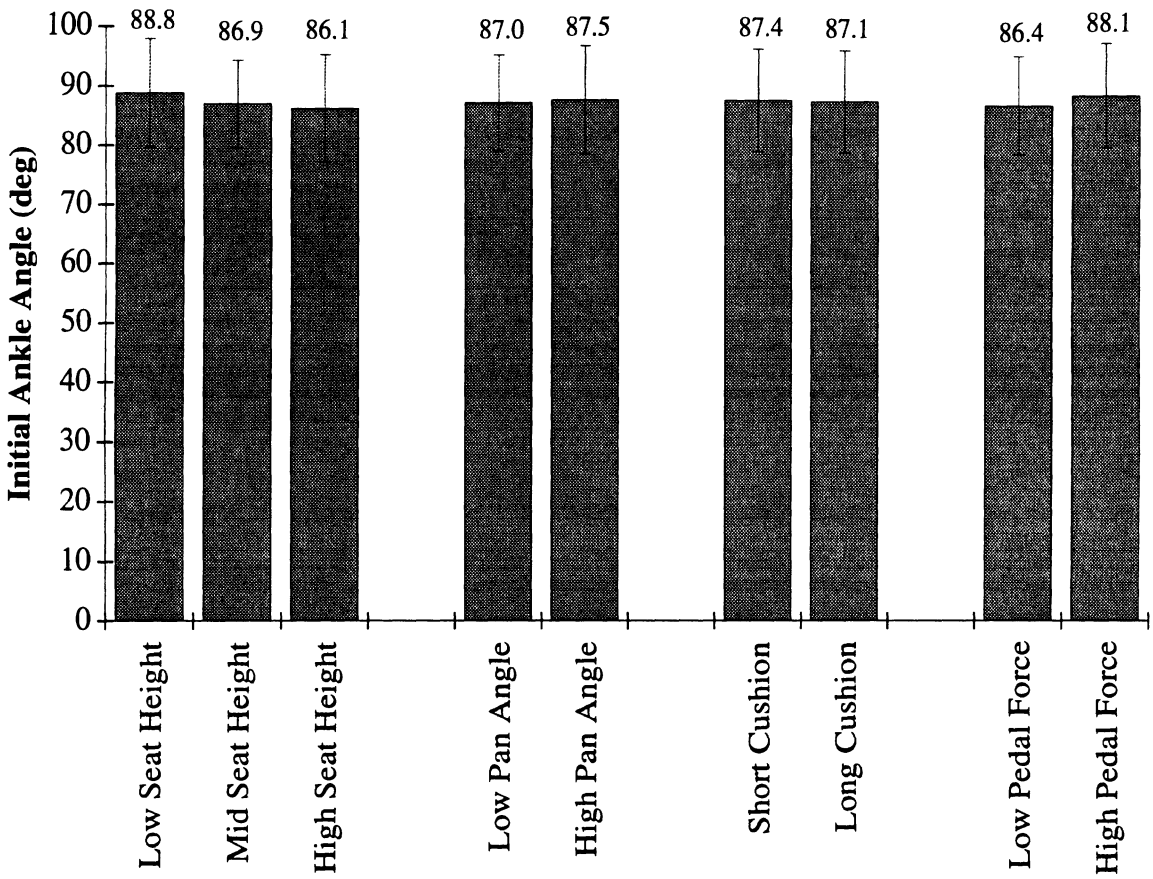
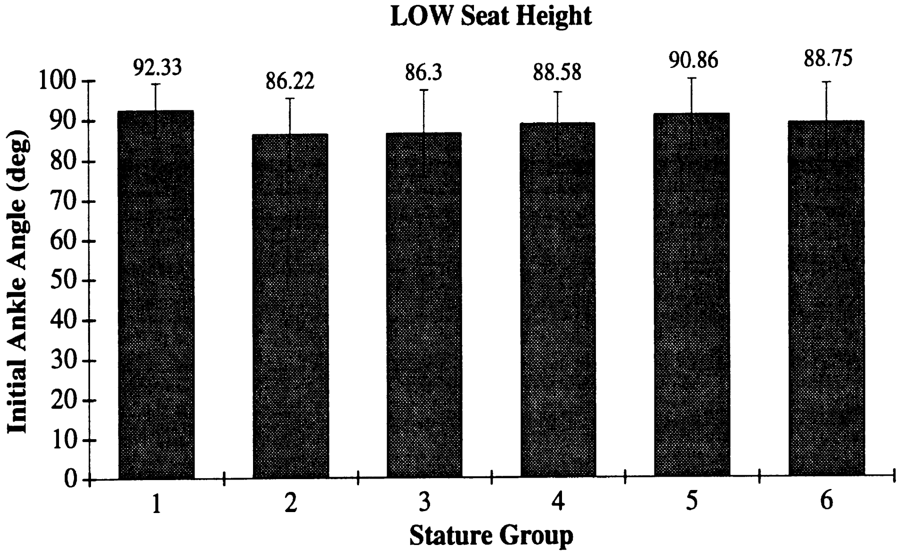
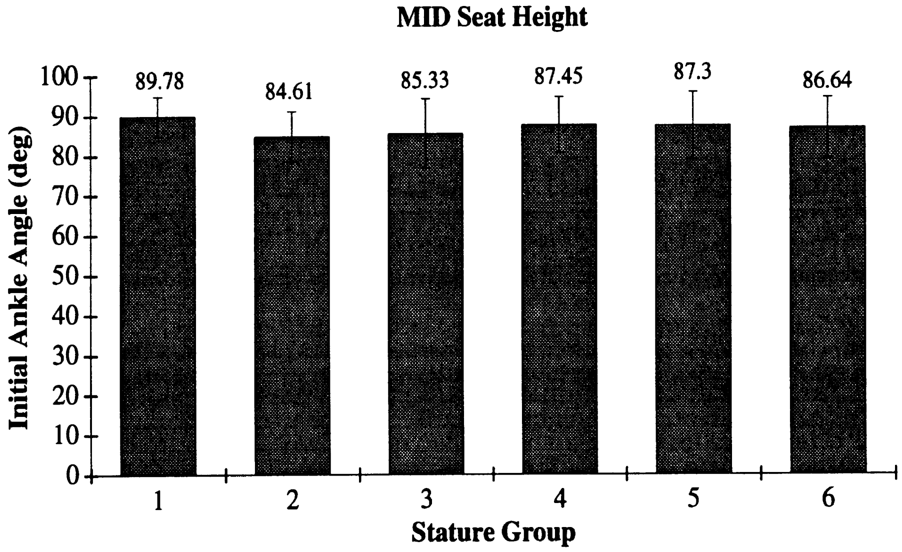


Figure 58. Overall mean initial ankle angle by independent variable.





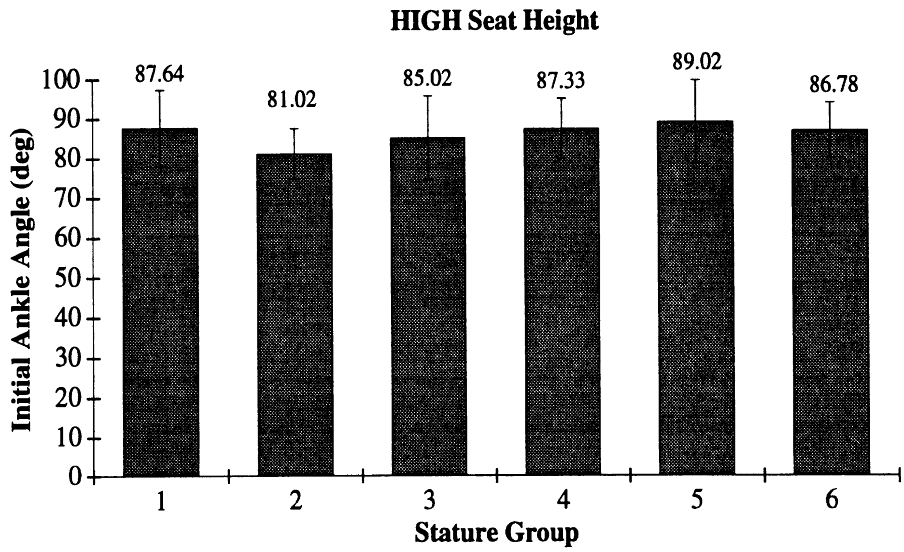


Figure 59. Initial ankle angle by stature group for each seat height.
(n=192)

3.6 RESTING FOOT FORCE

Table E-6 and Figure E-11 and E-12 in Appendix E summarize the results for resting foot force (RFF) by test condition, including the estimated actual force applied by the foot and the estimated equivalent force applied at the center of the accelerator pedal. The actual force values were computed using the measured moment and the distance from the pedal linkage pivot to the actual contact zone of the subject's foot on the pedal, while the equivalent force at the center of the pedal was computed using the distance from the pivot to the center of the pedal pad. These computations are described in Section D-10 of Appendix D.

Figure 60 shows frequency distributions of the calculated equivalent RFF at the center of the pedal pad for each seat height. The distributions are similar for all seat heights and are slightly skewed from a normal distribution toward higher values. The force values range from less than 2 lb to over 15 lb, but the overall mean values range from 4.9 lb to 5.2 lb.

Tables 23 and 24 and Figures 61 and 62 give the overall mean values of computed-actual and equivalent-center-of-pedal resting foot force, respectively, for each level of the independent variables. The mean values of the resting foot force at point of contact range from about 4.2 to 4.6 lb, while the equivalent resting foot force mean values range from about 4.6 to 5.2 lb. There is a small increase in mean RFF with increasing seat height and a small decrease with increasing seatpan angle.

Figures 63 and 64 compare the overall mean RFF values for the different subject groups at the three seat heights. There is, generally, a slight increase in mean values with increasing stature for the three female groups and for the three male groups. For example, at the low seat height, the overall mean RFF increases from 3.8 lb to 5.5 lb and from 4.3 lb to 4.8 lb from group 1 to group 3 and from group 4 to group 6, respectively. It is interesting, however, that mean RFF values for the male groups are not greater than those for the female groups, and, in fact, the overall mean RFF for all male subjects is somewhat lower than for all females. The low variability in RFF across stature and gender suggests that RFF force is influenced more by ankle joint properties than by foot or shoe mass.

As previously noted, mean RFF increases slightly with seat height. It has also been noted that foot pitch angle becomes more horizontal with increasing seat height. Figure 65 shows scatter plots of mean resting foot force by subject for all conditions versus mean foot pitch angle and heel position. As shown, RFF tends to decrease with more rearward heel position

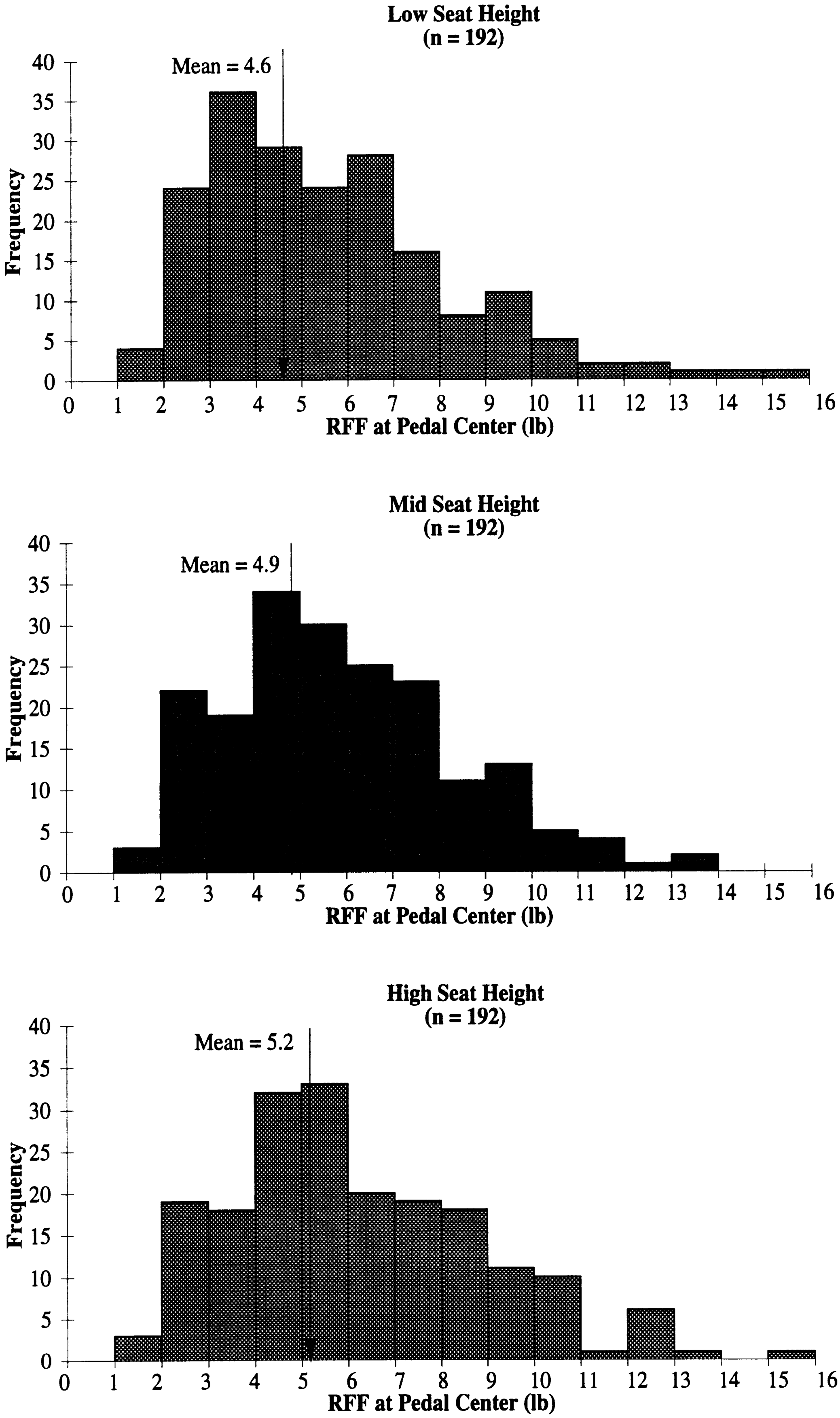


Figure 60. Frequency histograms of RFF at the pedal center by seat height.

Table 23
Overall Mean RFF at Point of Contact by Independent Variable (lb)

	N	Mean	Standard Deviation
Low Seat Height	192	4.16	2.33
Mid Seat Height	192	4.38	2.25
High Seat Height	192	4.62	2.39
Low Pan Angle	288	4.57	2.41
High Pan Angle	288	4.20	2.23
Short Cushion	288	4.42	2.30
Long Cushion	288	4.35	2.35
Low Pedal Force	288	4.37	2.38
High Pedal Force	288	4.40	2.27

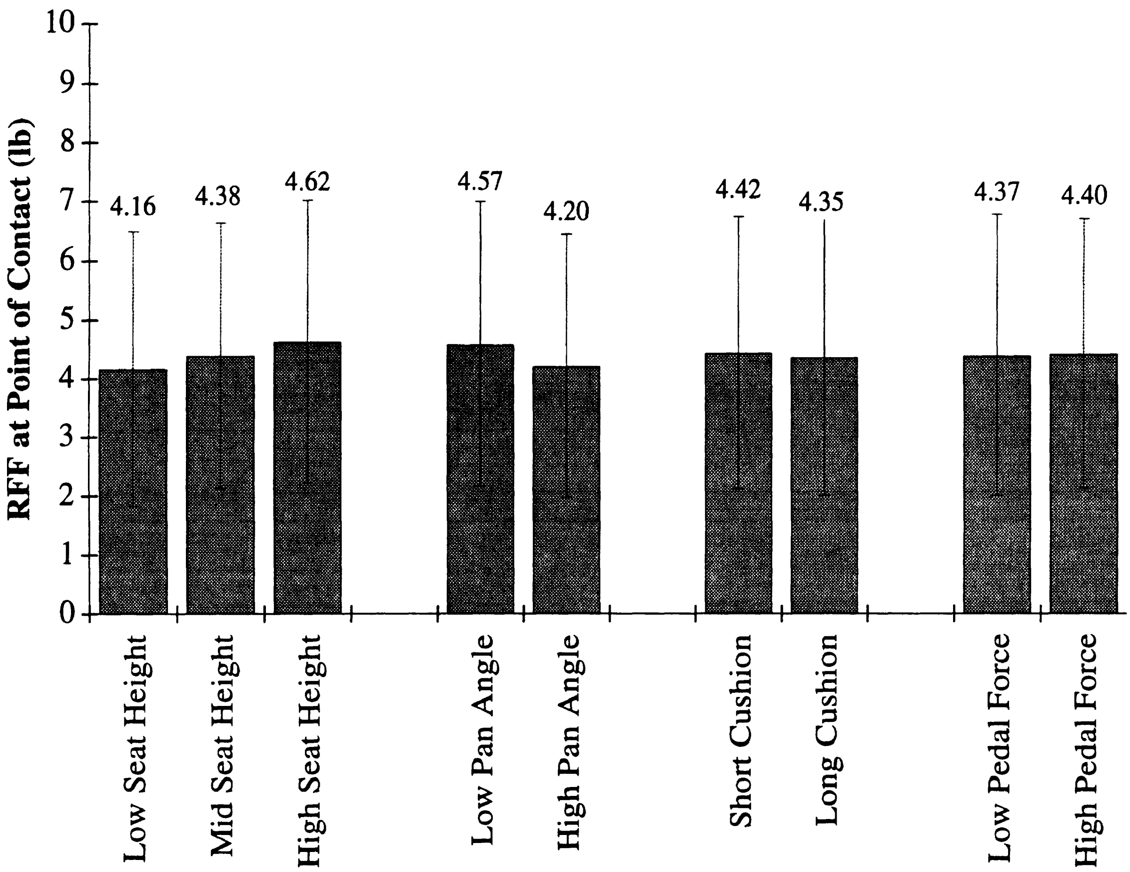


Figure 61. Overall mean RFF at point of contact by independent variable.

Table 24
Overall Mean Equivalent RFF at Pedal Center by Independent Variable (lb)

	N	Mean	Standard Deviation
Low Seat Height	192	4.61	2.63
Mid Seat Height	192	4.88	2.51
High Seat Height	192	5.2	2.7
Low Pan Angle	288	5.12	2.73
High Pan Angle	288	4.67	2.49
Short Cushion	288	4.93	2.58
Long Cushion	288	4.86	2.66
Low Pedal Force	288	4.95	2.73
High Pedal Force	288	4.83	2.51

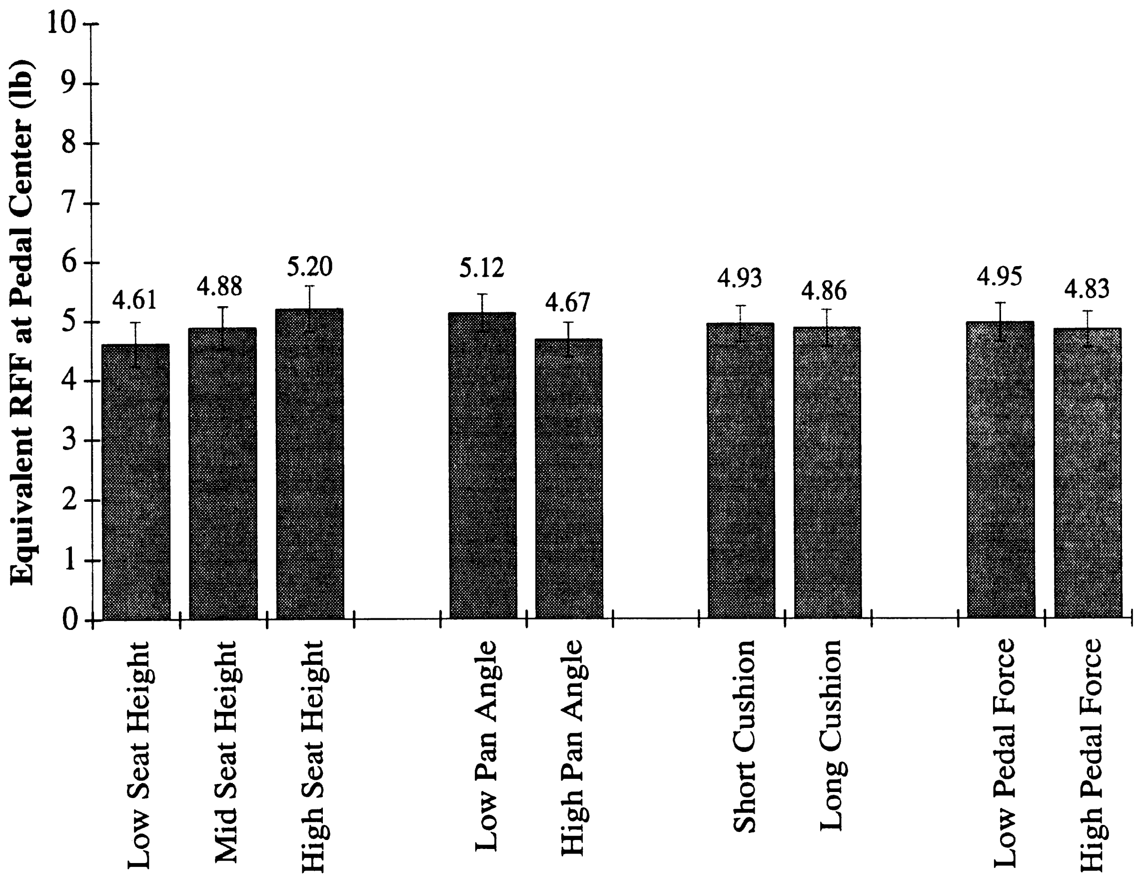


Figure 62. Overall mean equivalent RFF at pedal center by independent variable.

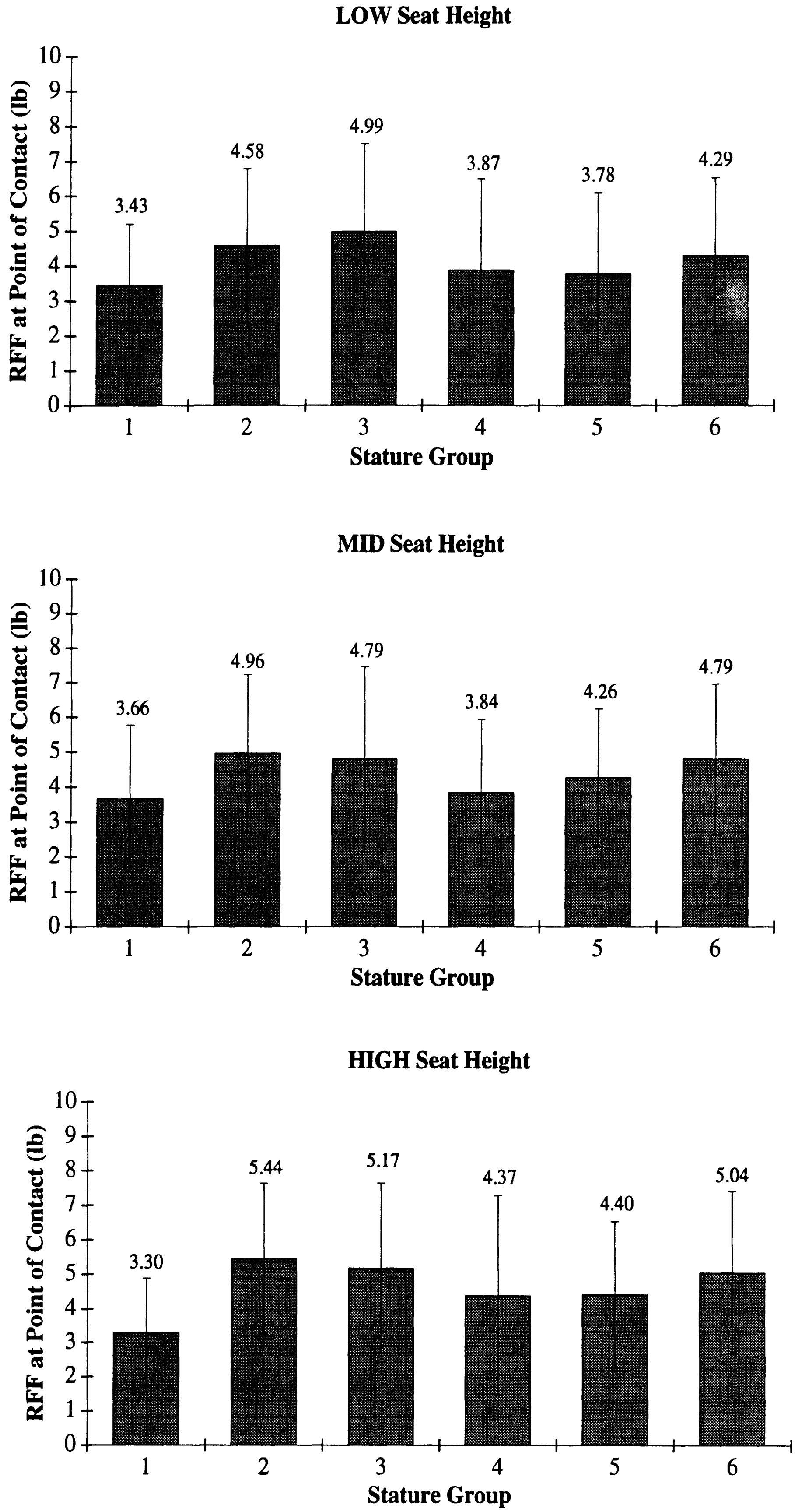


Figure 63. RFF at point of contact by stature group for each seat height. (n=192)

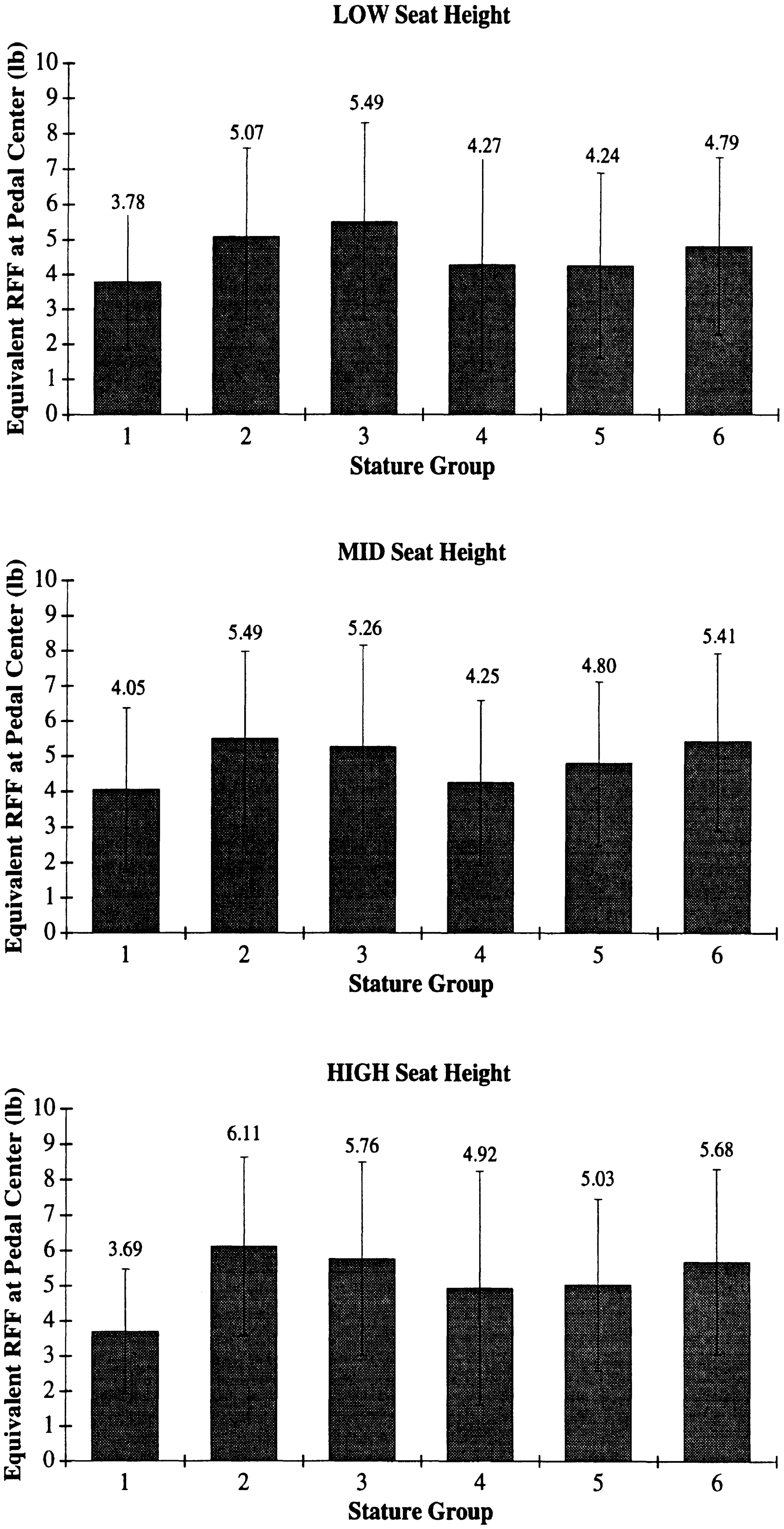
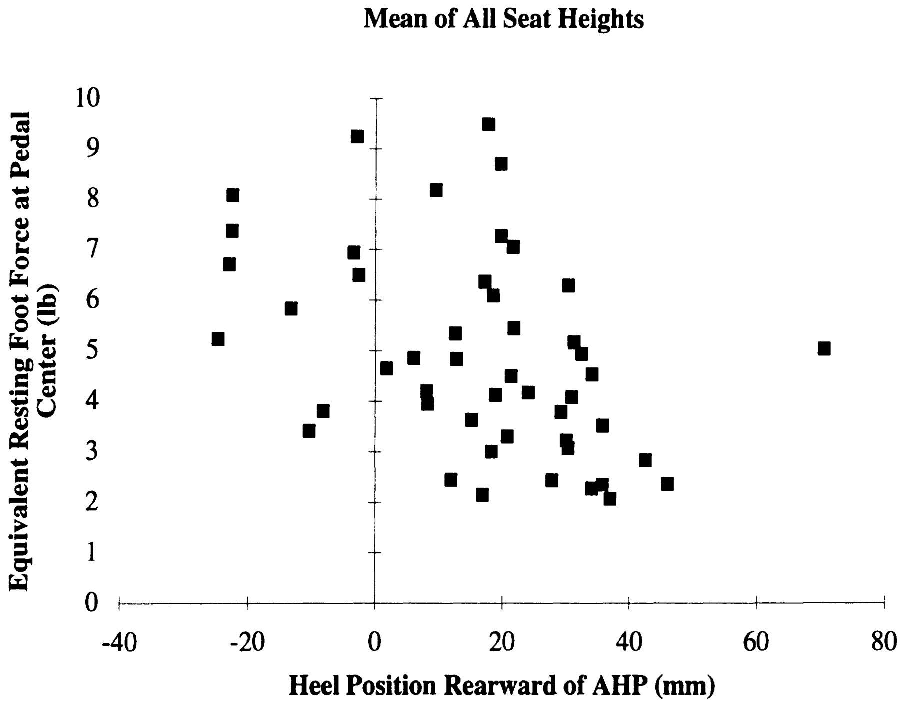


Figure 64. Equivalent RFF at pedal center by stature group for each seat height. (n=192)



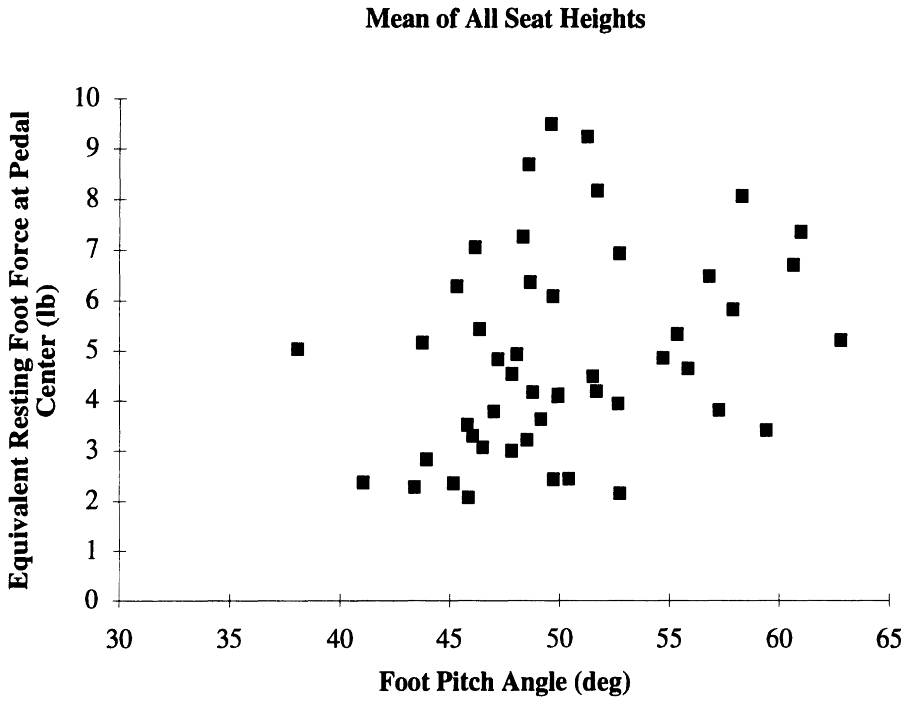


Figure 65. Mean equivalent RFF over all test conditions vs mean heel position rear of AHP and vs mean foot pitch angle.

and more vertical foot pitch angle. This is further evidence that RFF is due more to ankle joint properties than foot and shoe weight. In a previous, unpublished study, a relationship between driver knee angle and RFF was demonstrated. Figure 66 shows scatter plots of mean equivalent RFF versus knee angle at each seat height. The data show no relationships between RFF and driver knee angle.

3.7 PEDAL DISPLACEMENTS AND ANKLE EXTENSIONS

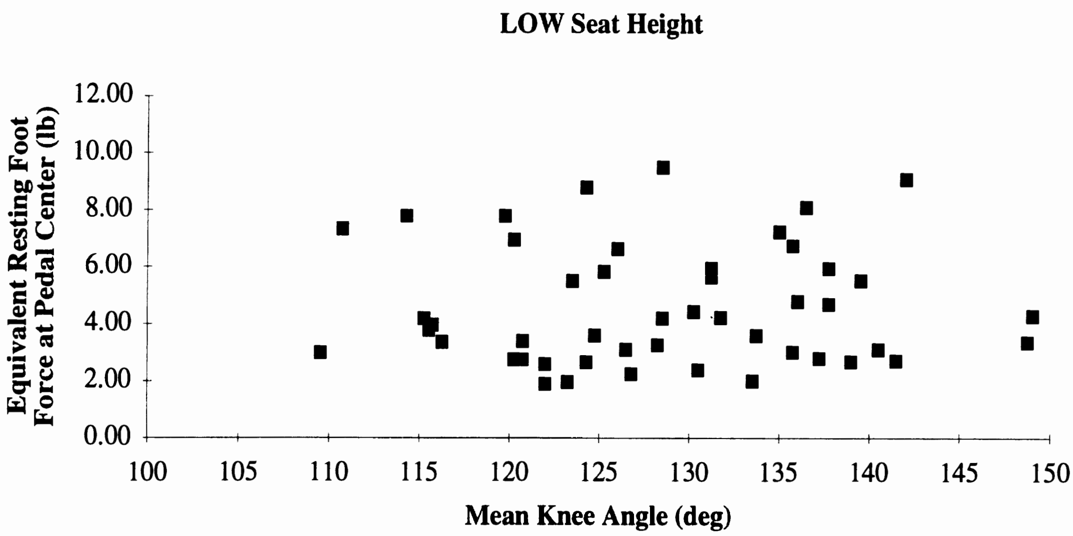
During testing, subjects were asked to depress the accelerator pedal in two ways -- first through a maximum range and then through a maximum- ***comfortable*** range. While performing these tasks, the pedal displacement and change in subject ankle angle (i.e., ankle extension) were measured by the procedures previously described (see Figures 20-21). Also, for the maximum-comfortable tests, peak pressure on the front of the seat, downward thigh displacement, and change in knee angle were measured or estimated by procedures described in Section 2.5. The results of these tests and measurements are described below.

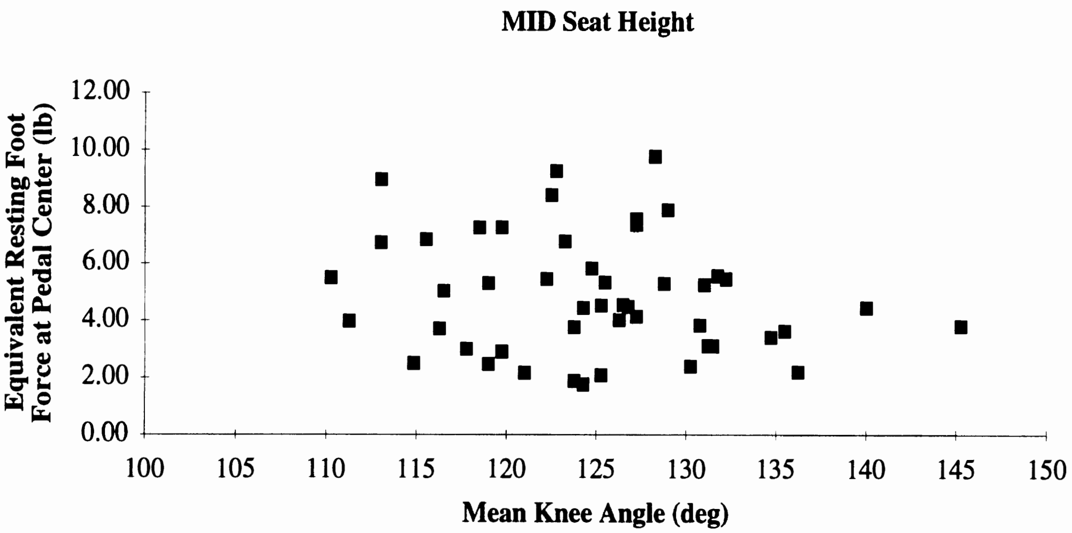
3.7.1 Maximum and Maximum-Comfortable Pedal Displacements and Ankle Extensions

Table E-7 and Figures E-14 and E-15 of Appendix E summarize the results of maximum pedal displacements (MPDs) and associated ankle extension angles for the different test conditions. Subject population mean maximum pedal displacements range from 69 to 100 mm, while mean ankle extension angles range from 18 to 30 degrees. By comparison Tables E-8 and Figures E-16 and E-17 summarize the results for maximum-comfortable pedal displacements (MCPDs) and associated ankle extension angles for the different test conditions. Subject population mean comfortable pedal displacements range from 42 to 73 mm, while mean ankle extensions ranged from 12 to 23 degrees.

Figure 67 shows scatter plots of maximum-comfortable pedal displacement versus ankle extension angle for all subjects tested at all test conditions at each of the seat heights, respectively. As expected, the correlations between the two measures are good, although pedal scrub, which results in heel slide (see below) and other anatomical factors (i.e., the ankle joint is not a perfect pin joint) reduce the theoretically perfect correlation between these measures.

As shown in the histograms of Figure 68, the distributions of MCPD are relatively normal, with a slight skewing toward larger values. The overall mean values range from 55.6 to 57.2. Tables 25 and 26 and Figures 69 and 70 compare the mean values of overall





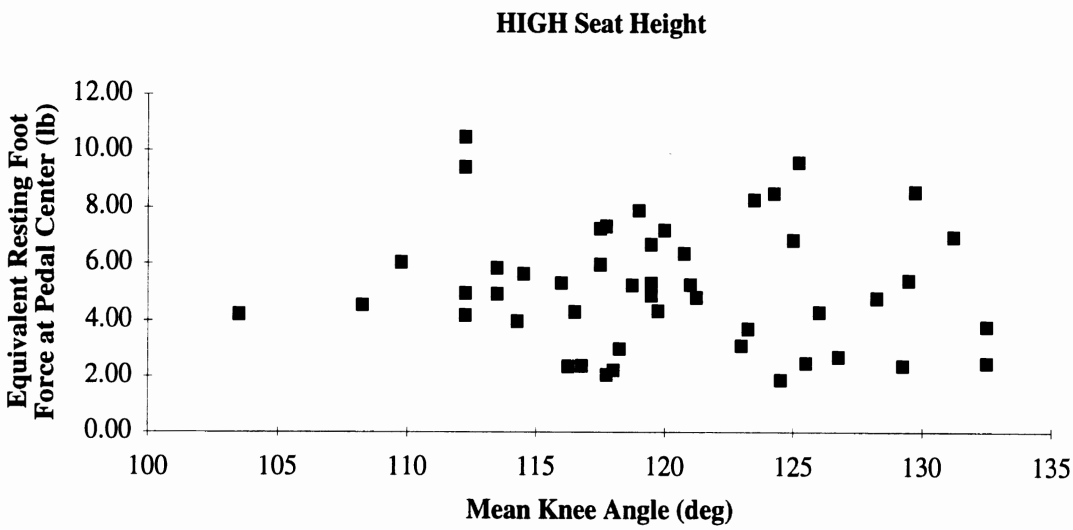


Figure 66. Equivalent resting foot force vs mean knee angle for each seat height.

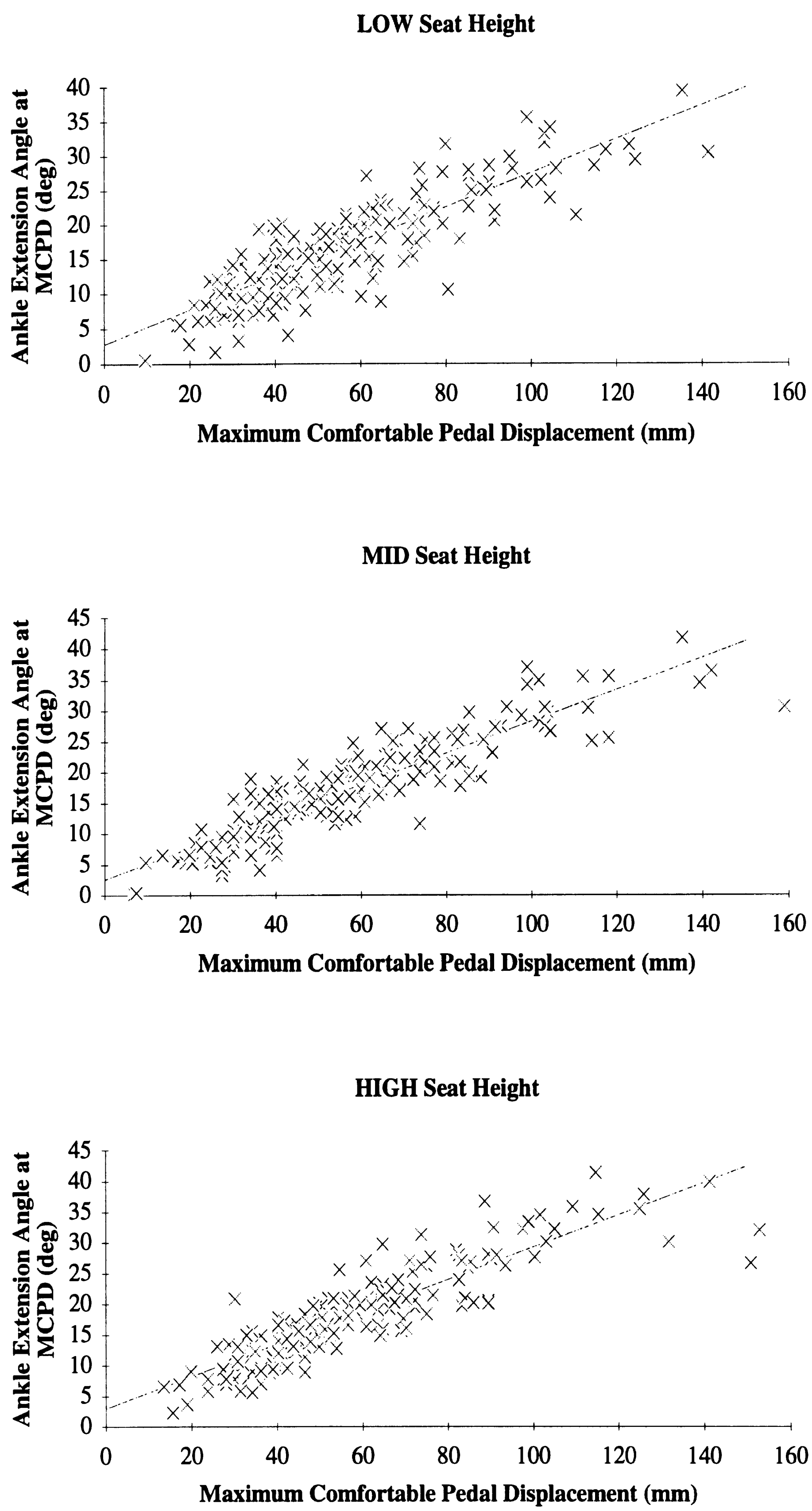


Figure 67. Maximum comfortable ankle extension angle vs pedal displacement for each seat height. (n=192)

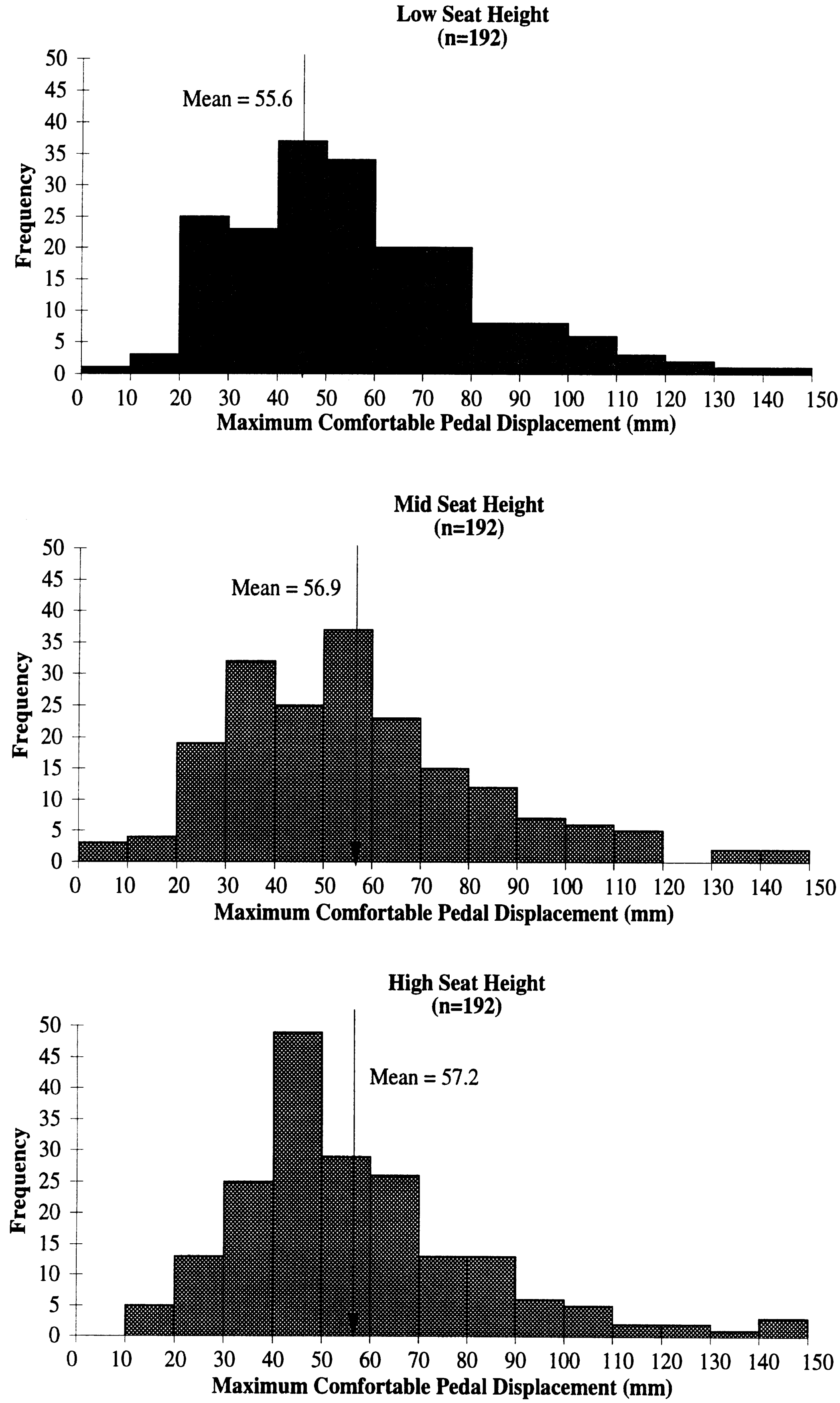


Figure 68. Frequency histograms of maximum comfortable pedal displacement by seat height.

Table 25
Overall Mean Maximum Comfortable Pedal Displacement by Independent Variable (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	55.6	24.76
Mid Seat Height	192	56.9	26.68
High Seat Height	192	57.2	25.31
Low Pan Angle	288	58.6	26.19
High Pan Angle	288	54.6	24.80
Short Cushion	288	56.8	25.91
Long Cushion	288	56.3	25.25
Low Pedal Force	288	65.5	25.97
High Pedal Force	288	47.6	21.74

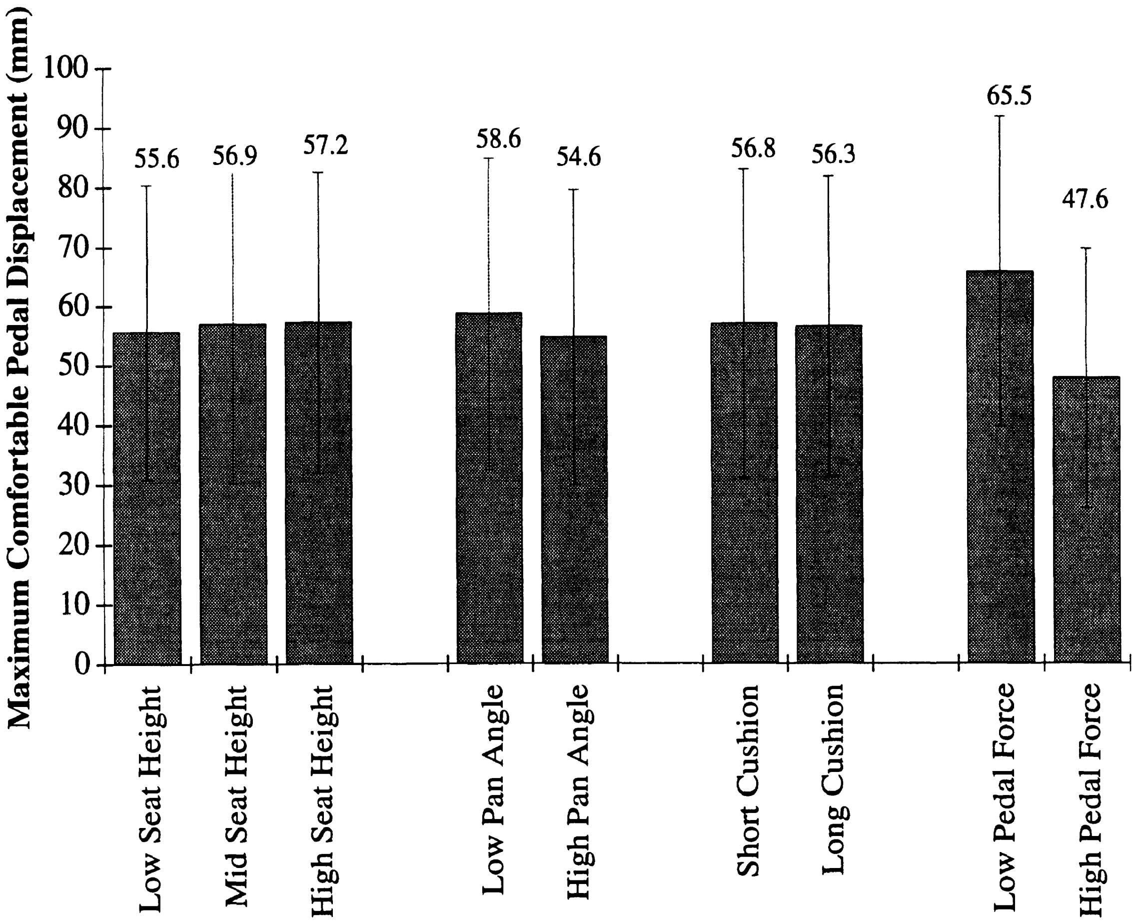


Figure 69. Overall mean maximum comfortable pedal displacement by independent variable.

Table 26
Overall Mean Ankle Extension at MCPD by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	16.5	7.19
Mid Seat Height	192	17.2	7.69
High Seat Height	192	18.0	7.57
Low Pan Angle	288	18.2	7.53
High Pan Angle	288	16.3	7.36
Short Cushion	288	17.6	7.76
Long Cushion	288	16.9	7.21
Low Pedal Force	288	20.2	6.91
High Pedal Force	288	14.3	6.89

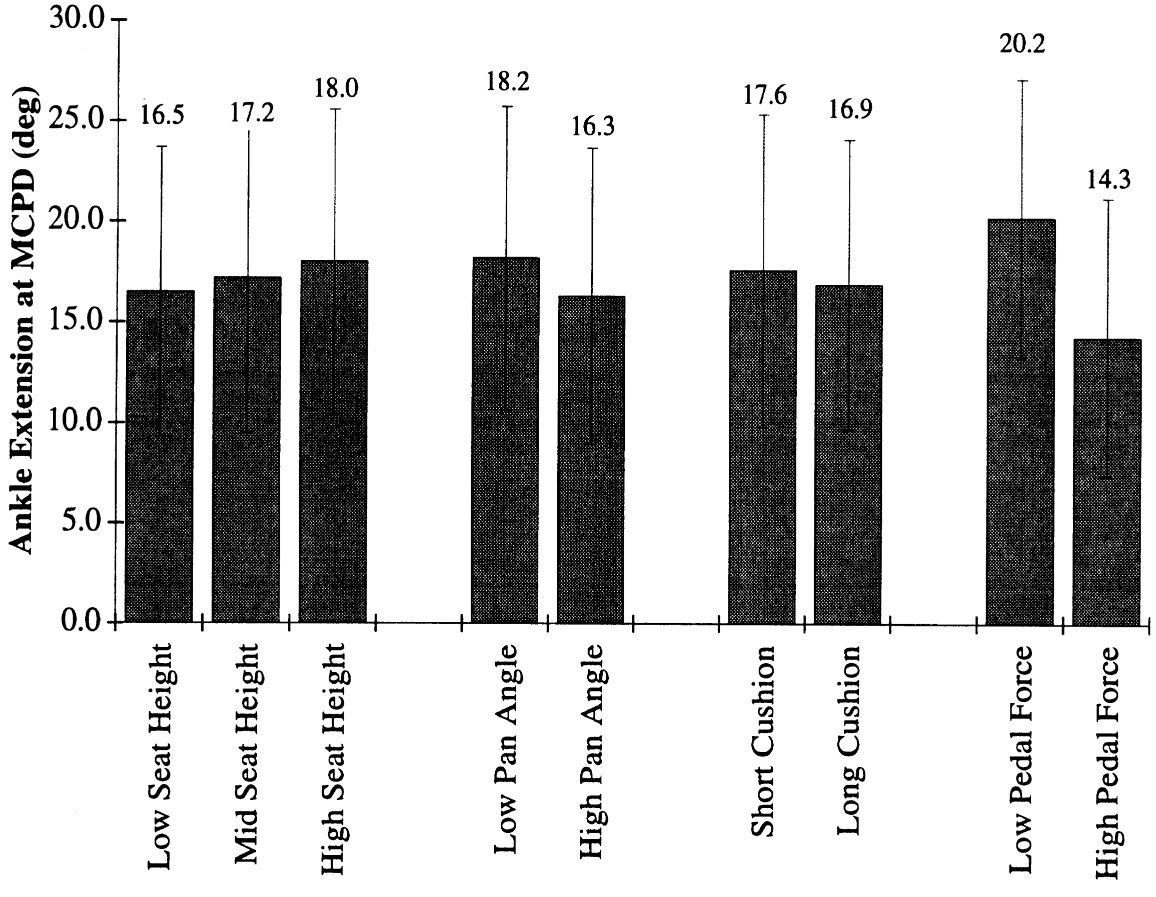


Figure 70. Overall mean ankle extension at MCPD by independent variable.

maximum-comfortable pedal displacement and ankle extensions for the different levels of the independent variables. The primary independent variable affecting pedal displacement is pedal force. Somewhat unexpectedly, seatpan angle, seat cushion length, and seat height have relatively little effect on these results.

Figure 71 shows the effects of gender/stature on pedal displacement and ankle extension. There is a trend within gender for taller subjects to have larger MCPDs but, overall, the mean values for tall females are the largest.

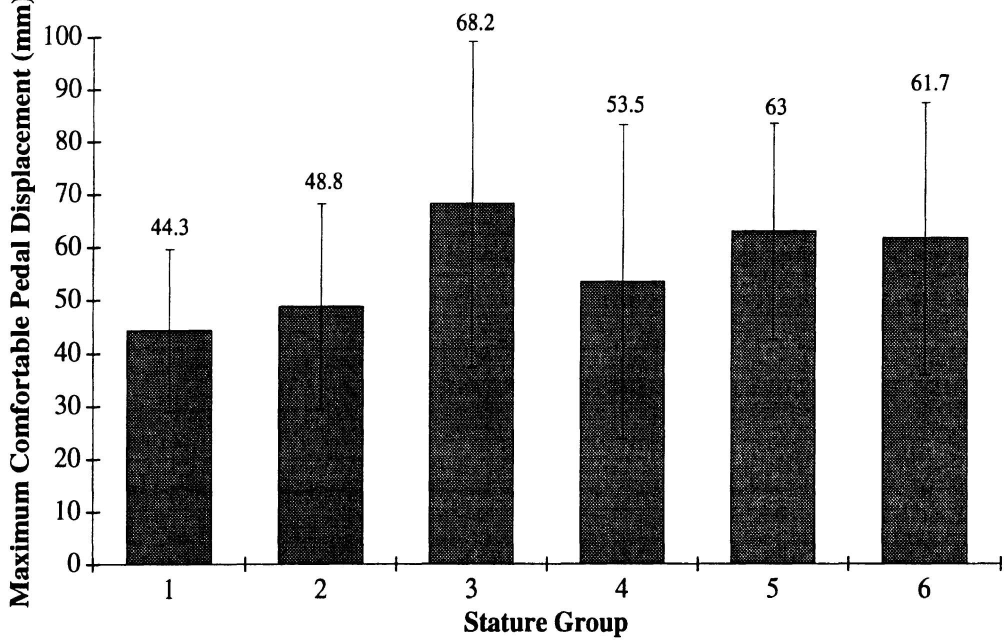
3.7.2 Equivalent Changes in Manikin Foot Angles

The pedal displacement results were used to compute changes in manikin foot angle based on initial foot orientation and manikin geometry as described in Section D9 of Appendix D. This was done for the manikin with the 95th-percentile male leg lengths at the corresponding 95th-percentile population seat position according to J1517, as well as for the manikin set to 50th-percentile male leg length and 50th-percentile population seat position from J1517.

The results of these calculations are plotted in Figures E-18 through E-21 of Appendix E and are summarized in Table E-9 and E-10. Figure 72 shows frequency distributions of equivalent change in 95th-percentile manikin for MCPD at the three seat heights. The values are normally distributed with an overall mean value of about 16 degrees at each seat height.

Tables 27 through 30 and Figures 73 through 76 give the overall mean change in 95th- and 50th-percentile manikin foot angle for the MPD and the MCPD. Changes in foot angle for the 95th-percentile manikin range from 19 to 24 degrees for maximum pedal displacements and 13 to 20 degrees for the maximum-comfortable pedal displacements. The overall mean changes in manikin foot angle are 21 and 16 degrees for maximum and maximum-comfortable displacements, respectively. For the 50th-percentile manikin, the mean values range from 14 to 21 degrees with an overall mean of 18 degrees for the maximum displacements, and from 10 to 16 degrees with a mean of 13 degrees for the maximum-comfortable displacements. These results are summarized in Table 31.

Figure 77 shows the effects of gender/stature on the change in manikin foot angle. As with pedal travel and ankle extension, there is a slight trend within gender for taller subjects to have larger changes in manikin foot angle, but overall, the mean values for the tall females are the largest.



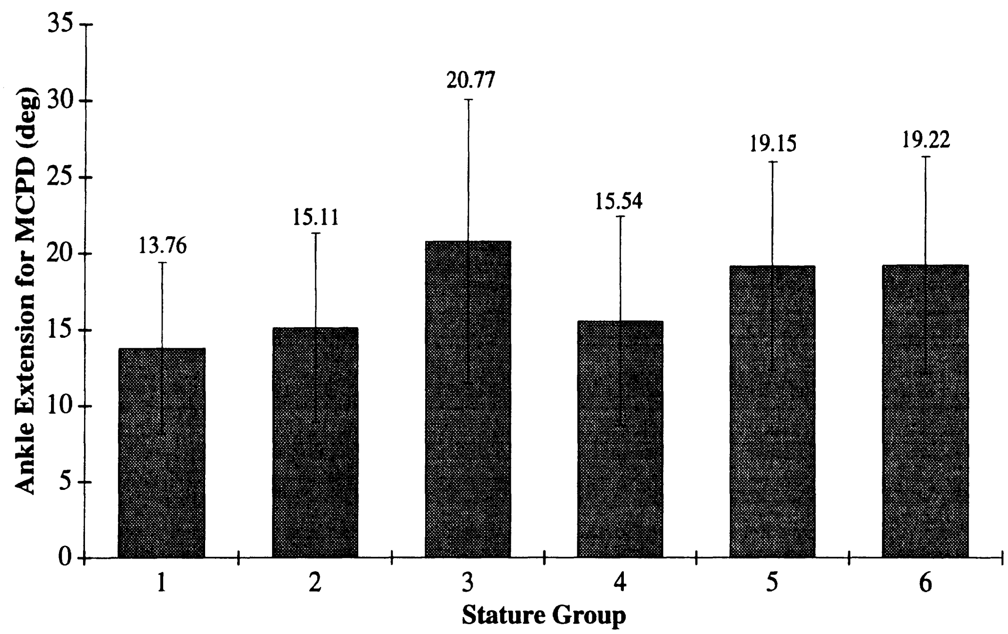


Figure 71. Maximum comfortable pedal displacement and associated ankle extension by stature group. (n=576)

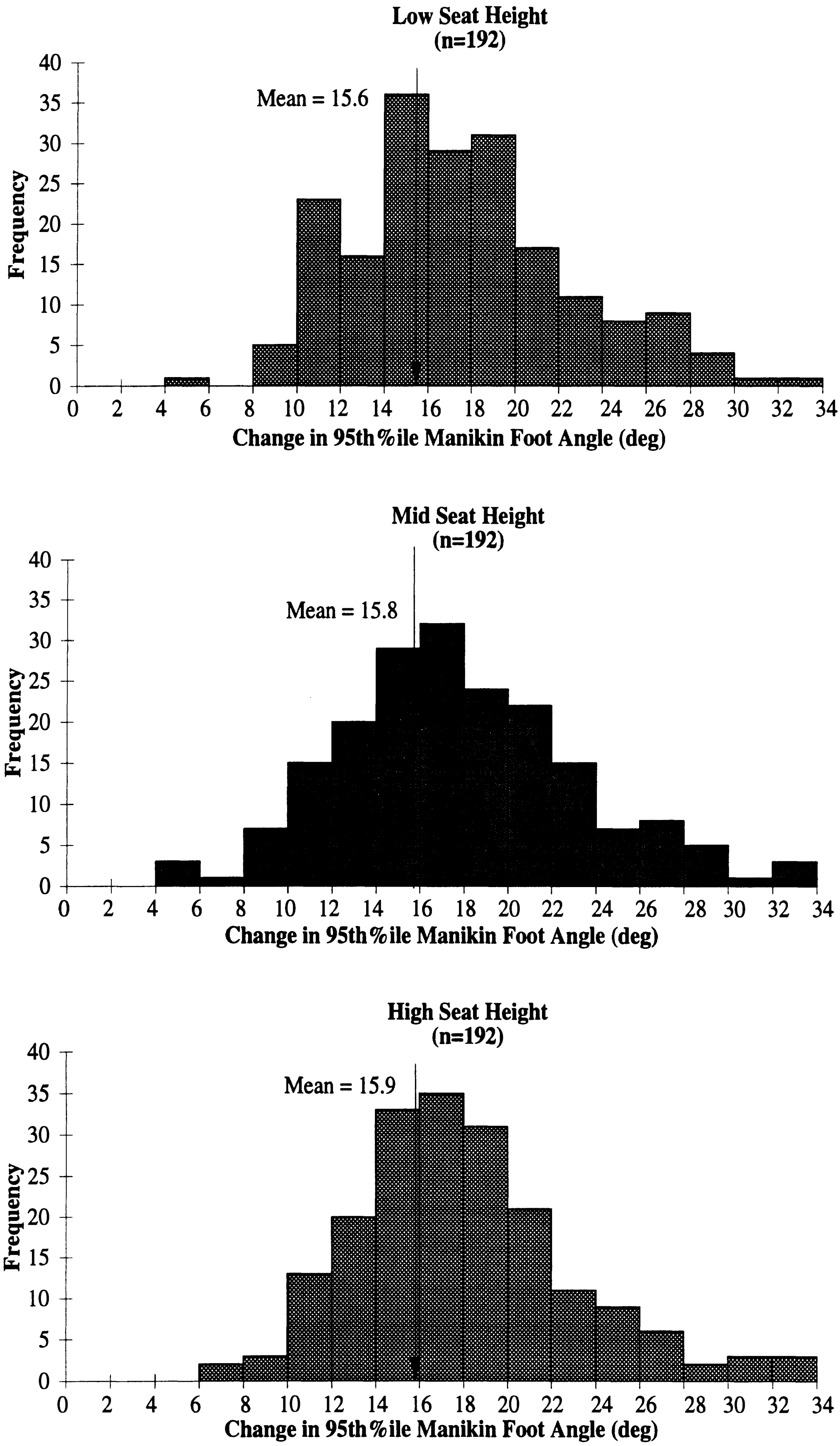


Figure 72. Frequency histograms of change in 95th%ile manikin foot angle by seat height.

Table 27
Overall Mean Change in 95th%ile Manikin Foot Angle for MPD by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	20.7	5.43
Mid Seat Height	192	20.9	5.60
High Seat Height	192	21.1	5.61
Low Pan Angle	288	21.2	5.59
High Pan Angle	288	20.6	5.48
Short Cushion	288	20.9	5.77
Long Cushion	288	20.9	5.31
Low Pedal Force	288	22.8	5.13
High Pedal Force	288	19.0	5.29

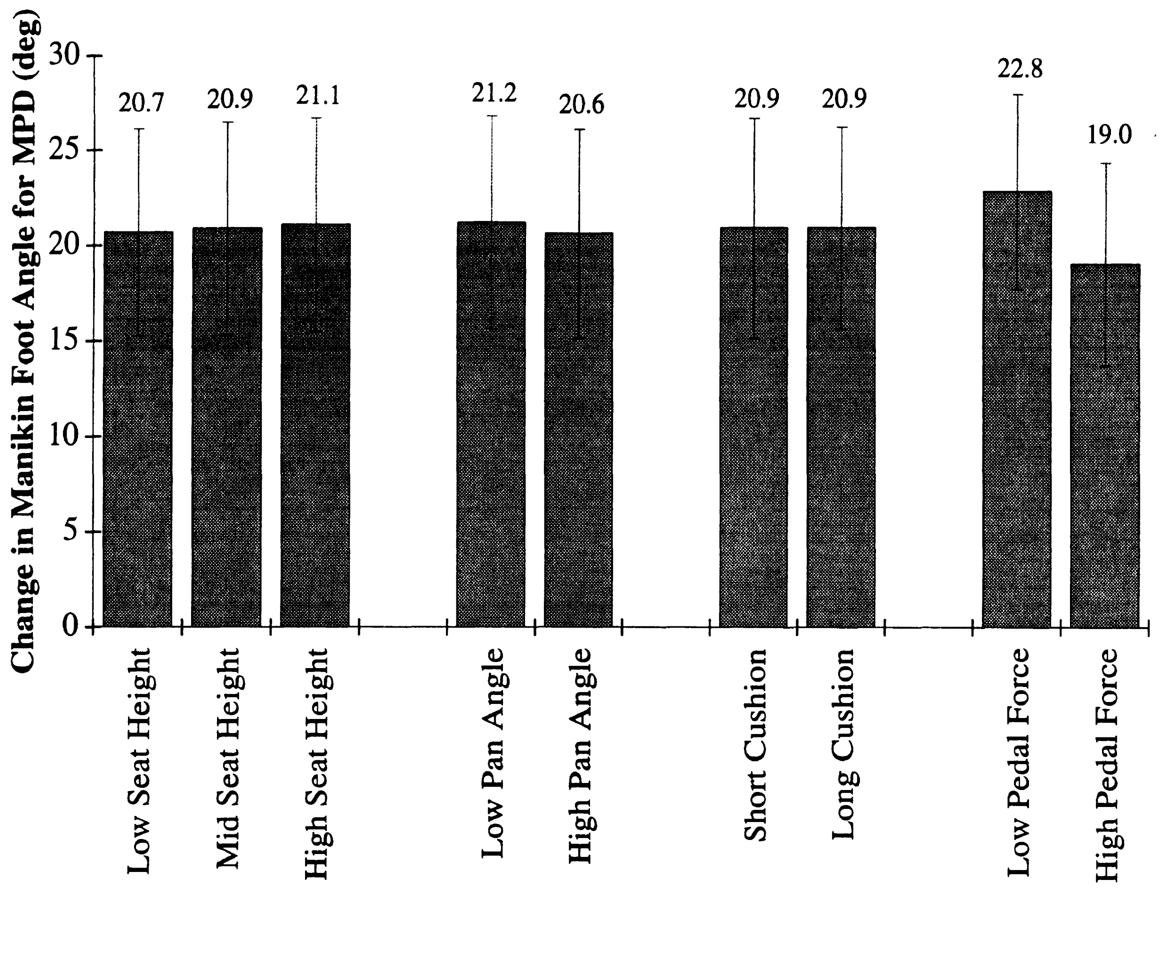


Figure 73. Overall mean change in 95th%ile manikin foot angle for MPD by independent variable.

Table 28
Overall Mean Change in 95th%ile Manikin Foot Angle for MCPD by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	15.6	5.05
Mid Seat Height	192	15.8	5.43
High Seat Height	192	15.9	5.03
Low Pan Angle	288	16.2	5.20
High Pan Angle	288	15.4	5.11
Short Cushion	288	15.8	5.25
Long Cushion	288	15.8	5.09
Low Pedal Force	288	17.7	4.88
High Pedal Force	288	13.9	4.73

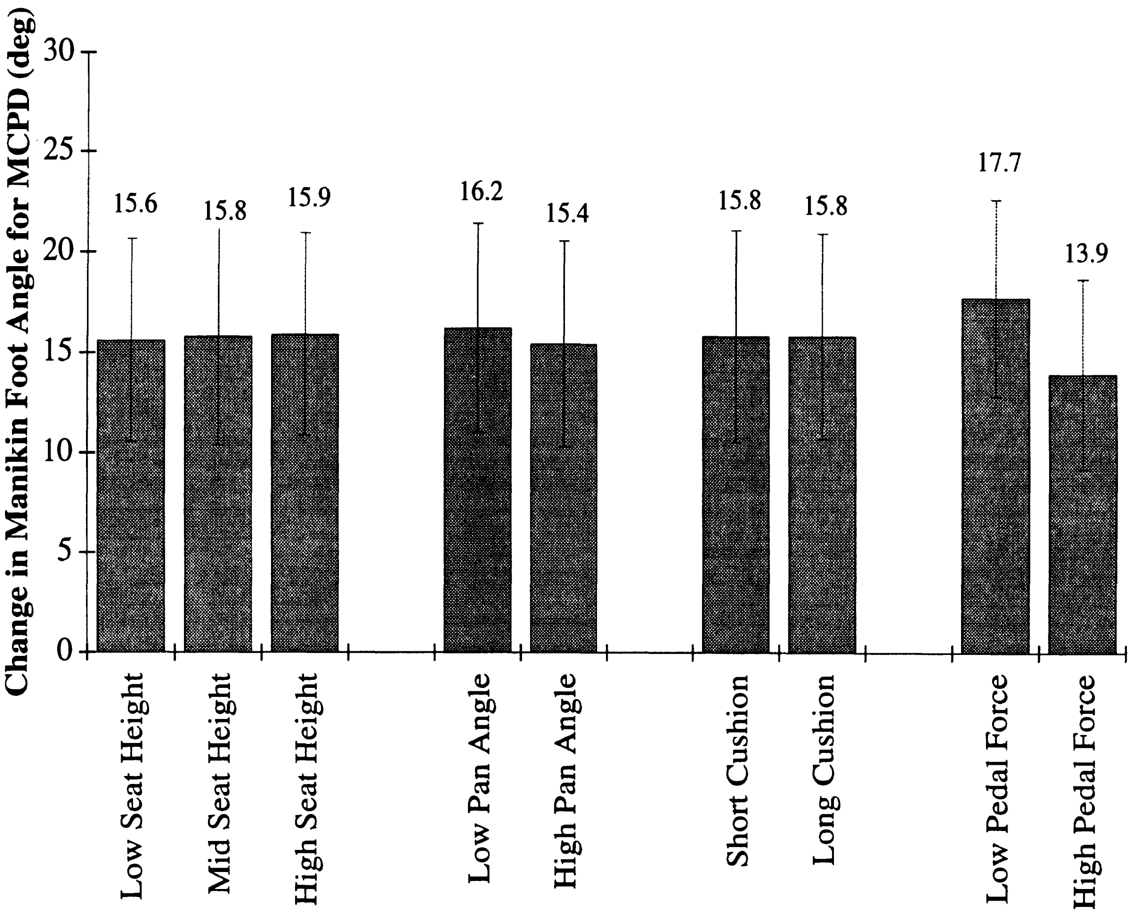


Figure 74. Overall mean change in 95th%ile manikin foot angle for MCPD by independent variable.

Table 29
Overall Mean Change in 50th%ile Manikin Foot Angle for MPD by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	17.4	6.39
Mid Seat Height	192	17.6	6.59
High Seat Height	192	17.9	6.91
Low Pan Angle	288	18.0	6.77
High Pan Angle	288	17.3	6.48
Short Cushion	288	17.8	6.93
Long Cushion	288	17.5	6.31
Low Pedal Force	288	19.8	6.90
High Pedal Force	288	15.5	5.58

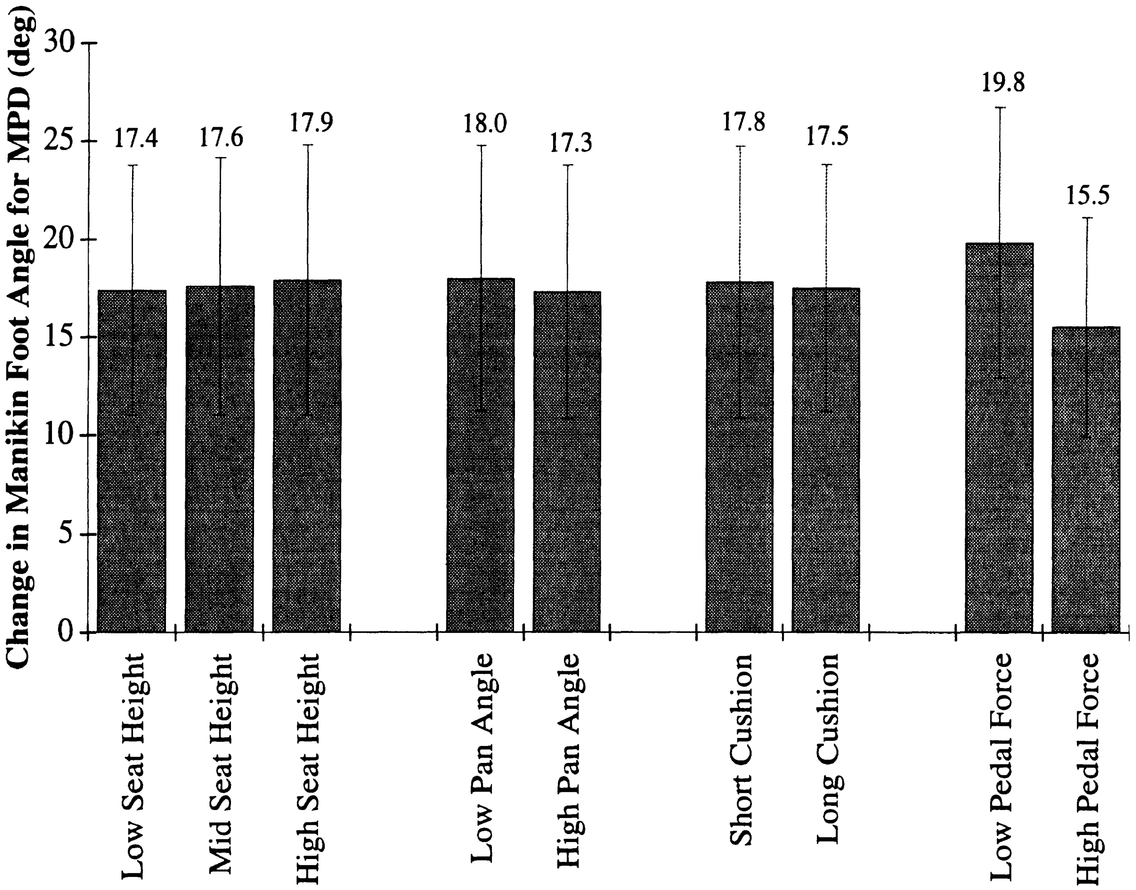


Figure 75. Overall mean change in 50th%ile manikin foot angle for MPD by independent variable.

Table 30
Overall Mean Change in 50th%ile Manikin Foot Angle for MCPD by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	12.2	4.69
Mid Seat Height	192	12.5	5.21
High Seat Height	192	12.6	4.91
Low Pan Angle	288	12.9	5.10
High Pan Angle	288	12.1	4.73
Short Cushion	288	12.5	4.97
Long Cushion	288	12.4	4.91
Low Pedal Force	288	14.2	5.11
High Pedal Force	288	10.7	4.09

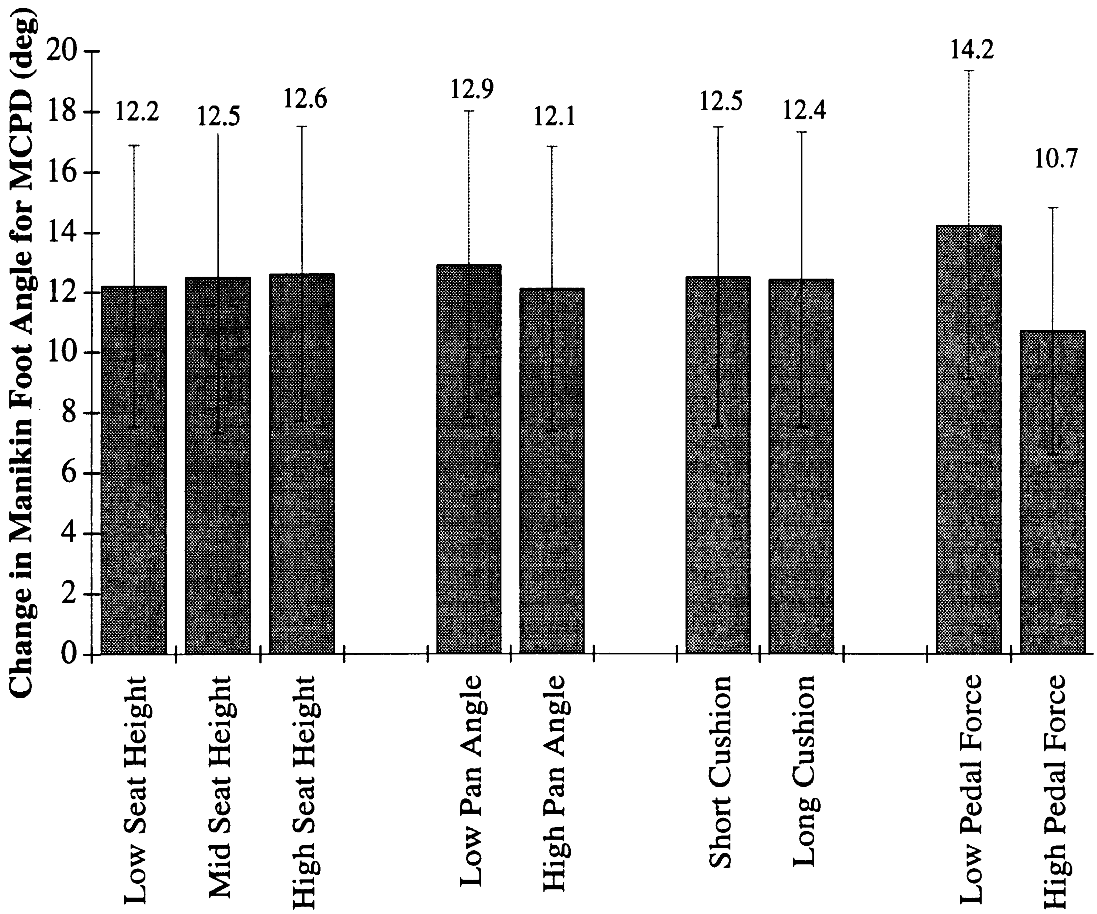


Figure 76. Overall mean change in 50th%ile manikin foot angle for MCPD by independent variable.

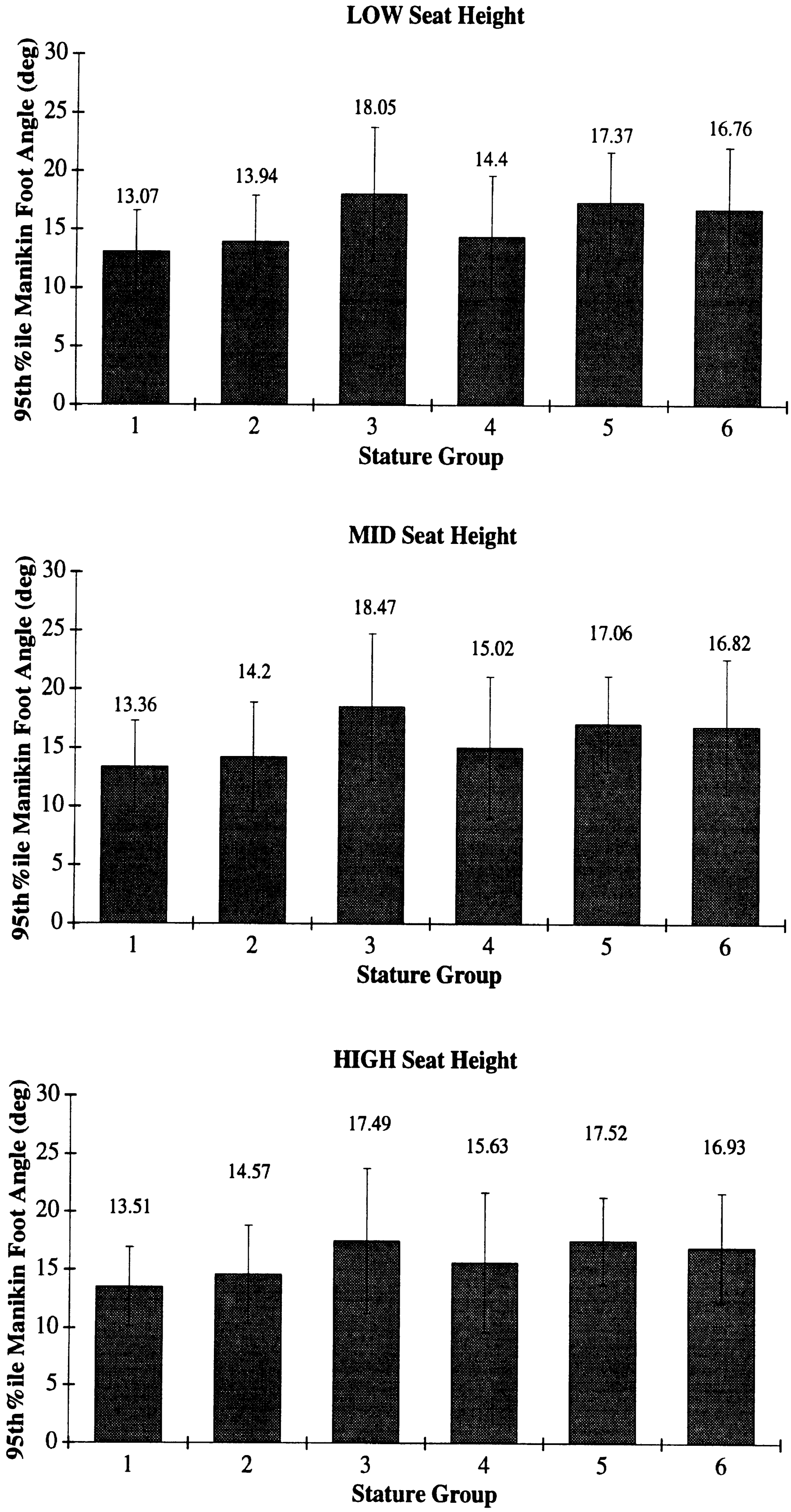


Figure 77. Change in manikin foot angle by stature group for each seat height. (n=192)

Table 31
Change in Manikin Foot Angle Summary

Measurement	Overall Mean Foot Angle Change for 95th-percentile Manikin	Overall Mean Foot Angle Change for 50th-percentile Manikin
MPD	21	18
MCPD	16	13

3.7.3 Downward Thigh Displacement, Change in Knee Angle, and Pressure on Seat Associated with Maximum-Comfortable Pedal Displacements

Table E-12 and Figures E-22 through E-26 summarize the downward thigh displacements, changes in knee angle, and peak pressures at the front and rear FSR sensors that were measured at each maximum-comfortable pedal displacement. It was hypothesized at the beginning of the study that high cushion angles and long cushion lengths may result in greater seat/thigh interaction and thereby influence maximum-comfortable pedal displacement. Tables 32 through 35 and Figures 78 through 81 show the overall mean downward thigh displacements, changes in knee angle, and overall mean pressures for each level of the independent variables. Thigh displacement and change in knee angle were affected by seat height, seatpan angle and pedal force, while the pressure at the front FSR was influenced by seat height, seatpan angle, and cushion length. With higher seat height, higher seatpan angle, and higher pedal force, the thigh displacement and change in knee angle decreases. With higher seat height, higher seatpan angle, and shorter cushion length, the pressure on the front FSR tended to increase. The pressure at the rear FSR did not significantly change with any of the independent variables, except for a slight change with seat height.

3.7.4 Heel Slide Associated with Maximum-Comfortable Pedal Displacements

Table F-13 and Figure F-26 summarize the results for heel slide measured during subject performance of maximum-comfortable pedal displacements. It is interesting that mean heel slide values for the Group A subjects tend to be lower than those for Group B subjects. No explanation for this difference is available at this time. Small differences in mean values of heel slide are seen to exist among the different test conditions. The effects of the independent variables on heel slide become more apparent in Figure 82 and Table 36, which present the overall mean values. Both seat height and pedal force level are seen to influence heel slide such that heel slide is greater at lower seat heights and higher pedal force levels. This effect of seat height follows from geometric considerations (i.e., the leg angle is more horizontal and the foot pitch angle is higher at lower seat heights resulting in a greater

Table 32
Overall Mean Downward Thigh Displacement by Independent Variable (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	26.3	20.33
Mid Seat Height	192	22.6	16.53
High Seat Height	192	19.1	12.24
Low Pan Angle	288	25.5	18.74
High Pan Angle	288	19.9	14.39
Short Cushion	288	23.3	16.97
Long Cushion	288	22.0	16.88
Low Pedal Force	288	25.3	17.13
High Pedal Force	288	20.1	16.33

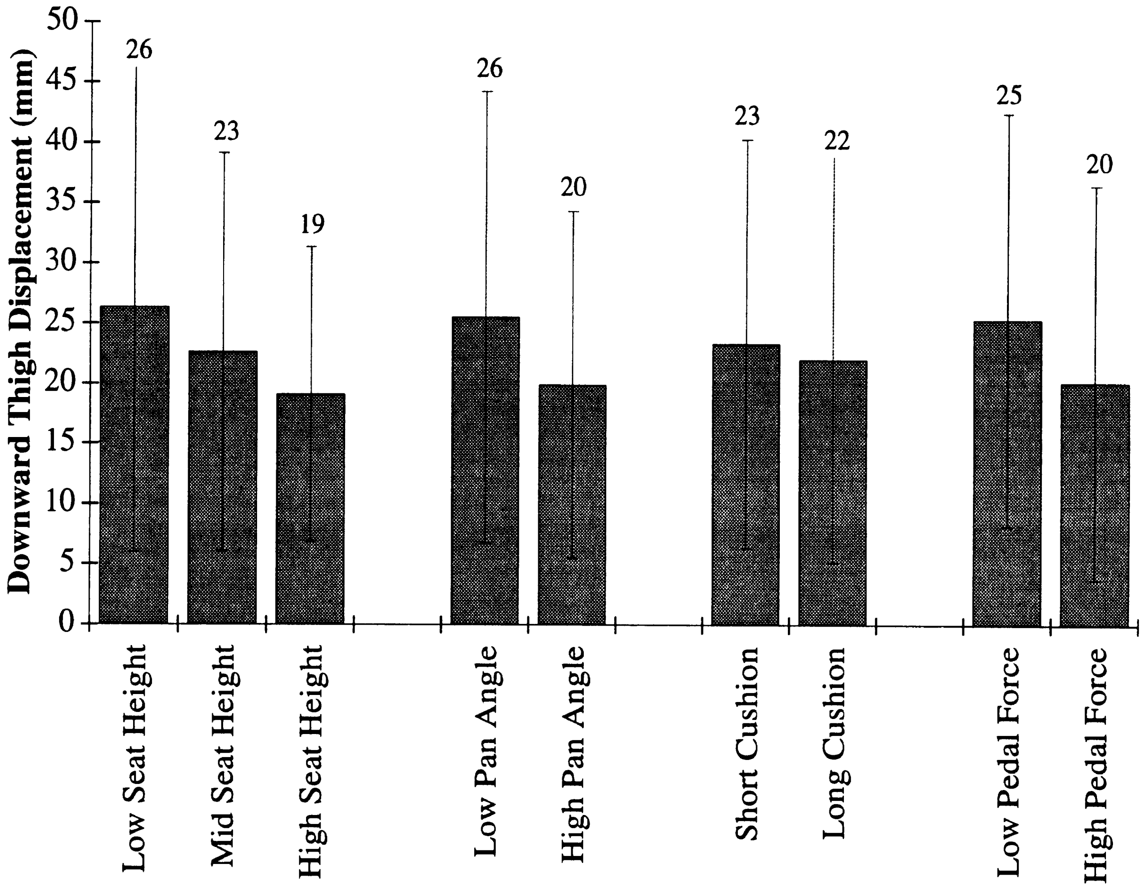


Figure 78. Overall mean downward thigh displacement by independent variable.

Table 33
Overall Mean Change in Knee Angle by Independent Variable (deg)

	N	Mean	Standard Deviation
Low Seat Height	192	7	6.07
Mid Seat Height	192	6	5.30
High Seat Height	192	5	4.06
Low Pan Angle	288	7	5.81
High Pan Angle	288	5	4.59
Short Cushion	288	6	5.12
Long Cushion	288	6	5.38
Low Pedal Force	288	7	5.12
High Pedal Force	288	5	5.28

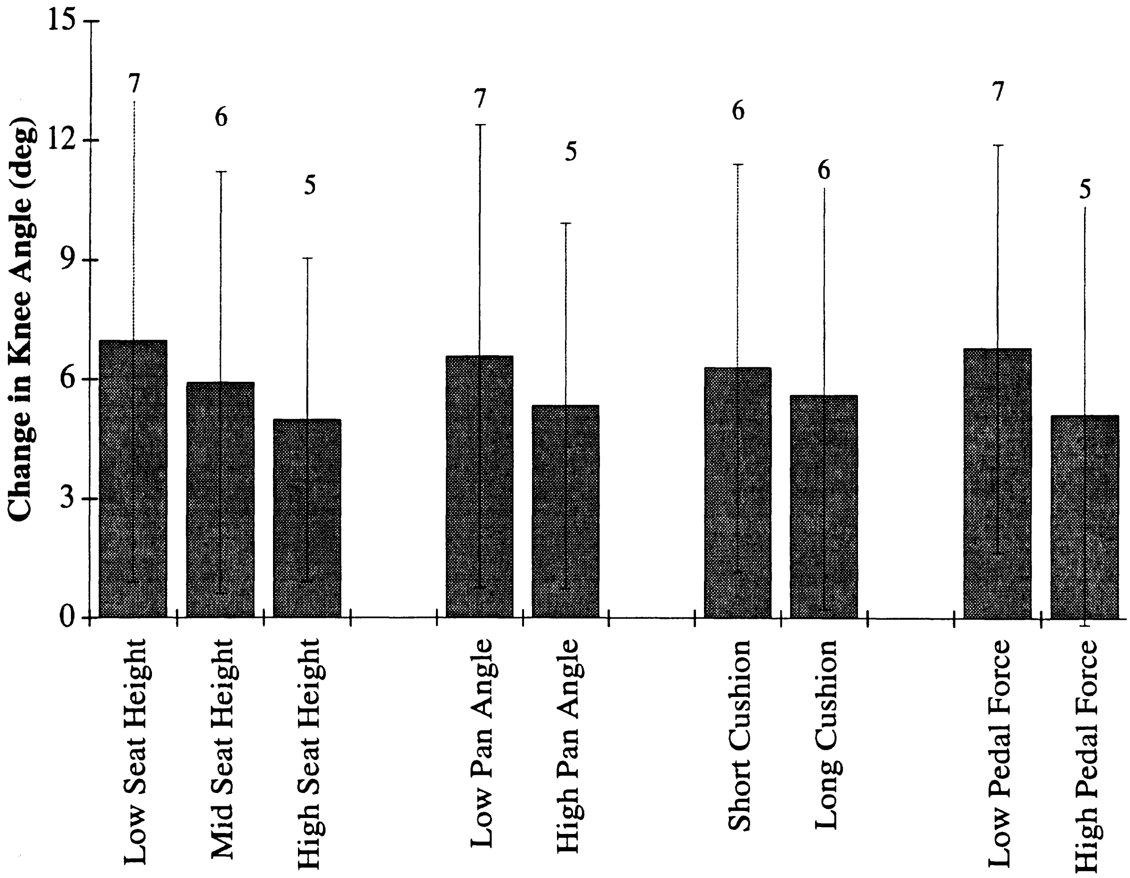


Figure 79. Overall mean change in knee angle by independent variable.

Table 34
Overall Mean Pressure at Front FSR by Independent Variable (psi)

	N	Mean	Standard Deviation
Low Seat Height	192	1.06	1.35
Mid Seat Height	192	1.19	1.31
High Seat Height	192	1.41	1.30
Low Pan Angle	288	0.96	1.15
High Pan Angle	288	1.48	1.43
Short Cushion	288	1.42	1.51
Long Cushion	288	1.01	1.07
Low Pedal Force	288	1.17	1.16
High Pedal Force	288	1.26	1.47

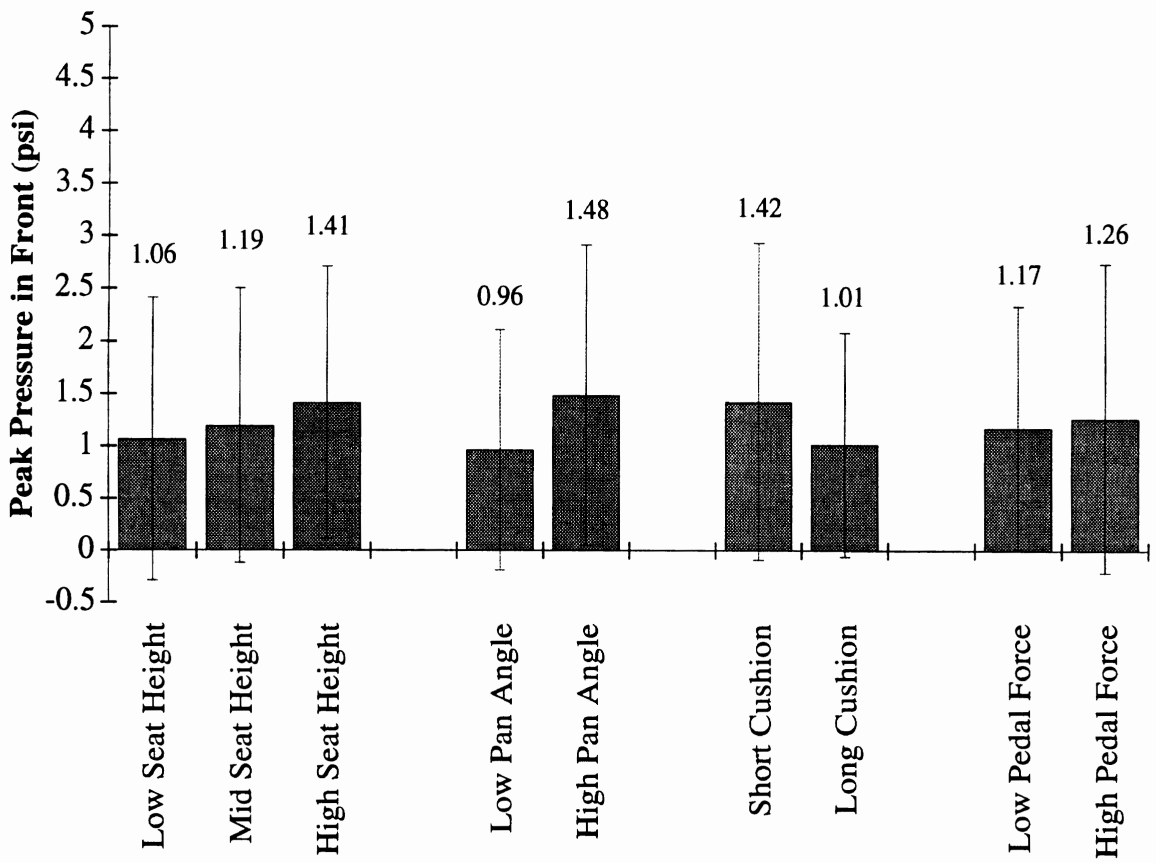


Figure 80. Overall mean pressure at front FSR by independent variable.

Table 35
Overall Mean Pressure at Back FSR by Independent Variable (psi)

	N	Mean	Standard Deviation
Low Seat Height	192	1.02	0.46
Mid Seat Height	192	1.11	0.41
High Seat Height	192	1.23	0.42
Low Pan Angle	288	1.00	0.42
High Pan Angle	288	1.23	0.43
Short Cushion	288	1.17	0.43
Long Cushion	288	1.06	0.44
Low Pedal Force	288	1.07	0.42
High Pedal Force	288	1.17	0.46

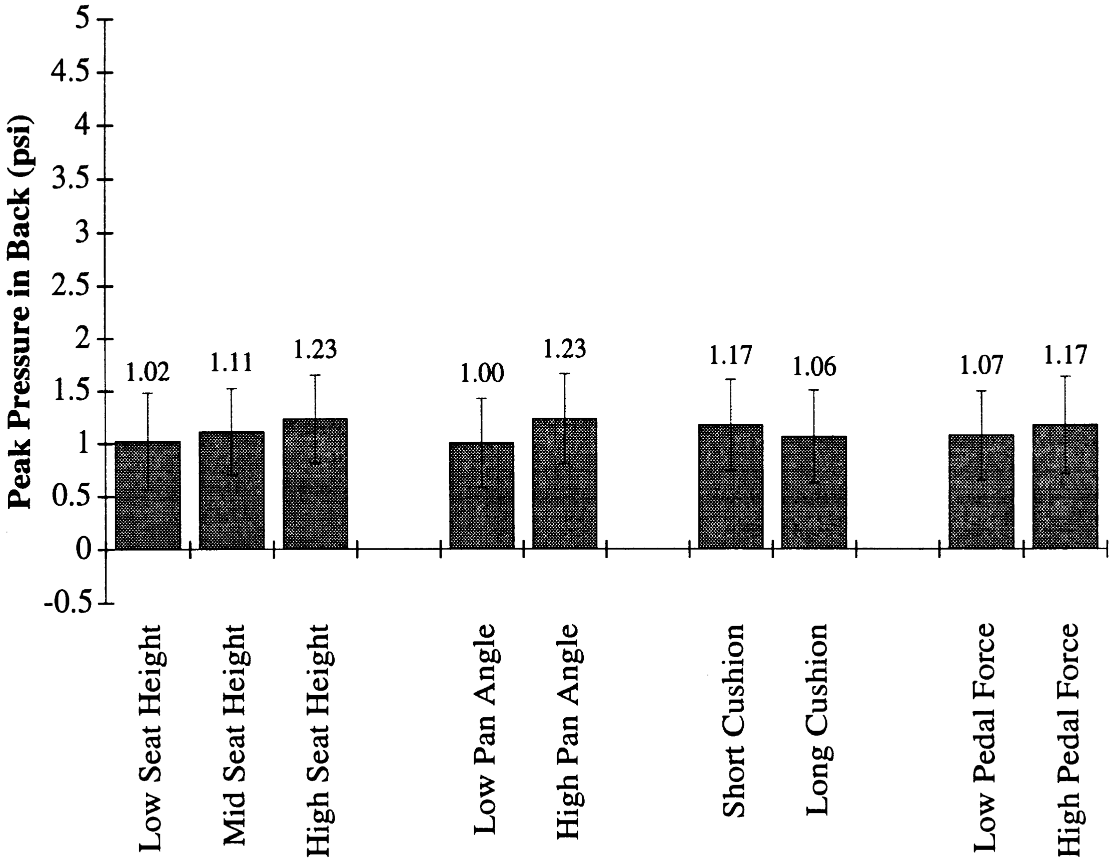


Figure 81. Overall mean pressure at back FSR by independent variable.

Table 36
Overall Mean Forward Heel Slide by Independent Variable (mm)

	N	Mean	Standard Deviation
Low Seat Height	192	11	13.8
Mid Seat Height	192	10	12.02
High Seat Height	192	7	9.81
Low Pan Angle	288	10	12.98
High Pan Angle	288	9	11.08
Short Cushion	288	10	11.92
Long Cushion	288	9	12.24
Low Pedal Force	288	8	12.62
High Pedal Force	288	11	11.41

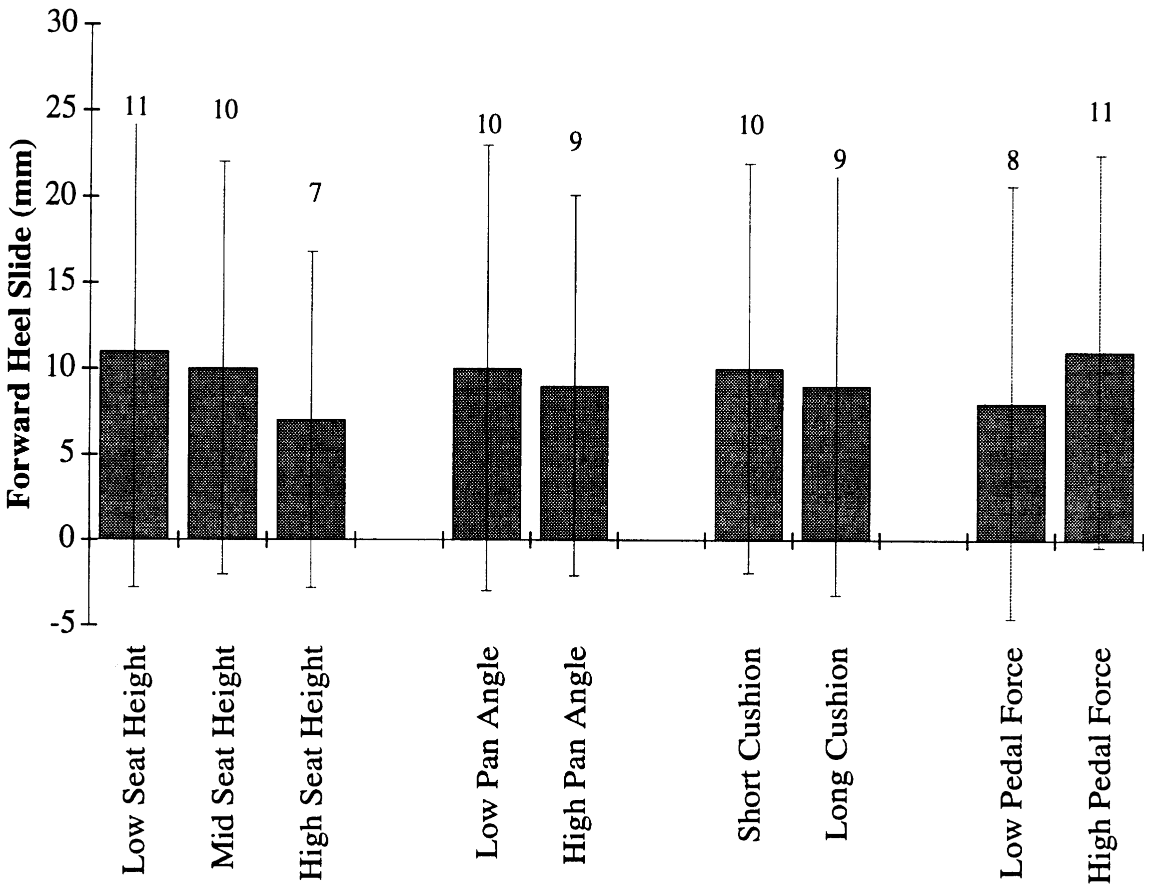


Figure 82. Overall mean forward heel slide by independent variable.

tendency to slide the heel forward during pedal actuation). The effect of pedal force on heel slide is also as might be expected.

3.8 STATISTICAL ANALYSIS OF RESULTS

The previous sections have presented numerical and graphical summaries of the values and relationships of dependent variable measurements to independent seat and package variables and have revealed a number of relationships. Table 37 summarizes the results obtained by using analysis of variance to examine the statistically significant differences of relationships among dependent variables and independent vehicle package, seat, and subject (i.e., anthropometric) variables. Column headings contain independent variables, while row headings contain dependent variables. Thus each cell represents the main effect of a specific independent variable on a specific dependent variable. Cell entries are the p-values associated with that main effect when tested using ANOVA. P-values less than .05 (shaded cells) indicate variables where the relationship is considered significant.

These ANOVA results confirm statistically the observations previously noted including that:

- preferred lateral heel position is different for males and females, with males placing their heel further to the left and rotating the foot more to the right to reach the accelerator pedal;
- preferred fore/aft heel position is a function of seat height and cushion angle, such that the heel is placed more rearward for lower seat heights and higher cushion angles;
- driver knee angle and leg angle (i.e., between knee and ankle) are influenced by seat height and cushion angle, such that the knee angle is larger and the leg angle is lower (to horizontal) for lower seat heights and lower cushion angles;
- thigh angle tends to be different for males and females and is a function of seat height, such that higher seat heights produce lower thigh angles and females tend to have lower thigh angle than males;
- driver seat position is influenced by driver size, gender, seat height, and seat cushion angle[2], such that more rearward seat positions result for taller drivers, male drivers, lower seat heights, and lower cushion angles;
- seatback angle is affected by seat height and cushion angle, such that higher seat heights and lower cushion angles produce lower (i.e., more vertical) seatback angles;

---

[2] While ANOVA shows the effect of cushion angle on seat position to be statistically significant, many subjects in this study chose more rearward seat positions for the higher cushion angle, especially at the highest seat height.

Table 37
Summary of ANOVA Results

Dependent Variable	Independent Variable					
	Stature	Gender	Seat Ht. (H30)	Cushion Angle	Cushion Length	Pedal Force
Heel Position Y	0.5558	0.0001	0.5214	0.1393	0.8374	0.1109
Heel Position X	0.0175	0.9236	0.0001	0.0001	0.7921	0.0926
Foot Rotation Angle	0.2408	0.0001	0.5482	0.3689	0.5022	0.7910
Foot Pitch Angle	0.1807	0.7204	0.0001	0.0001	0.8878	0.0006
Knee Angle	0.9370	0.8043	0.0001	0.0001	0.4515	0.0351
Leg Angle	0.3571	0.1940	0.0001	0.0001	0.2304	0.4805
Thigh Angle	0.1588	0.0027	0.0001	0.1183	0.1298	0.2134
Seat Position (re BOF)	0.0001	0.0001	0.0001	0.0001	0.5796	0.0379
Seatback Angle	0.5213	0.1218	0.0001	0.0395	0.3385	0.3496
Ankle Extension for MCPD	0.0117	0.2307	0.0041	0.0001	0.0051	0.0001
MCPD	0.0497	0.2226	0.4026	0.0001	0.6157	0.0001
Δ95th%ile Manikin Ft. Angle	0.0432	0.1930	0.4393	0.0001	0.7409	0.0001
Downward Thigh Disp.	0.0523	0.6430	0.0001	0.0001	0.0215	0.0001
Seat Pressure at Front FSR	0.0884	0.6993	0.0001	0.0001	0.0001	0.1870
Seat Pressure at Back FSR	0.3170	0.7797	0.0001	0.0001	0.0001	0.0004
Resting Foot Force@Ped. Ctr.	0.2124	0.8449	0.0169	0.0078	0.7109	0.5897
Forward Heel Slide	0.2359	0.6708	0.0001	0.0264	0.2963	0.0221

- driver ankle extension and pedal displacement during maximum-comfortable pedal displacement are influenced by cushion angle and pedal force, such that higher cushion angles and higher pedal forces result in lower pedal displacements and ankle extensions;

- downward thigh displacement during maximum comfortable pedal displacement is reduced for higher seat heights, higher cushion angles, higher pedal forces, and, to a lesser extent, for longer cushion lengths, and these reductions are accompanied by increased pressure exerted by the thigh on the front of the seat cushion;

- resting foot force is relatively independent of vehicle package and seat factors, being only weakly influenced by seat height and cushion angle;

- forward heel slide is related to seat height, cushion angle, and pedal force, such that lower seat heights, lower cushion angles and higher pedal forces result in more heel slide.

APPENDIX A

Subject Forms

The University of Michigan Transportation Research Institute
INFORMED CONSENT FOR EXPERIMENTAL PROCEDURE

Human Factors of Driver Seating and Control Packaging

I understand that the purpose of this study is to investigate the effects of interior vehicle geometry on driver preferred seat position in late model vehicles. I agree to allow several standard measurements to be taken that will describe my general body proportions and size. If I qualify for one of the size categories in the study, I will be asked to drive seven test vehicles over local roads and to adjust the seat front/back position to my preferred location, stopping, if necessary, to make the adjustment safely. Upon completion of the drive, two photographs will be taken of me in the vehicle to record my eye position.

I understand that my participation in this study is voluntary and is conditional to review of my responses to a health questionnaire and my physical qualifications with regard to experimental design criteria. I understand that I will be paid for my participation at a rate of $10/hr, and that I may discontinue my involvement at any time without prejudice or change in my rate of pay.

The Transportation Research Institute is a research organization and, as such, my records and personal information may be reviewed by research staff. I understand however, that all data and results will remain confidential and will be used in scientific publications and presentation only in coded form not identifying me.

In the unlikely event of physical injury resulting from research procedures, the University will provide first-aid medical treatment. Additional medical treatment will be provided in accordance with the determination by the University of its responsibility to provide such treatment. However, the University does not provide compensation to a person who is injured while participating as a subject in research.

If significant new knowledge is obtained during the course of this research which may relate to my willingness to continue participation, I will be informed of this knowledge. The person(s) below listed may be contacted for more information about any aspect of this study. Any questions or concerns about my rights as a research subject, may be directed to the Office of Patient-Staff Relations, A-6028 University Hospital, Telephone 763-5456.

One copy of this document will be kept together with research records on this study. A second copy has been given to me to keep.

I agree to the conditions set forth above and have had an opportunity to discuss my concerns regarding my participation in the proposed study. I hereby consent to participate in the study.

NAME (please print):______________________________________

Signature: ______________________________________

WITNESS Signature:______________________________________ Date: _________

Investigator: Lawrence W. Schneider, Ph.D. 936-1103 (work), 996-3861 (home)

The University of Michigan Transportation Research Institute

HEALTH QUESTIONNAIRE

(please print)

SUBJECT NO: ___________

DATE: ___________

NAME:____ PHONE (S): ___________________

Last First Middle

____

ADDRESS: ____

Street City State Zip

SOCIAL SECURITY NO.: ______________________ BIRTHDATE: ____________ AGE: _______

HEIGHT: _____________ WEIGHT: _____________

DIRECTIONS: Answer all questions. If you are uncertain as to how to best answer a question please circle *Yes* or *No* and explain further either at space provided after question or at the end of the questionnaire with the letter and # marked.

1. Do you have a valid and current driver's license?	*Yes*	*No*
a. Approximately how many miles do you drive a year?________________________		
2. Does severe rheumatism (or arthritis) interfere with your work?	*Yes*	*No*
3. Are you under a doctor's care?	*Yes*	*No*
a. If yes, give name of doctor: ____________________________		
4. Are you currently taking any medications?	*Yes*	*No*
a. If yes, give name of medication: ____________________________		
5. Do you need glasses for reading or other close work?	*Yes*	*No*
6. Do you need glasses for seeing things at a distance?	*Yes*	*No*
7. Were you ever in an automobile accident where you might have suffered "whiplash" or neck injury?	*Yes*	*No*
8. Has a doctor ever said your blood pressure was too high or too low?	*Yes*	*No*
9. Do you have pains in the back or neck that make it hard for you to keep up with your daily activities?	*Yes*	*No*
10. Are you troubled by a serious bodily disability or deformity?	*Yes*	*No*
a. If yes, please explain: ____________________________		
11. Were you ever knocked unconscious?	*Yes*	*No*
a. If yes, please explain: ____________________________		
12. Have you ever had a serious injury?	*Yes*	*No*
a. If yes, please explain: ____________________________		

Additional comments: (Please include date, symptoms, frequency of occurrence, and any other relevant data)

* NOTE: This questionnaire modified from the Cornell Medical Index for the R.I.W.U. multiphase testing, June 1951.

Subject No.____________

Sex ________________

SUBJECT INFORMATION FORM

SUBJECT NAME:________________________ HT:__________

PHONE NUMBER WT:__________

HOME:______________________ AGE:__________

WORK:______________________

YEARS OF DRIVING:________________

Please list the vehicles you currently drive regularly, in order of frequency. (Include YEAR AND MODEL)	Manual Seats		Transmission	
1. ____________________________	Y	N	Auto	Manual
2. ____________________________	Y	N	Auto	Manual
3. ____________________________	Y	N	Auto	Manual

Approximate miles per year driven:____

APPENDIX B

Seating Buck Measurements and Calibration

INDEX TO SECTIONS

B1. SEATPAN ANGLE MEASUREMENT PROCEDURE

1. Place seat in design position.

2. Drape muslin cloth over seat.

3. Place legless, unweighted H-Point machine on the seat, being careful to align the machine with the seat centerline.

4. Install the two hip weights into the machine in the standard position.

5. Place two of the round weights (weights that are normally placed on the upper torso area of the manikin) in the left and right sides of the hip area. These weights should have the same orientation as the secured hip weights and should be directly outboard of the hip weights (see picture).

6. Add the two thigh weights to the forward portion of the machine, in the standard position.

7. Check the level indicator and level the machine.

8. Apply a 35-pound load to the machine bottom pan push spring, located between the two thigh weights.

9. Add four more of the round weights (weights that are normally placed on the upper torso area of the manikin) to the hip area of the machine, alternating left and right sides, directly outboard of the hip weights.

10. Place the remaining two round weights in the front of the machine, between the thigh weights and the forward structure of the machine.

11. Set the seatback angle on the SAE protractor to zero, level the back angle vertical bar and lock it into position. The seatpan angle is determined by reading the angle on the hip protractor and subtracting 90 degrees.

B2. SEAT POSITION CALIBRATION RESULTS

Measurement	Test Condition			
	1	2	3	4
H-Point to AHP Vertical (desired)	180	180	180	180
H-Point to BOF Horizontal (desired)	904	904	904	904
H-Point to AHP Vertical (actual)	180	181	182	182
H-Point to BOF Horizontal (actual)	909	901	906	898
Seat Platform Z Scale After Adjusting	72	75	123	123
Seat Platform X Scale After Adjusting	39	29	79	79
Seatback Angle on Inclinometer (deg)	26	25	24	24
Back Angle from Manikin (deg)	27.5	26	27	27
Foot Angle (deg)	73.5	72	74	72
Ankle Angle (deg)	87	87	87	87
Hip Angle (deg)	97	95	96	96
Knee Angle (deg)	132	131	132	132

Measurement	Test Condition			
	5	6	7	8
H-Point to AHP Vertical (desired)	270	270	270	270
H-Point to BOF Horizontal (desired)	858	858	858	858
H-Point to AHP Vertical (actual)	265	271	273	268
H-Point to BOF Horizontal (actual)	857	857	862	856
Seat Platform Z Scale After Adjusting	171	205	222	227
Seat Platform X Scale After Adjusting	63	70	103	95
Seatback Angle on Inclinometer (deg)	22	21.5	22	22
Back Angle from Manikin (deg)	23.5	23.5	25	25
Foot Angle (deg)	63.5	64.5	65	65.5
Ankle Angle (deg)	87	87	87	87
Hip Angle (deg)	96	96	97.5	96.5
Knee Angle (deg)	125	126	126	125.5

Measurement	Test Condition			
	9	10	11	12
H-Point to AHP Vertical (desired)	360	360	360	360
H-Point to BOF Horizontal (desired)	775	775	775	775
H-Point to AHP Vertical (actual)	357	360	360	359
H-Point to BOF Horizontal (actual)	770	775	781	774
Seat Platform Z Scale After Adjusting	260	263	312	317
Seat Platform X Scale After Adjusting	140	128	173	166
Seatback Angle on Inclinometer (deg)	20	20	20	20
Back Angle from Manikin (deg)	22.5	22	23	23
Foot Angle (deg)	53	52	56	51.5
Ankle Angle (deg)	87	87	87	87
Hip Angle (deg)	97	96.5	97	97
Knee Angle (deg)	116	116	115	115

B3. BUCK DIMENSIONS

Package Dimension	Low Seat Ht. Measurement (mm/deg)	Mid Seat Ht. Measurement (mm/deg)	High Seat Ht. Measurement (mm/deg)
AHP-to-SgRP Z Distance (H30)	180	270	360
AHP-to-SgRP X Distance	904	858	775
BOF-to-SgRP X Distance	971	953	902
Seat Track Travel	288	288	288
Seat Track Rise Angle re Horizontal	8	4	0
Steering Wheel Diameter	381	381	381
Steering Wheel Angle re Vertical	22	22	22
Ctr. of Steering Wheel-to-AHP X	531	455	370
Ctr. of Steering Wheel-to-AHP Z	568	645	727
Ctr. of Steering Wheel-to-BOF X	598	549	497
Ctr. of Steering Wheel-to-SgRP X	373	403	405
Ctr. of Steering Wheel-to-SgRP Z	388	375	367
Design Seatback Angle	21	24	27
Accelerator Pedal Pad angle re Hor.	58.0	49.0	39.5
Accelerator Pedal Height	133	113	98
Brake Pedal Pad Angle re Hor.	67.0	60.5	48.0
Brake Pedal Height	168	162	146
Step-over Height	61	59	57

APPENDIX C

Subject Anthropometry

Table C-1a
Subject Anthropometry

Group #	Subject #	Stature w/shoes (mm)	Stature w/o shoes (mm)	Weight (kg)	Forearm Length (mm)	Arm Length (mm)	Erect Sitting Height (mm)
1A	11101	1553	1535	50	424	338	835
	11102	1575	1545	69	409	306	844
	11103	1577	1557	75	419	341	814
	11104	1499	1477	53	406	321	803
2A	11201	1606	1585	81	428	353	822
	11202	1636	1603	62	421	338	872
	11203	1674	1655	66	462	354	843
	11204	1644	1612	65	438	364	824
3A	11301	1689	1672	71	493	371	821
	11302	1704	1678	55	453	368	853
	11303	1706	1676	89	451	371	871
	11304	1722	1698	95	461	372	904
4A	21101	1663	1644	70	470	357	859
	21102	1661	1638	76	451	356	835
	21103	1662	1648	72	446	336	845
	21104	1670	1650	63	445	353	896
5A	21201	1782	1754	93	505	400	903
	21202	1774	1750	90	501	370	872
	21203	1786	1761	84	473	386	931
	21204	1751	1721	78	470	380	854
6A	21301	1857	1834	88	510	377	982
	21302	1794	1754	83	506	392	894
	21303	1905	1876	92	517	422	951
	21304	1880	1865	89	519	394	927

Table C-1b
Subject Anthropometry cont'd

Subject #	Erect Shoulder Height (mm)	Shoulder Breadth (mm)	Knee Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Trochanter-Lateral Femoral Condyle Length (mm)
11101	565	390	469	533	429	379
11102	550	408	450	582	484	369
11103	536	424	486	571	472	380
11104	534	372	448	523	428	343
11201	558	402	495	603	500	400
11202	600	403	493	556	473	400
11203	573	402	525	615	505	423
11204	552	376	497	601	506	372
11301	558	414	554	635	504	420
11302	577	390	526	587	487	419
11303	621	419	529	635	519	406
11304	623	461	537	637	534	440
21101	578	438	521	568	458	383
21102	590	429	504	598	463	432
21103	560	429	551	620	517	404
21104	615	416	490	578	442	416
21201	612	437	562	627	520	440
21202	615	463	557	640	520	457
21203	638	427	534	637	516	437
21204	584	422	527	636	509	412
21301	623	446	555	624	507	445
21302	641	424	560	649	537	446
21303	670	472	604	650	502	471
21304	620	476	600	668	543	448

Table C-1c
Subject Anthropometry cont'd

Subject #	Foot Length (mm)	Shoe Weight (gm)	Age (yrs)
11101	237	284	39
11102	228	269	38
11103	230	255	57
11104	227	369	22
11201	240	227	66
11202	240	(--)	39
11203	258	198	26
11204	230	213	64
11301	255	383	29
11302	253	354	20
11303	250	241	56
11304	253	312	24
21101	255	326	61
21102	260	312	65
21103	240	227	21
21104	262	468	23
21201	277	454	66
21202	278	411	38
21203	256	340	52
21204	265	907	70
21301	290	340	33
21302	278	907	60
21303	277	510	30
21304	275	369	38

Table C-1d
Subject Anthropometry cont'd

Group #	Subject #	Stature w/shoes (mm)	Stature w/o shoes (mm)	Weight (kg)	Forearm Length (mm)	Arm Length (mm)	Erect Sitting Height (mm)
	12101	1571	1546	61	424	350	791
1B	12102	1531	1504	57	421	348	760
	12103	1533	1503	45	422	323	801
	12104	1544	1522	40	443	354	799
	12201	1598	1580	61	427	355	814
2B	12202	1629	1594	70	449	353	860
	12203	1638	1613	78	426	344	872
	12204	1606	1586	65	433	338	858
	12301	1722	1701	59	464	354	865
3B	12302	1697	1676	71	448	369	883
	12303	1750	1720	65	466	371	908
	12304	1712	1690	84	457	394	859
	22101	1649	1627	69	446	360	850
4B	22102	1665	1638	78	457	338	879
	22103	1679	1657	71	438	344	890
	22104	1700	1664	66	472	330	852
	22201	1791	1776	78	529	394	875
5B	22202	1809	1777	72	526	408	846
	22203	1755	1727	91	500	392	880
	22204	1759	1727	65	478	346	876
	22301	1886	1860	85	495	385	994
6B	22302	1837	1812	94	518	393	920
	22303	1863	1834	75	500	403	982
	22304	1848	1830	84	499	397	908

Table C-1e
Subject Anthropometry cont'd

Subject #	Erect Shoulder Height (mm)	Shoulder Breadth (mm)	Knee Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Trochanter-Lateral Femoral Condyle Length (mm)
12101	537	400	495	554	448	396
12102	509	393	489	567	471	406
12103	543	392	453	553	450	378
12104	538	351	479	541	455	378
12201	549	417	490	589	471	420
12202	590	408	487	583	470	424
12203	590	411	498	600	505	386
12204	577	409	492	546	459	350
12301	588	398	527	608	490	448
12302	609	400	524	608	476	418
12303	625	409	538	598	497	423
12304	572	434	547	639	548	457
22101	579	453	500	589	489	409
22102	607	471	510	579	475	406
22103	600	447	510	573	460	357
22104	561	430	530	585	480	390
22201	576	452	571	652	531	469
22202	585	447	556	651	537	422
22203	618	430	560	610	486	423
22204	584	418	544	624	518	404
22301	689	476	566	647	538	434
22302	641	451	556	647	511	436
22303	651	467	561	620	501	397
22304	614	475	589	656	548	427

Table C-1f
Subject Anthropometry cont'd

Subject #	Foot Length (mm)	Shoe Weight (gm)	Age (yrs)
12101	235	439	67
12102	240	213	64
12103	220	326	25
12104	242	383	68
12201	230	170	32
12202	246	496	24
12203	240	369	46
12204	237	255	35
12301	255	326	38
12302	255	241	53
12303	260	510	26
12304	245	298	38
22101	255	340	47
22102	260	383	20
22103	258	411	52
22104	260	652	29
22201	281	340	61
22202	275	737	38
22203	283	340	71
22204	272	312	21
22301	270	354	24
22302	279	879	52
22303	265	553	20
22304	286	439	20

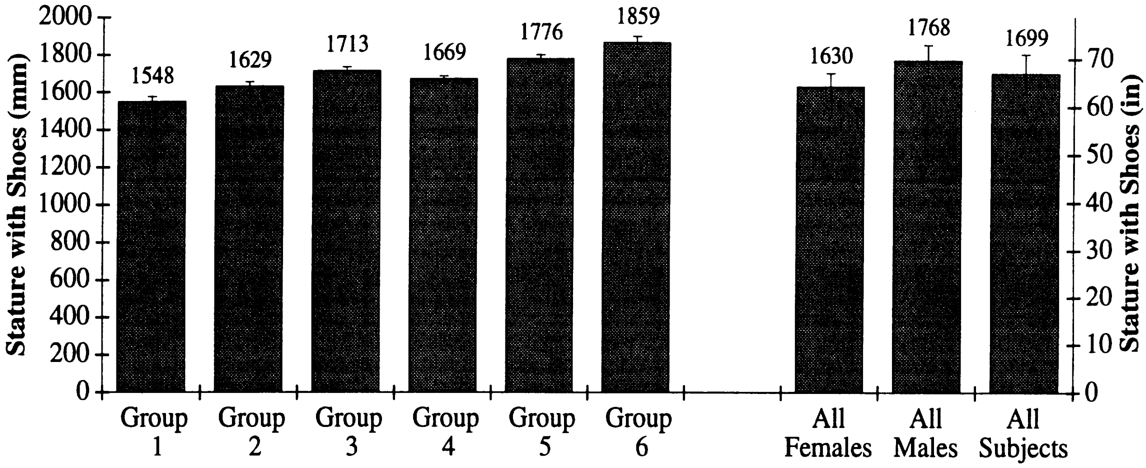


Figure C1. Mean values and standard deviations of stature with shoes by subject group.

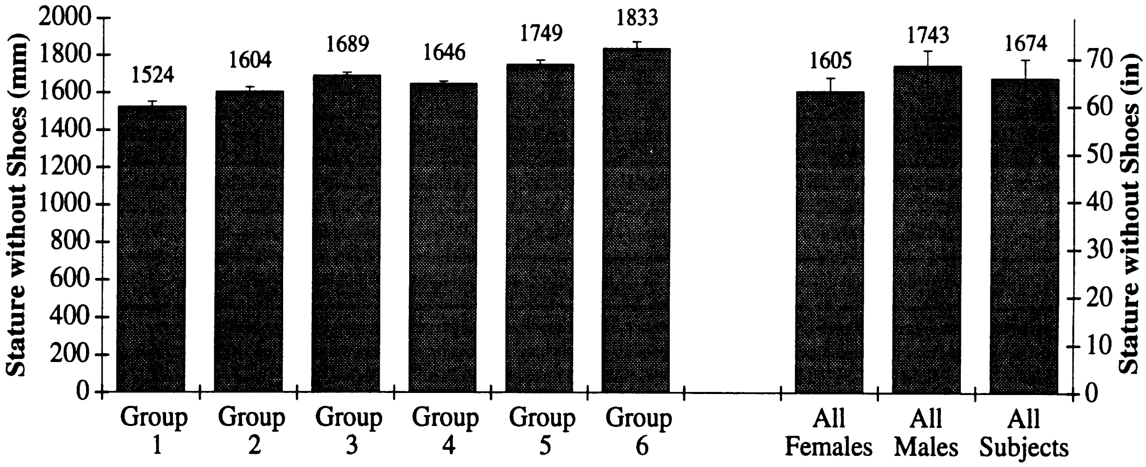


Figure C2. Mean values and standard deviations of stature without shoes by subject group.

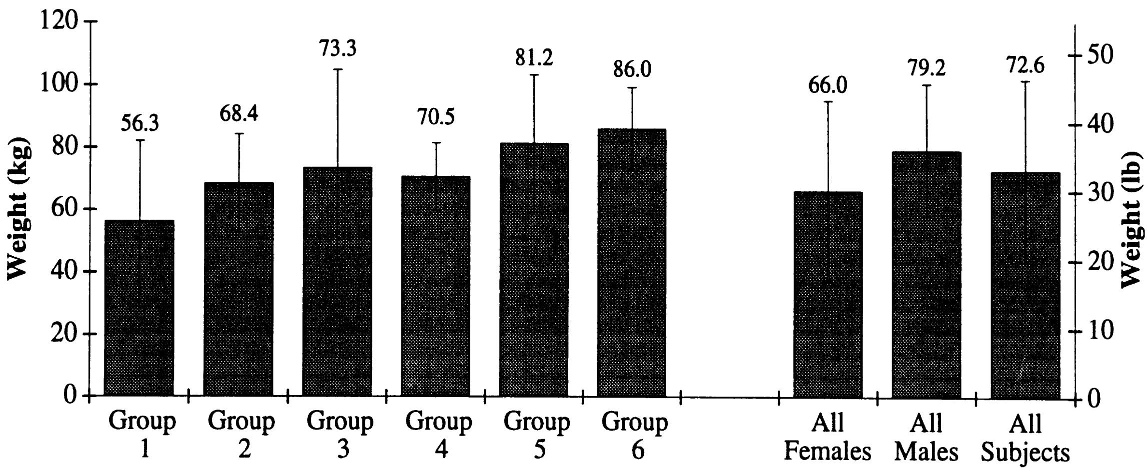


Figure C3. Mean values and standard deviations of weight by subject group.

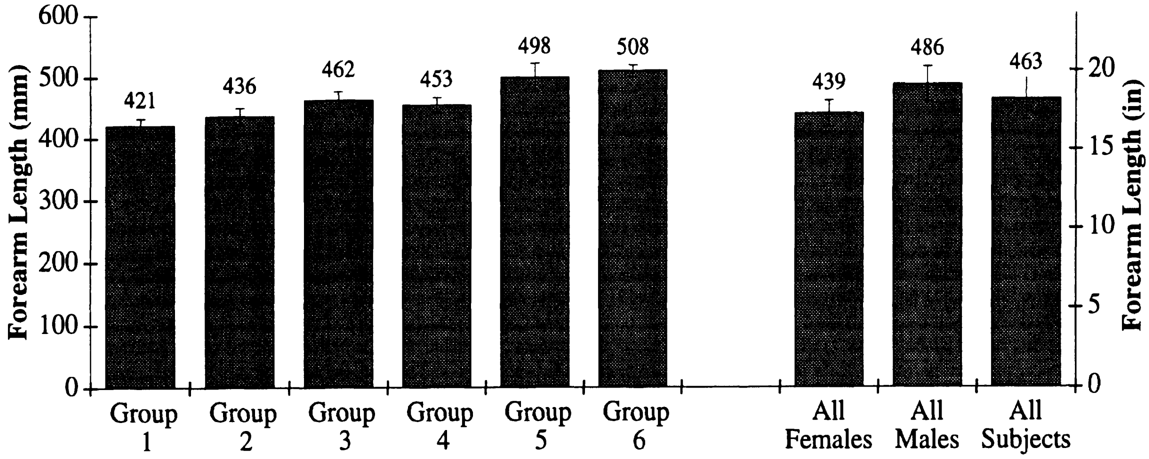


Figure C-4. Mean and standard deviation of forearm length by subject group.

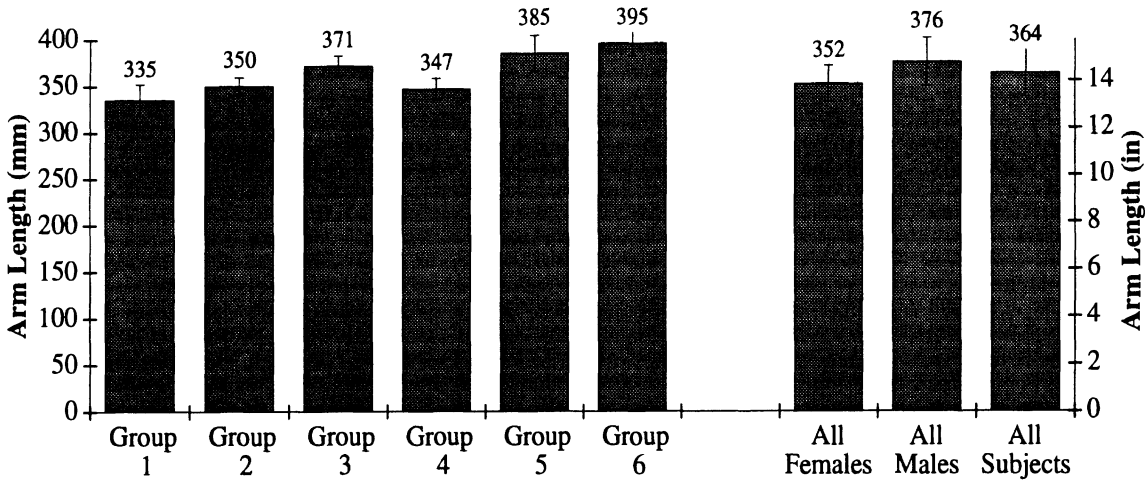


Figure C-5. Mean values and standard deviations of arm length by subject group.

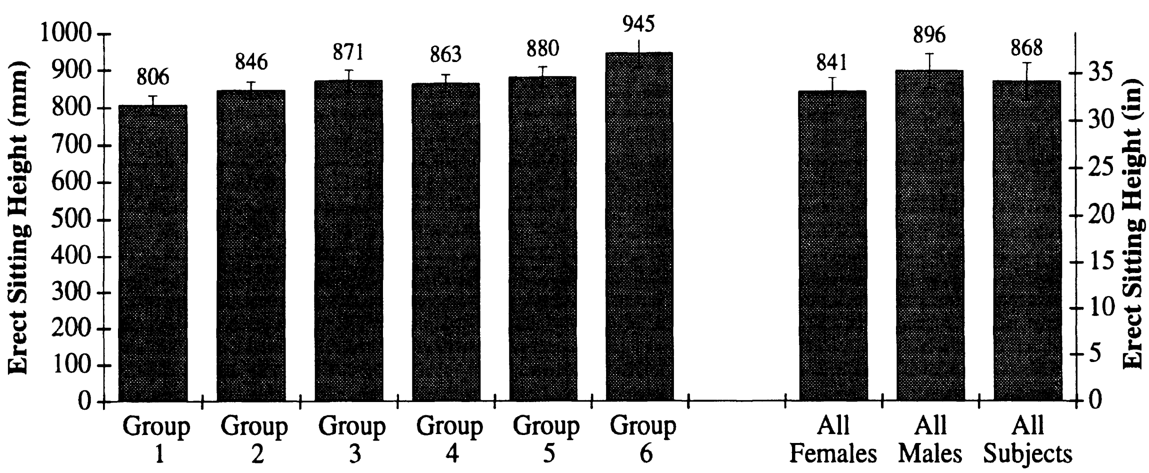


Figure C-6. Mean and standard deviation of erect sitting height by subject group.

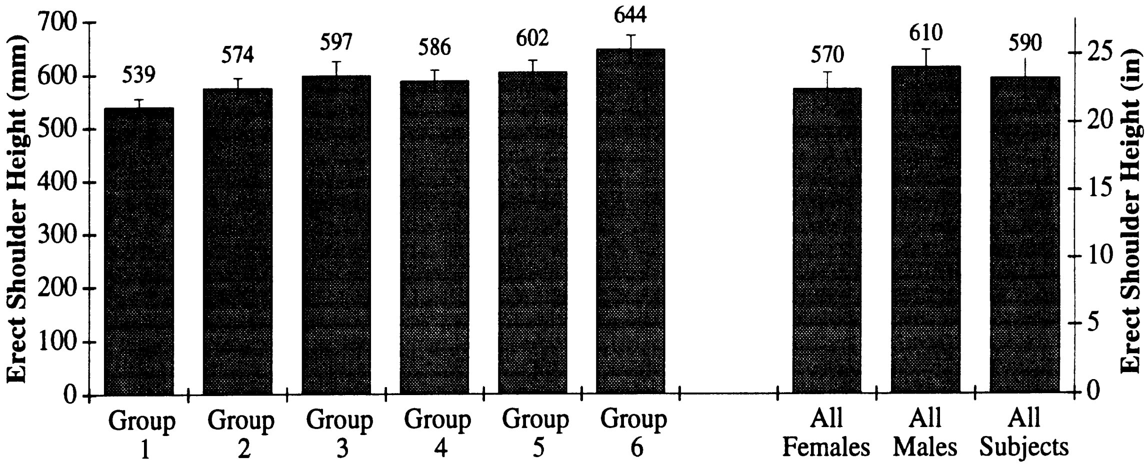


Figure C-7. Mean values and standard deviations of erect shoulder height by subject group.

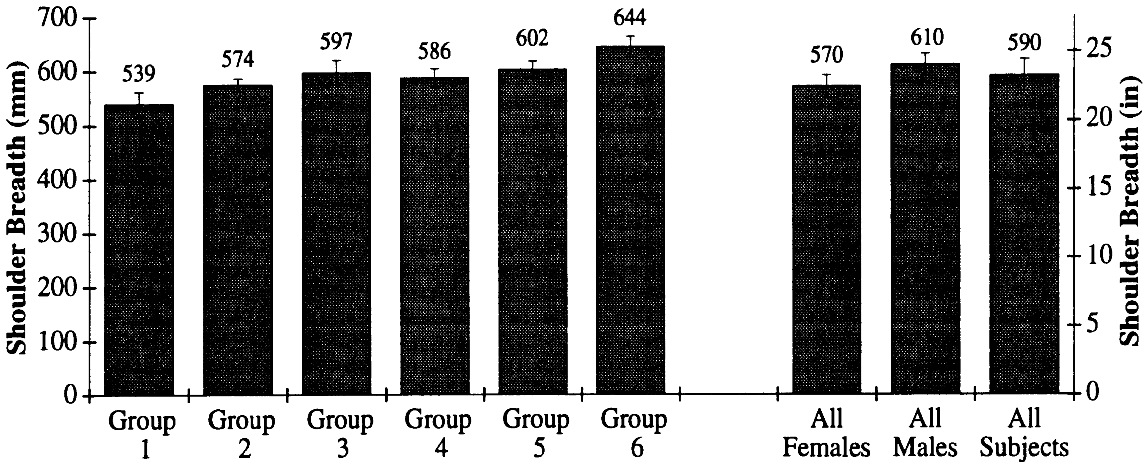


Figure C-8. Mean values and standard deviations of shoulder breadth by subject group.

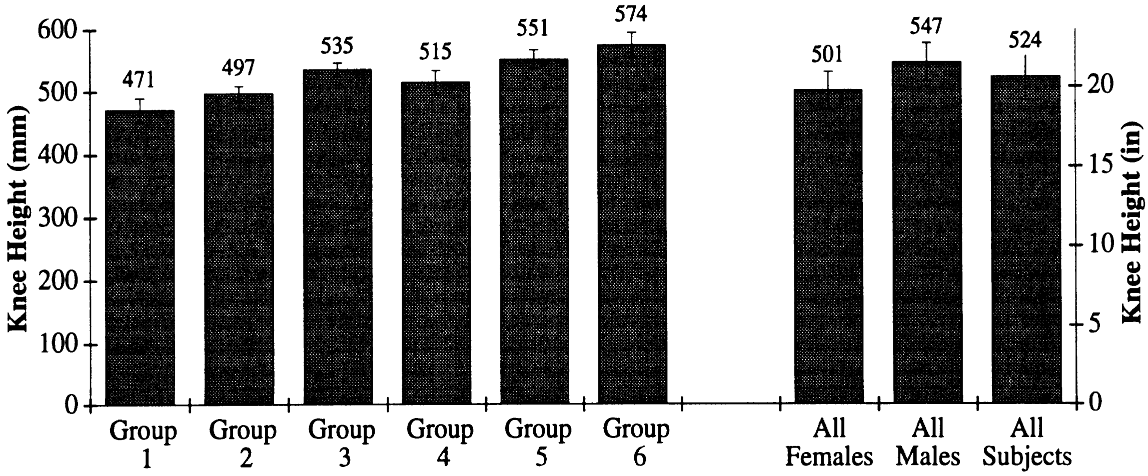


Figure C-9. Mean values and standard deviations of knee height by subject group.

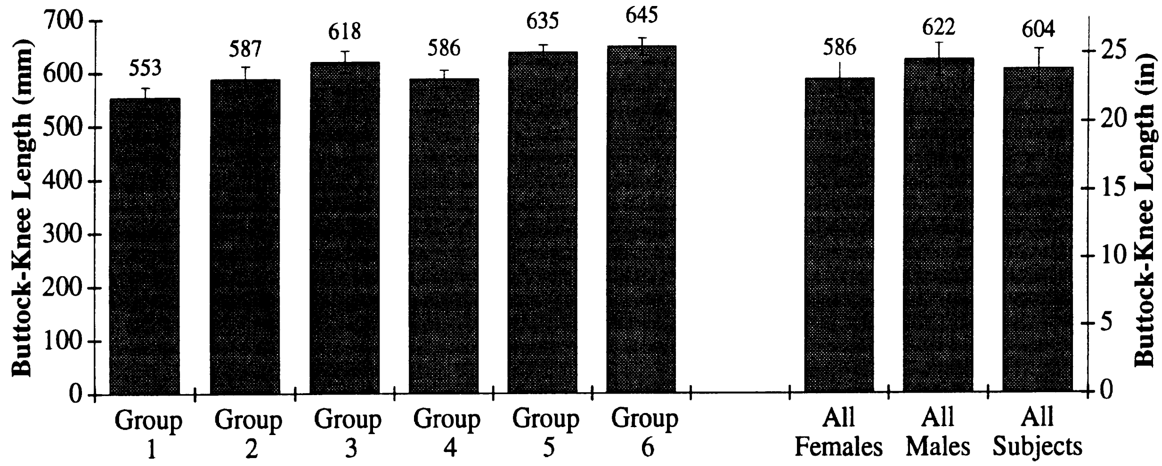


Figure C-10. Mean values and standard deviations of buttock to knee length by subject group.

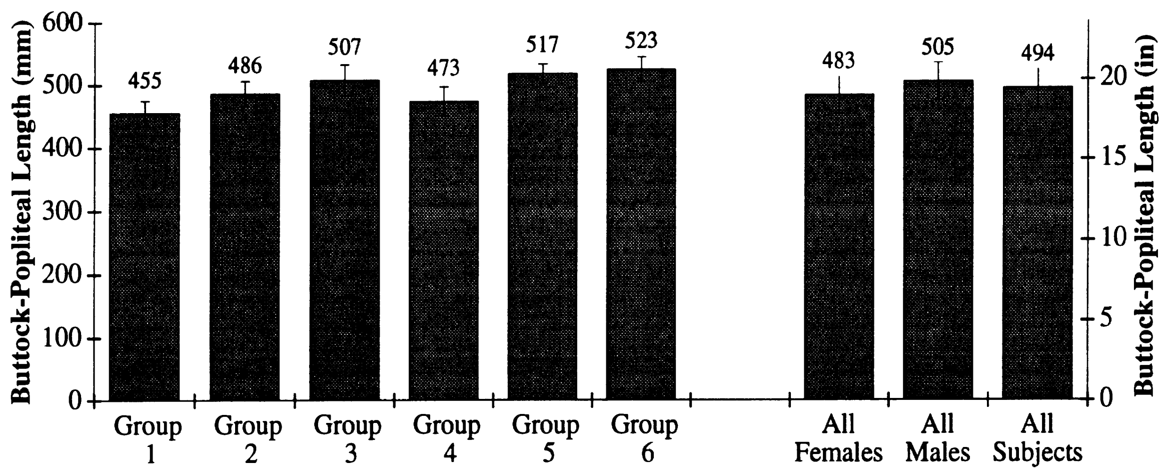


Figure C-11. Mean values and standard deviations of buttock to popliteal length by subject group.

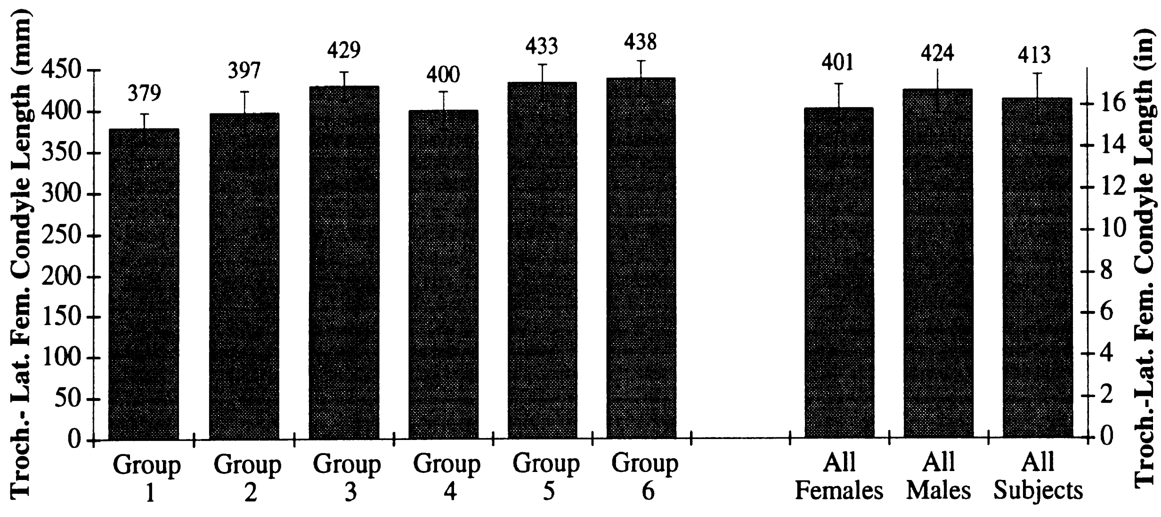


Figure C-12. Mean values and standard deviations of trochanter- lateral femoral condyle length.

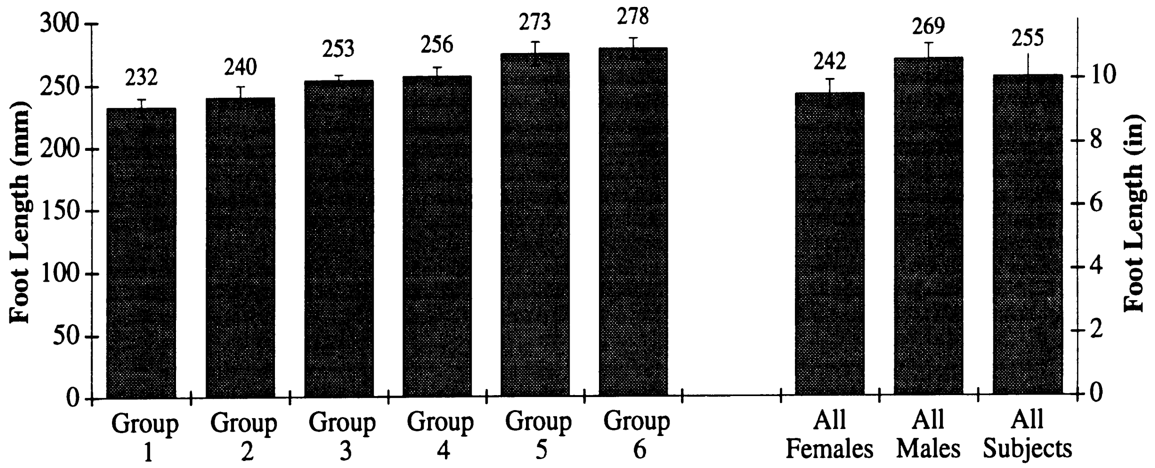


Figure C-13. Mean values of foot length by subject group.

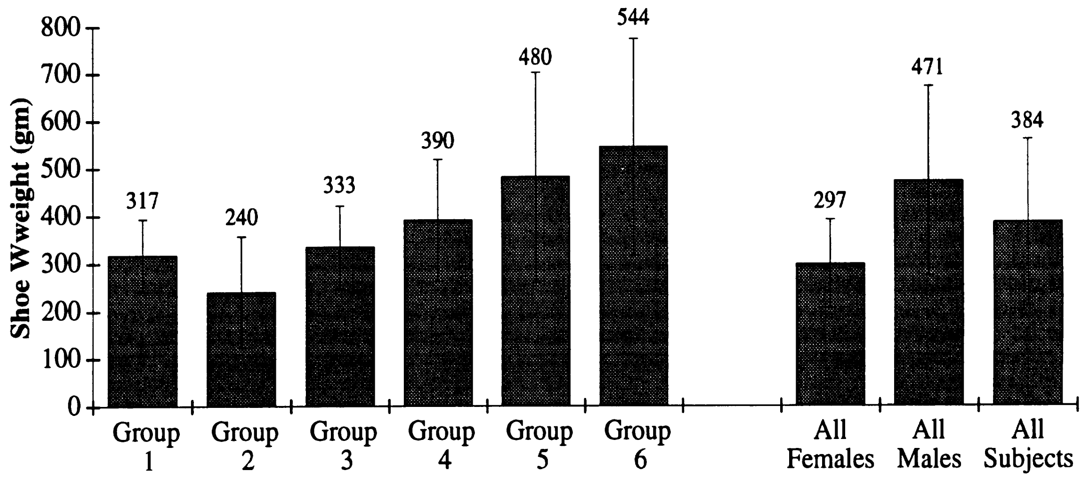


Figure C-14. Mean values of shoe weight by subject group.

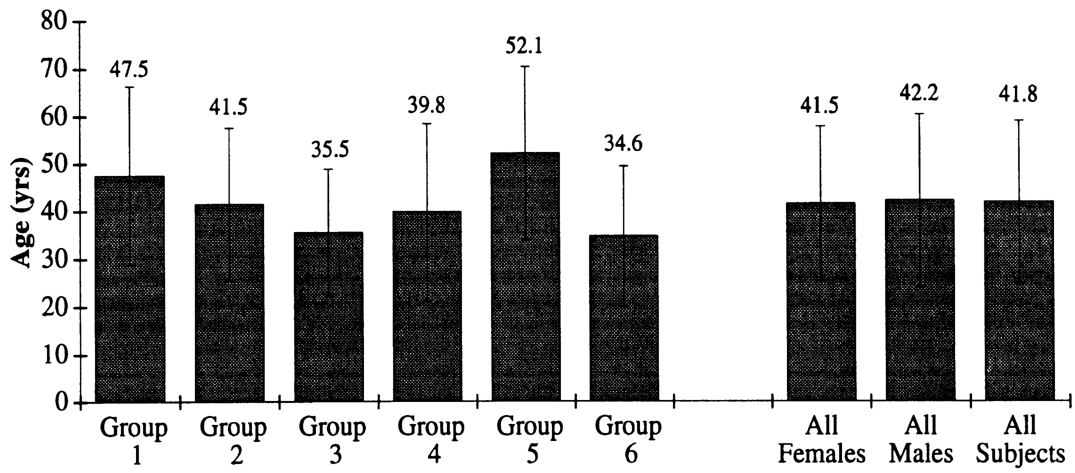


Figure C-15. Mean values and standard deviations for age by subject group.

Table C-2
Vehicles Owned or Operated by Subjects at the Time of the Study

Subject No.	Vehicle	Subject No.	Vehicle
11101	Mustang '94 / Pontiac Firebird '86	21101	Mazda 323 / Saab 900
11102	Honda Accord '92/Chev. Truck '93	21102	Bonneville '89 4-door
11103	Crown Vic. '87 / Cougar XR-7 '93	21103	Ford Festiva'89/Mercury Cougar'91
11104	Mustang '85	21104	Saturn '93 / Buick Century '86
11201	Buick Skylark '89/Park Avenue '89	21201	Buick Skylark '89/Park Avenue '89
11202	Ford Explorer '91 (2-dr.)	21202	Mustang '88/ Ford F-900 Truck '85
11203	Honda Civic 2D EX / Mazda 323	21203	Honda Civic '87
11204	Olds Sierra '88	21204	Buick '81/ Olds '87/ Ford P.V. '76
11301	Geo Metro '90 / VW Rabbit '81	21301	Dodge Stealth
11302	Escort L '85.5 / Explorer '93	21302	Buick LeSabre '86/Voyager '93
11303	Oldsmobile 98 '94 / Chevy 5-10 '88	21303	Mazda 323 '89
11304	Saturn SL2 '93 / Ford Van '92	21304	Ford Tempo '85 / Ford Ranger '85
12101	Buick '90 / Seirra Wagon '86	22101	Toronado '83 / Mercury '89
12102	Toyota Camry '92	22102	Firebird/Buick Regal/Buick Skylark
12103	Toyota Tercel '88	22103	Ford Tempo '87 / Olds Delta 88 '87
12104	Colt '87 / Civic '85 / Escort '85	22104	Chevy Sprint '88
12201	Dodge Shadow '90	22201	Cadillac '77
12202	Volkswagon Golf '87/Rabbit '83	22202	Escort '92
12203	Taurus '93 / Escort GT '93	22203	Honda Accord '85
12204	Plymouth Reliant SE '85	22204	Taurus '91/Civic '90/Grand Am'91
12301	Geo Spectrum '89/Bonneville '81	22301	Honda Accord '82
12302	Dodge Charger '86	22302	Sable '87 / Sable '90 / Taurus '87
12303	Toyota Corolla '85/Taurus Wag.'88	22303	Mercury Capri '81
12304	Chevy S-10 PV	22304	Jeep Cherokee '94/Mustang GT '89

APPENDIX D

Calculations of Dependent Variables from Measured Data

INDEX TO SECTIONS

D1.
SEAT POSITION re AHP AND BOF

The design H-Point location for each seat height was determined using the equations in SAE J1516 and J1517. The results are listed in Table D1-1.

Table D1-1
Design H-Point Location

Seat Height	H-Point-to-AHP Vert. Distance (mm)	Foot Angle re J1516 (deg)	AHP - BOF Distance (mm)	H-Point-to-AHP Hor. Distance (mm)	H-Point-to-BOF Hor. Distance re J1517 (mm)
Low	180	71	67	904	971
Mid	270	62	94	858	953
High	360	51	127	775	902

The subject's selected seat position is based on the manikin H-Point calibration. A scale was placed on the seat track as shown in Figure D1-1. The seat was calibrated such that when the scale reads 100 mm, the manikin H-Point is at the design location. Therefore, after a subject has chosen his/her preferred seat position, the scale reading is taken and 100 mm is subtracted from it. Then, multiplying this by the cosine or sine of the track angle, which is different at each seat height, the horizontal and vertical distances that the H-Point has moved from the design position are determined. Finally, subtracting these values from the design distances to the accelerator heel point and ball-of-foot, the subject's H-Point to AHP or BOF distance is determined.

The equations used for each seat height are as follows:

Low Seat Height:
H-Point-to-AHP vertical distance = 180 + SIN(8)*(Scale Reading - 100)
H-Point-to-AHP horizontal distance = 904 - COS(8)*(Scale Reading - 100)
H-Point-to-BOF horizontal distance = 971.4 - COS(8)*(Scale Reading - 100)

Mid Seat Height:
H-Point-to-AHP vertical distance = 270 + SIN(4)*(Scale Reading - 100)
H-Point-to-AHP horizontal distance = 858 - COS(4)*(Scale Reading - 100)
H-Point-to-BOF horizontal distance = 952.7 - COS(4)*(Scale Reading - 100)

High Seat Height:
H-Point-to-AHP vertical distance = 360 + SIN(0)*(Scale Reading - 100)
H-Point-to-AHP horizontal distance = 775 - COS(0)*(Scale Reading - 100)
H-Point-to-BOF horizontal distance = 902 - COS(0)*(Scale Reading - 100)

Table D1-2 shows data points for these equations. Figures D1-2 and D1-3 present plots for each. The plots are grouped into graphs according to H-Point distance.

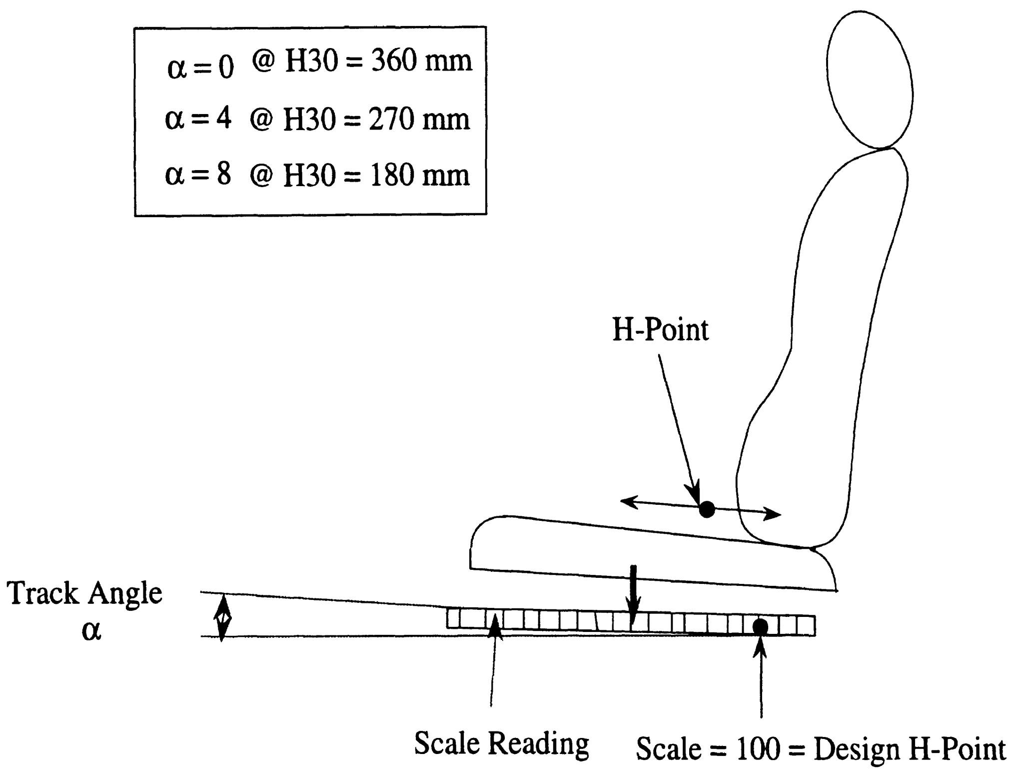


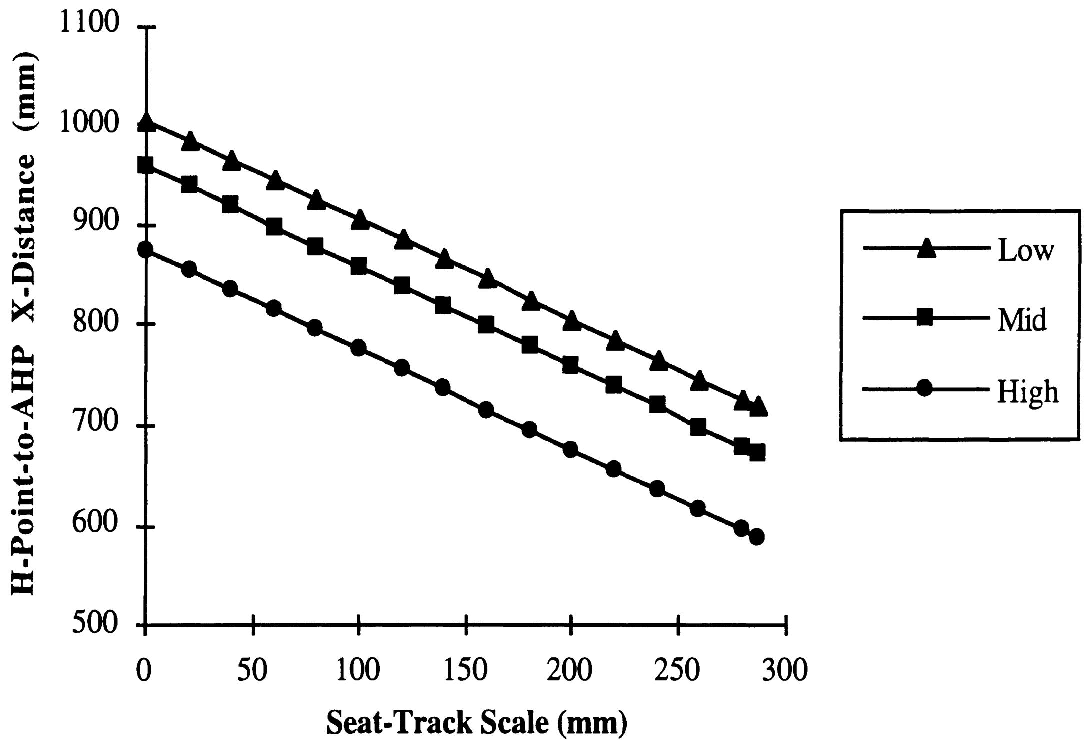
Figure D1-1. Subject H-point determination.

Table D1-2
Seat Track Calibration

Seat Track Scale Reading	Low Seat Height*			Mid Seat Height*		
	H-Point to AHP		BOF to AHP	H-Point to AHP		BOF to AHP
	(vertical)	(hor)	(hor)	(vertical)	(hor)	(hor)
0	166	1003	1070	263	958	1052
20	169	983	1051	264	938	1033
40	172	963	1031	266	918	1013
60	174	944	1011	267	898	993
80	177	924	991	269	878	973
100**	180	904	971	270	858	953
120	183	884	952	271	838	933
140	186	864	932	273	818	913
160	188	845	912	274	798	893
180	191	825	892	276	778	873
200	194	805	872	277	758	853
220	197	785	853	278	738	833
240	199	765	833	280	718	813
260	202	746	813	281	698	793
280	205	726	793	283	678	773
287	206	719	786	283	671	766

Seat Track Scale Reading	High Seat Height*		
	H-Point to AHP		BOF to AHP
	(vertical)	(hor)	(hor)
0	360	875	1002
20	360	855	982
40	360	835	962
60	360	815	942
80	360	795	922
100**	360	775	902
120	360	755	882
140	360	735	862
160	360	715	842
180	360	695	822
200	360	675	802
220	360	655	782
240	360	635	762
260	360	615	742
280	360	595	722
287	360	588	715

* All distances are given in mm
** Design position



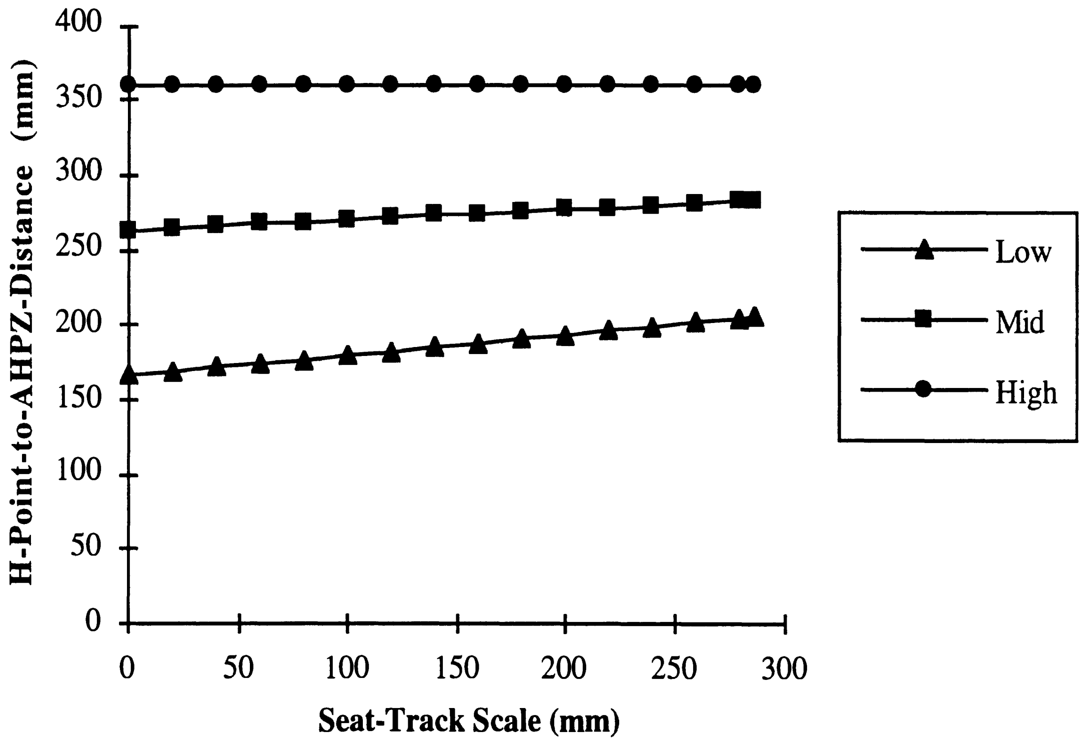


Figure D1-2. H-Point-to-AHP distance vs seat-track scale position.

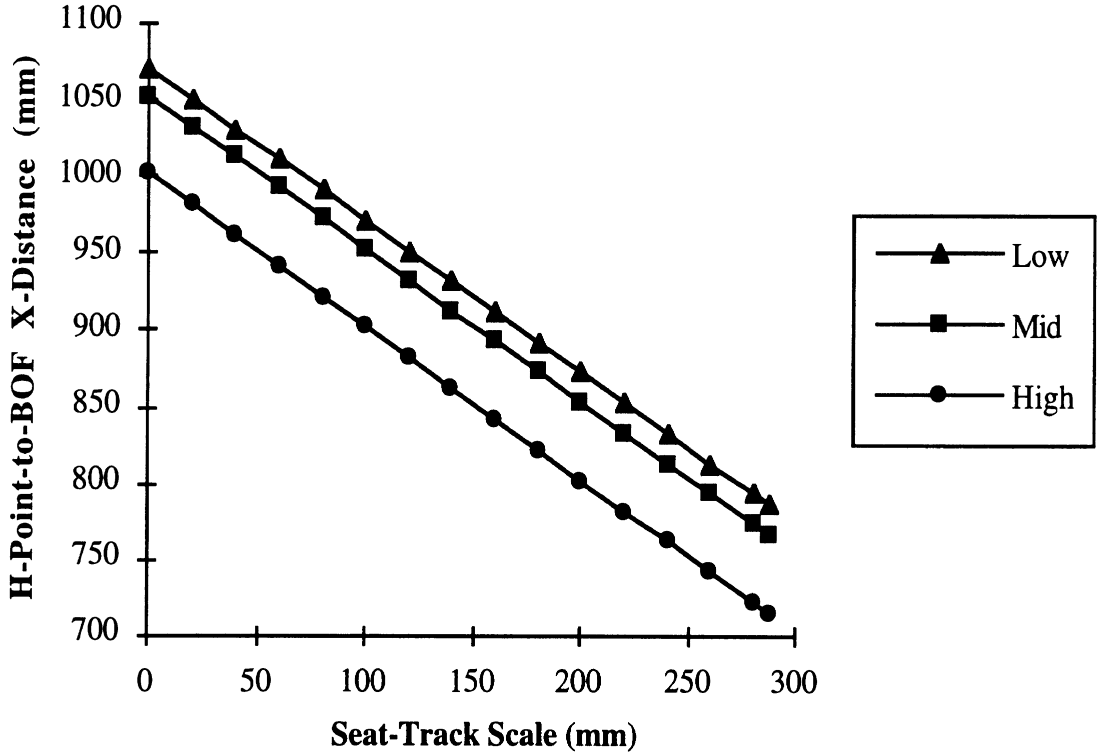


Figure D1-3. H-point-to-BOF distance vs seat-track scale position.

D2.
SEATBACK ANGLE

An inclinometer is bolted to the seatback as shown in Figure D2-1. During the J826 H-Point calibration of the seat, readings from the inclinometer corresponding to the readings from the manikin back angle were recorded. A plot of Manikin angle vs inclinometer angle is given in Figure 2.

At the design seatback angles - 20, 24, and 27 - it was found that, on average, the manikin back angle was two degrees more reclined than the reading of the inclinometer. Therefore, the equation used in data analysis is:

$$\theta_m = \theta_i + 2$$

Where θ_m is the Manikin back angle and θ_i is the inclinometer reading.

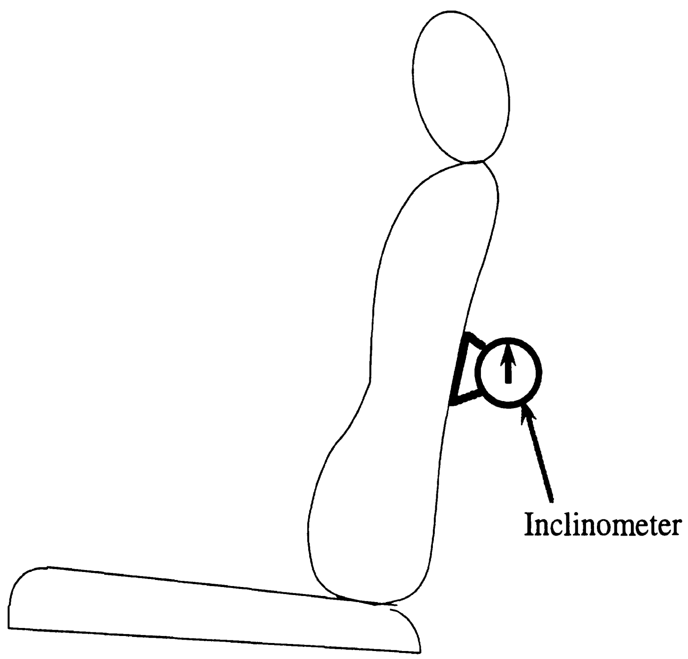


Figure D2-1. Seatback angle measurement.

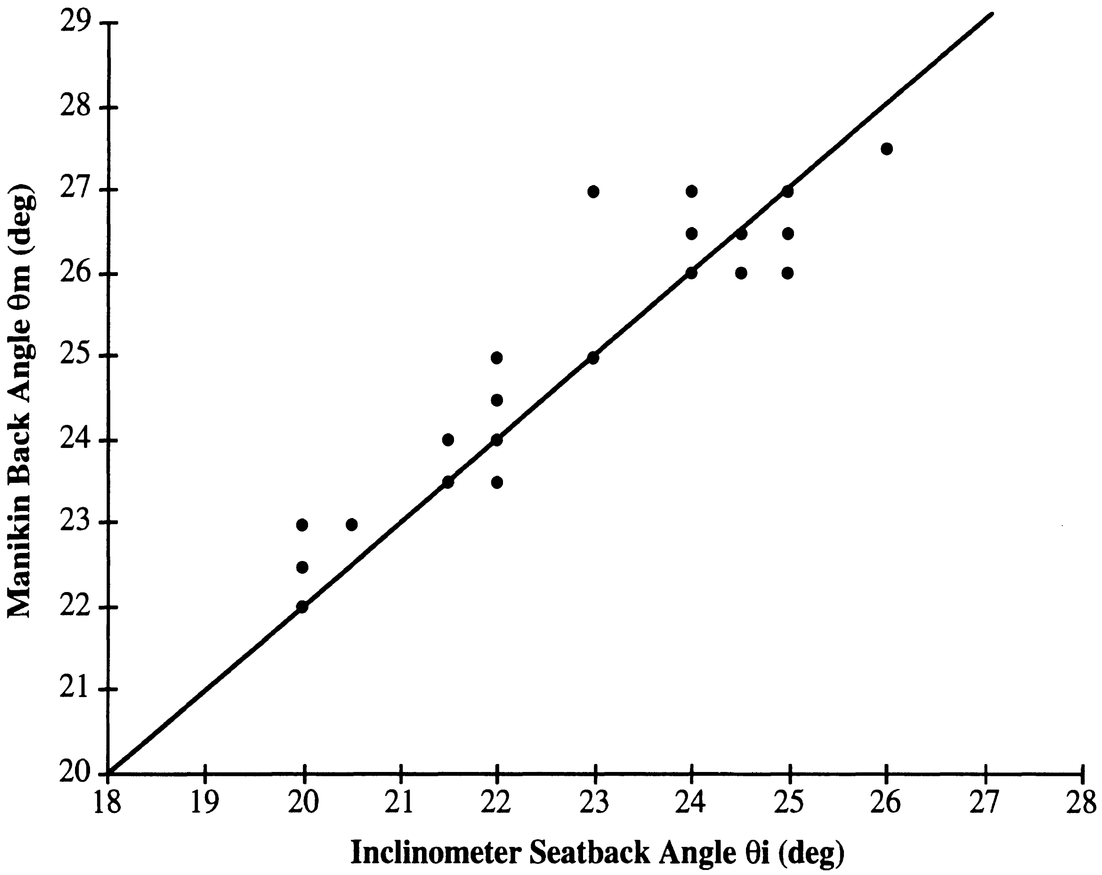


Figure D2-2. Inclinometer seatback angle vs manikin back angle.

D3.
HEEL POSITION

To determine the subject's right heel position, a grid was constructed on the rubber mat of the heel surface as shown in Figure D3-1. A marker is placed at the location of the subjects' heels after they have found their preferred location, and the x and y coordinates of the marker are then read from the grid.

The grid was constructed and located such that the AHP is at x=191 mm and the seat centerline is at y=275 mm. The program subtracts these references from the heel position read from the grid to determine the distances of the subject's heel position from AHP and seat centerline.

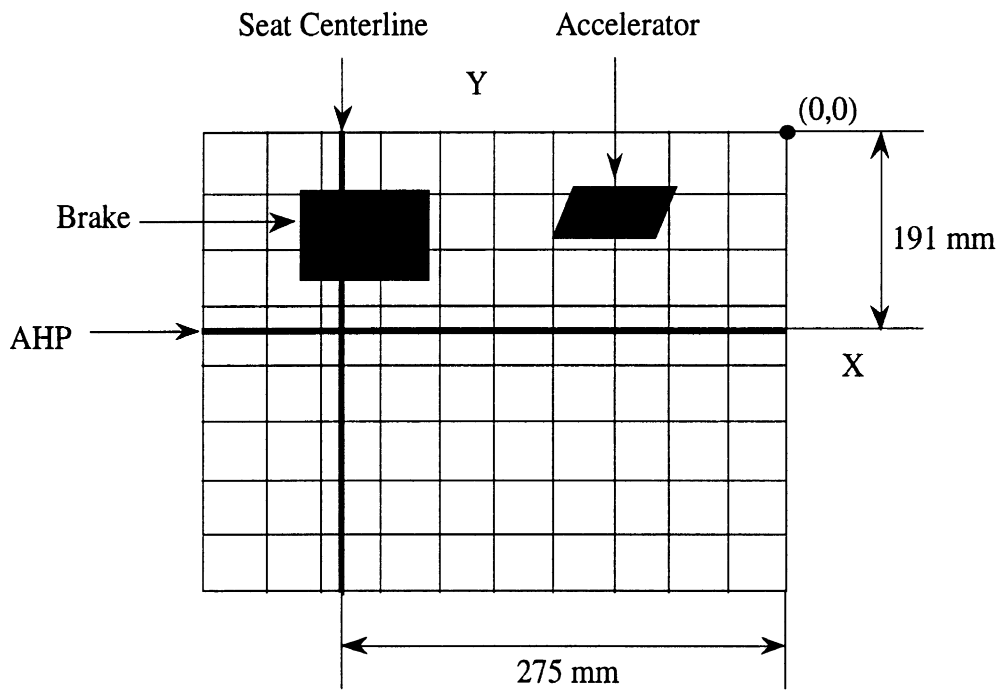


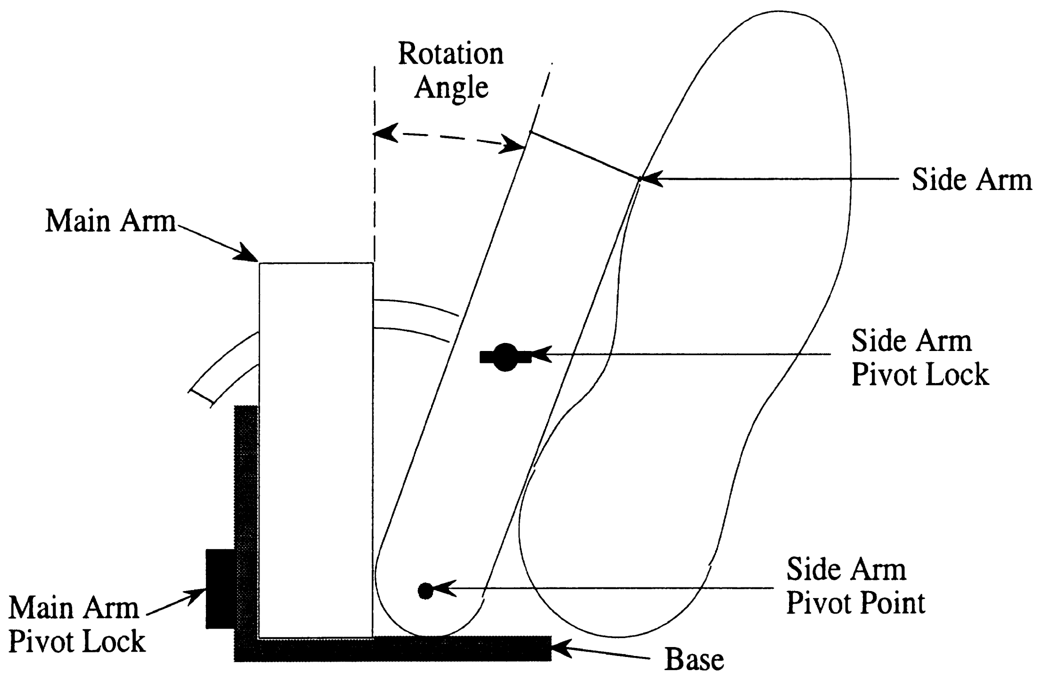
Figure D3-1. Heel position grid.

D4.
FOOT PITCH AND ROTATION ANGLES

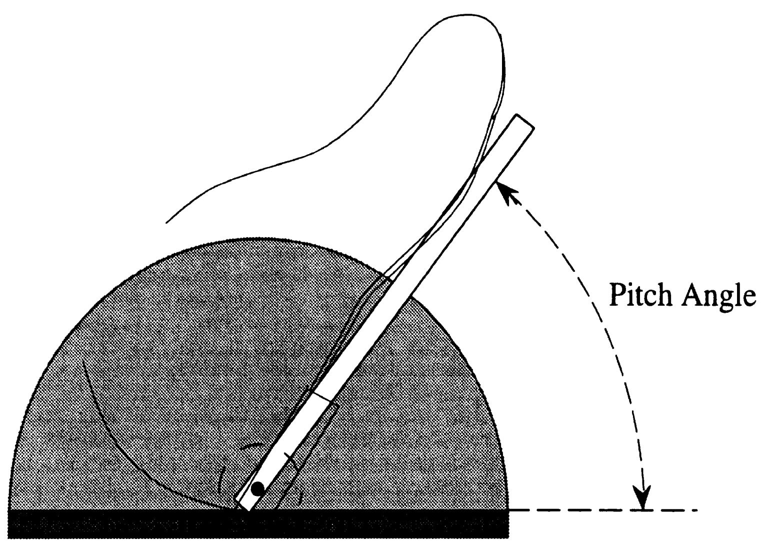
To determine the initial foot pitch and rotation angles, a special foot angle measuring device (FAMD) was constructed. Front and side views of the FAMD are shown in Figure D4-1. Once the subject has chosen his preferred seat and heel positions, the FAMD is placed on the floor so that the longitudinal axis of the base is aligned with the x-axis of the grid.

While maintaining this orientation, the base is moved as necessary and the pitch and rotation angles of the side arm are adjusted so that the right edge of the side arm aligns with and contacts the inside of the bottom of the subjects shoe above the sole and heel (i.e. so that it aligns with the bottom of the subject's foot). With the side arm so aligned, the side arm and main arm are locked into position and the device is removed for angle measurements.

To measure the pitch angle, the base of the FAMD is placed on a rigid horizontal surface and an inclinometer is placed on the top surface of the main arm to read the angle with respect to the horizontal. This is illustrated in Figure D4-2. A protractor is then positioned so that it's base is aligned with the right edge of the main arm and it's vertex is in line with the point of "v" between the main and side arms. The left edge of the side arm then determines the rotation angle. This is illustrated in Figure D4-3.

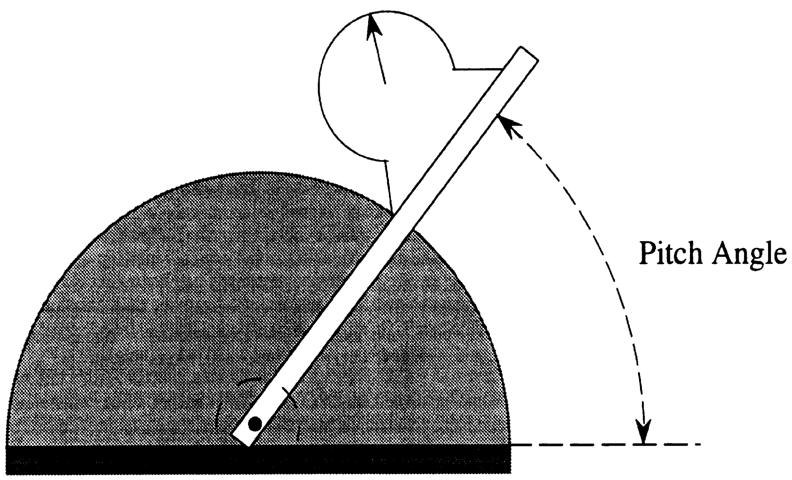


Front View



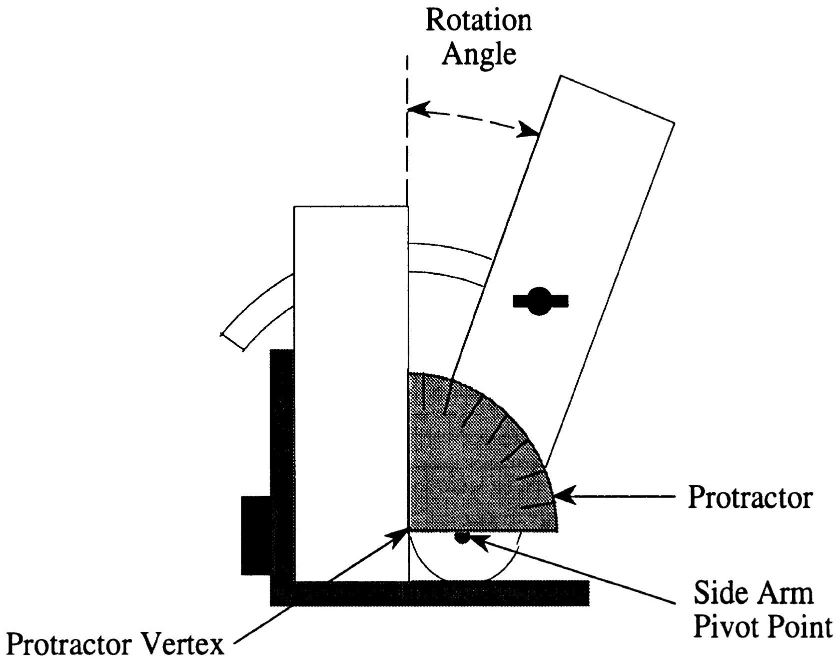
Side View

Figure D4-1. Front and side views of the foot angle measuring device.



Side View

Figure D4-2. Measurement of Pitch Angle



Front View

Figure D4-3. Measurement of Rotation Angle

D5.
THIGH PRESSURE

Two FSR sensors were attached to the right side of the seat cushion to determine the thigh pressure on the right leg. FSR #220 is located near the front of the seat cushion, where it just begins to curve down. FSR #223 is located approximately two inches rearward of #220.

The two FSR sensors were calibrated on a smooth metal platform, as illustrated in Figure D5-1. A thin piece of rubber was placed on top of the FSR, followed by a small metal plate to assure that the load was distributed evenly and only over the area of resistance. Different known weights were then placed on the small metal plate.

Table D5-2 shows the results of the calibration, listing the applied weights, the corresponding pressure and the average voltage from three trials with each weight. Figure D5-3 show plots of pressure vs voltage. The equations for the best-fit curves for these plots are as follows:

FSR #220 (front):

$$P_1=-1.663*10^{-5} + 1.597*10^{-5}*E^{v} - 9.481*10^{-10}*E^{2v} - 3.937*10^{-15}*E^{3v} + 9.669*10^{-18}*E^{4v} - 6.868*10^{-5}*v + 2.823*10^{-4}*v^2$$

FSR #223 (back):

$$P_2=5.632*10^{-6} + 1.0002*10^{-5}*E^{v} - 8.530*10^{-10}*E^{2v} -2.329*10^{-13}*E^{3v} + 1.754*10^{-17}*E^{4v} - 2.402*10^{-5}*v + 1.035*10^{-4}*v^2$$

where v is the voltage, which will be read off of the strip chart, and P is the pressure in kilograms/cm^2.

During calibrating on the flat platform, each FSR had an initial unloaded voltage of 3.17 volts and is incorporated into the equations above. After attaching the tapes to the seat, however, the initial voltages changed. These initial voltages are entered into the equation to give P_{i1} and P_{i2}. By subtracting P_1 and P_2, which are the pressures obtained by entering 3.17 volts into the above equations, from P_{i1} and P_{i2}, respectively, the initial offset pressures DP_1 and DP_2 are obtained. For the remaining pressures the following equations are used:

FSR #220 (front):

$$P_1=-1.663*10^{-5} + 1.597*10^{-5}*E^{v} - 9.481*10^{-10}*E^{2v} - 3.937*10^{-15}*E^{3v} + 9.669*10^{-18}*E^{4v} - 6.868*10^{-5}*v + 2.823*10^{-4}*v^2 - DP_1$$

FSR #223 (back):

$$P_2=5.632*10^{-6} + 1.0002*10^{-5}*E^{v} - 8.530*10^{-10}*E^{2v} -2.329*10^{-13}*E^{3v} + 1.754*10^{-17}*E^{4v} - 2.402*10^{-5}*v + 1.035*10^{-4}*v^2 - DP_2$$

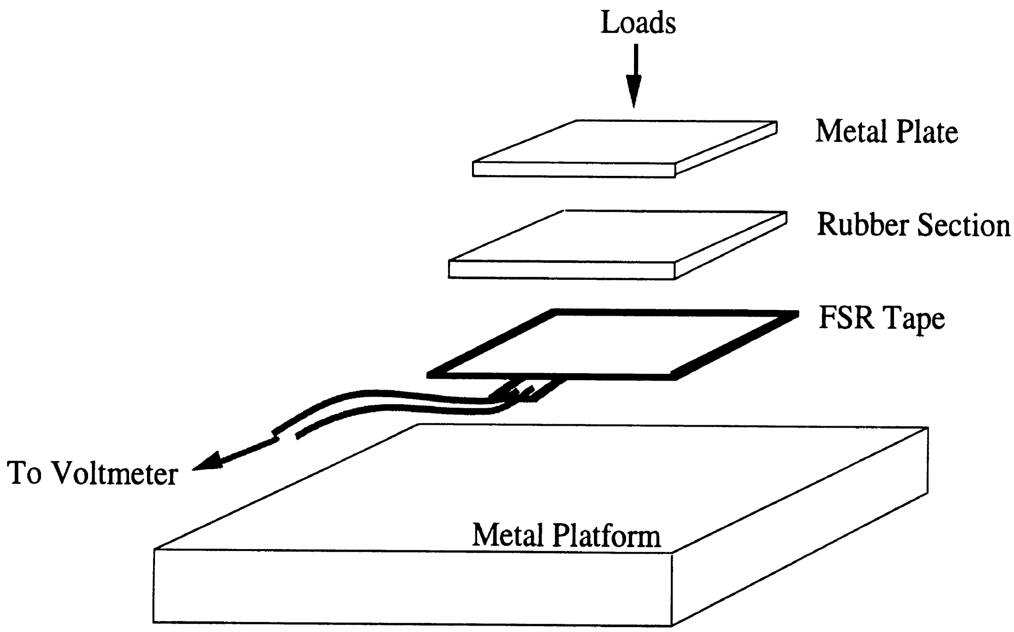


Figure D5-1. FSR calibration set-up.

Table D5-2
FSR Sensor Calibration Results

FSR #220 Average Voltage	Pressure (kg/cm^2)	FSR #223 Average Voltage	Pressure (kg/cm^2)
3.10	0.000	3.17	0.000
3.36	0.001	3.48	0.001
3.50	0.002	3.50	0.001
4.00	0.006	4.00	0.003
4.50	0.009	4.50	0.004
5.00	0.012	5.50	0.007
5.50	0.016	6.00	0.009
6.50	0.021	6.10	0.009
6.70	0.024	6.30	0.010
6.90	0.028	6.50	0.011
7.00	0.030	6.70	0.013
7.10	0.034	6.90	0.015
7.39	0.040	7.10	0.018
7.47	0.041	7.30	0.021
7.57	0.043	7.67	0.034
7.71	0.047	7.96	0.040
7.79	0.049	8.05	0.041
7.88	0.052	8.15	0.043
8.00	0.063	8.28	0.047
8.07	0.066	8.33	0.049
8.32	0.070	8.41	0.052
8.41	0.076	8.49	0.063
8.47	0.079	8.54	0.066
8.60	0.087	8.68	0.070
8.66	0.093	8.77	0.076
8.72	0.096	8.82	0.079
8.80	0.103	8.90	0.087
8.84	0.109	8.97	0.093
8.87	0.112	8.99	0.096
8.89	0.116	9.04	0.103
8.96	0.124	9.08	0.109
9.02	0.133	9.10	0.112
		9.13	0.116
		9.16	0.124
		9.19	0.133

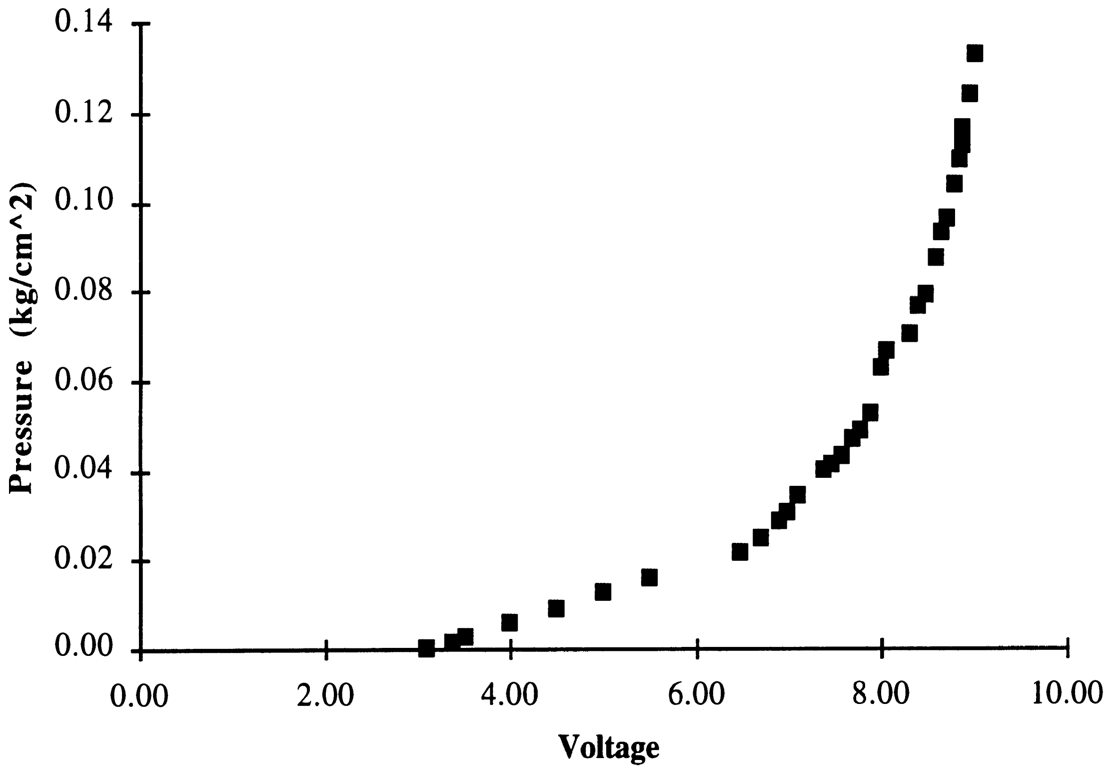


Figure D5-2. Pressure vs voltage for FSR #220.

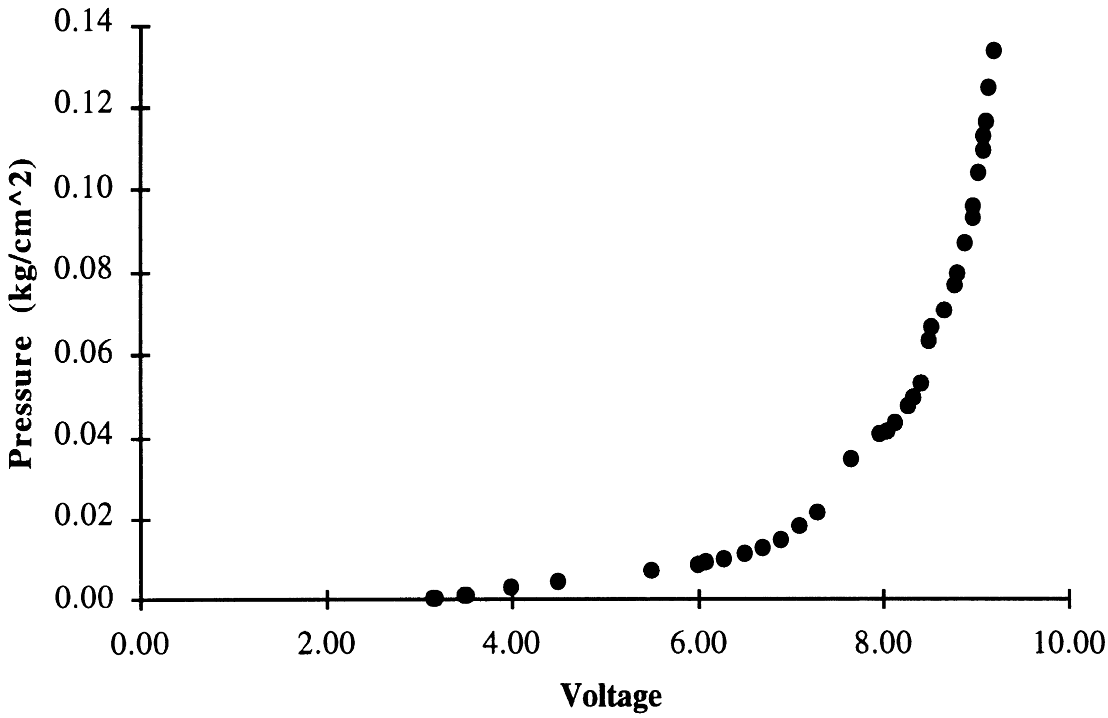


Figure D5-3. Pressure vs voltage for FSR #223.

D6.
DOWNWARD THIGH DISPLACEMENT

To determine the vertical displacement of the thigh, a marker is placed on the subject's thigh just proximal to the knee-cap. The vertical displacement of this thigh point is measured using a standard anthropometer as the subject operates the accelerator pedal from the undepressed position through a comfortable range. This is illustrated in Figure D6-1.

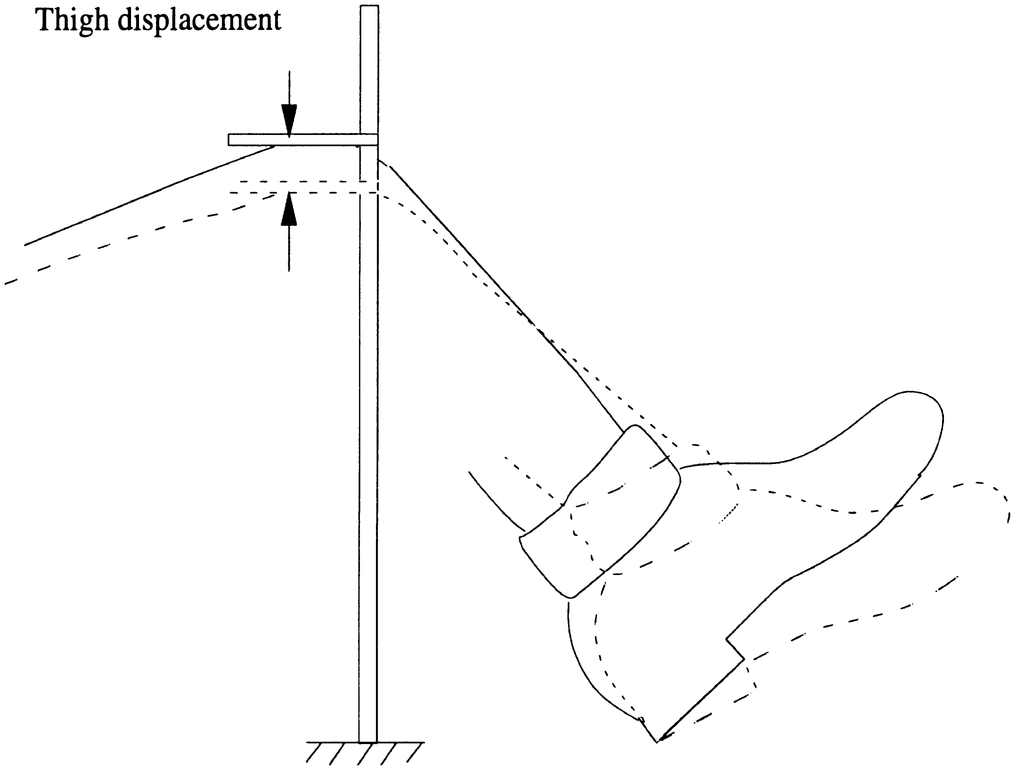


Figure D6-1. Downward thigh displacement measurement.

D7.
ANKLE EXTENSION AND EVERSION ANGLES

Ankle extension and eversion angles were measured by means of a Penny & Giles twin-axis goniometer. This device consists of two plastic bases connected by a measuring wire. This wire is instrumented with four strain gauges equally spaced around the circumference of the wire, which provide electrical output in relation to two perpendicular angles between the plastic bases.

Prior to subject testing, one plastic base was attached to the outside edge of the subject's shoe by Velcro and the other base was attached to the subject's leg just above the ankle using double-sided adhesive. This is illustrated in Figure D7-1. In this orientation, one axis measures the change in ankle eversion angle and the other axis measures the change in ankle extension angle.

The goniometer cables were connected to an angle display unit (ADU), which provides the excitation voltage for the goniometer gauges as well as a readout of the angles in degrees. The ADU is connected to a strip chart that records the change in voltage during subject testing.

The foot angle measuring device (FAMD) was used to calibrate the goniometer as illustrated in Figure D7-2. One plastic base was attached to the base of the FAMD and one to the side-arm. Inversion/eversion angle (E/I angle) was calibrated by moving the sidearm upward, while voltage and inclinometer angles were read simultaneously. Sample results are listed in Table D7-1 and a plot of change in angle vs strip chart voltage is presented in Figure D7-3. The equation of the best-fit line of this plot is:

$$\text{E/I angle } \theta = -82.64563v + 204.8359$$

where v is the ADU output voltage.

To calibrate the flexion/extension angle (F/E angle), the sidearm is rotated outward in increments while recording the rotation angle from an adjustable triangle and the voltage from the strip chart. The results are listed in Table D7-2 and a plot of change in angle vs strip chart voltage is presented in Figure D7-4. The equation of the best-fit line of this plot is:

$$\text{F/E angle } \gamma = -87.1094v + 215.9875$$

where v is the ADU output voltage.

During testing, the extension and eversion output signals are adjusted to a known voltage after the subject has achieved his/her preferred seat, heel, and foot positions, with the shoe placed on the undepressed accelerator pedal. The strip chart then provides direct measures of the change in angles during pedal operation.

The initial ankle angle can be calculated having measured the initial foot angle and leg angle. Knowing the initial ankle angle and change in ankle angle, the maximum ankle extension angle can be determined.

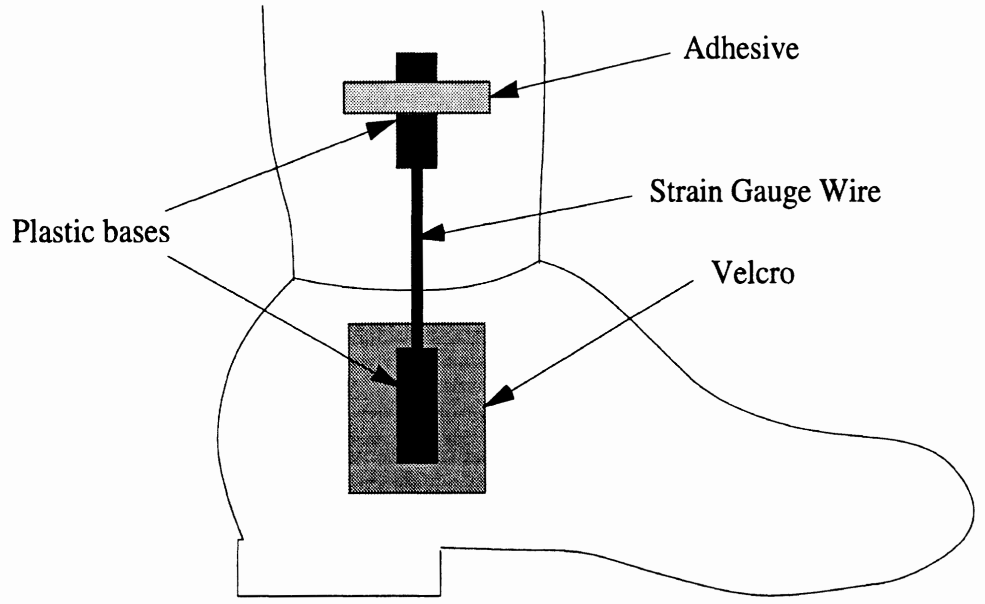
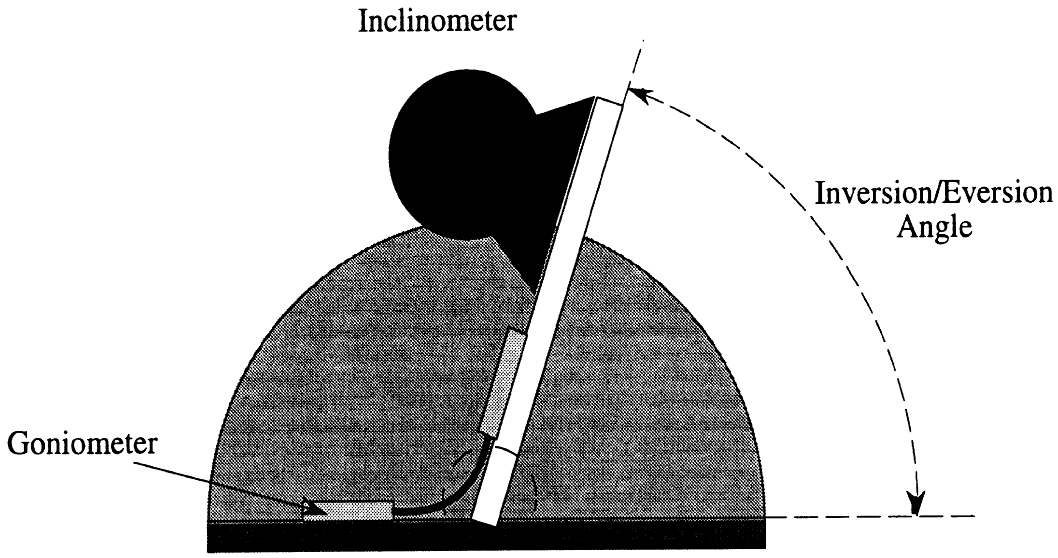
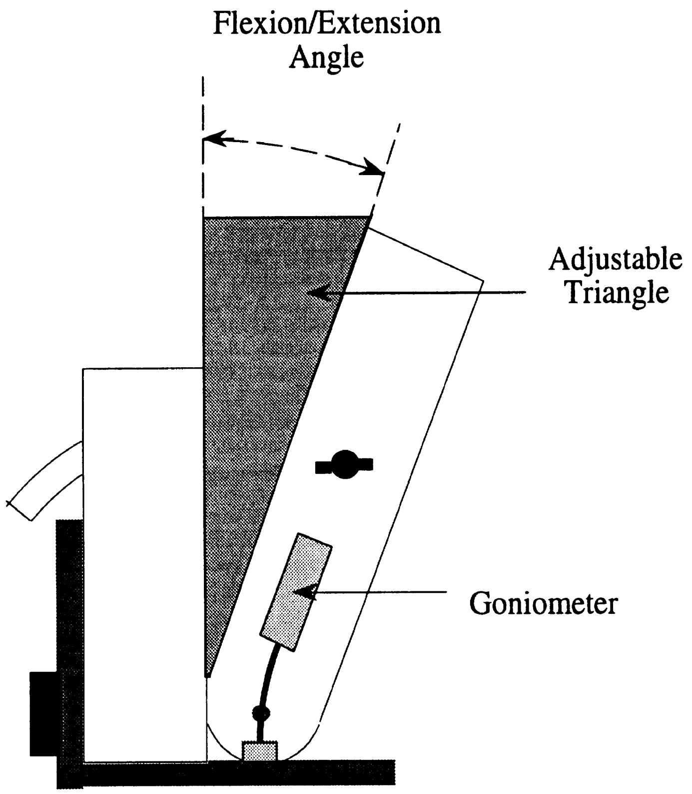


Figure D2-2. Goniometer placement.



Side View



Front View

Figure D7-2. Goniometer calibration.

Table D7-1
Goniometer Calibration for Inversion/Eversion Angle

Inclinometer Reading (deg)	ADU Output Voltage
0	2.47
5	2.42
10	2.35
20	2.25
30	2.12
40	2.00
50	1.87
60	1.75
70	1.62
80	1.52
89	1.40

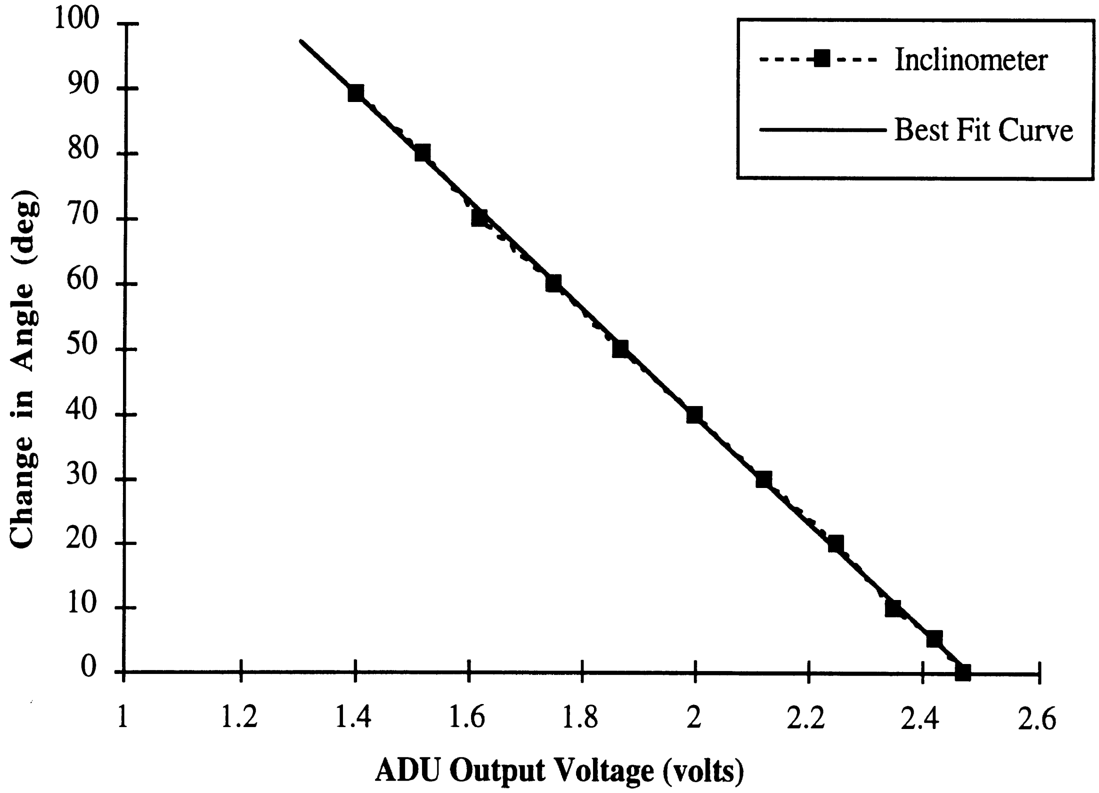


Figure D2-3. Change in eversion/inversion angle vs voltage.

Table D7-2
Goniometer Calibration for Flexion/Extension Angle

Adjustable Triangle (deg)	ADU Output Voltage
0	2.47
15	2.32
29	2.15
45	1.97
50	1.92
55	1.87
60	1.80
65	1.72
68.5	1.67

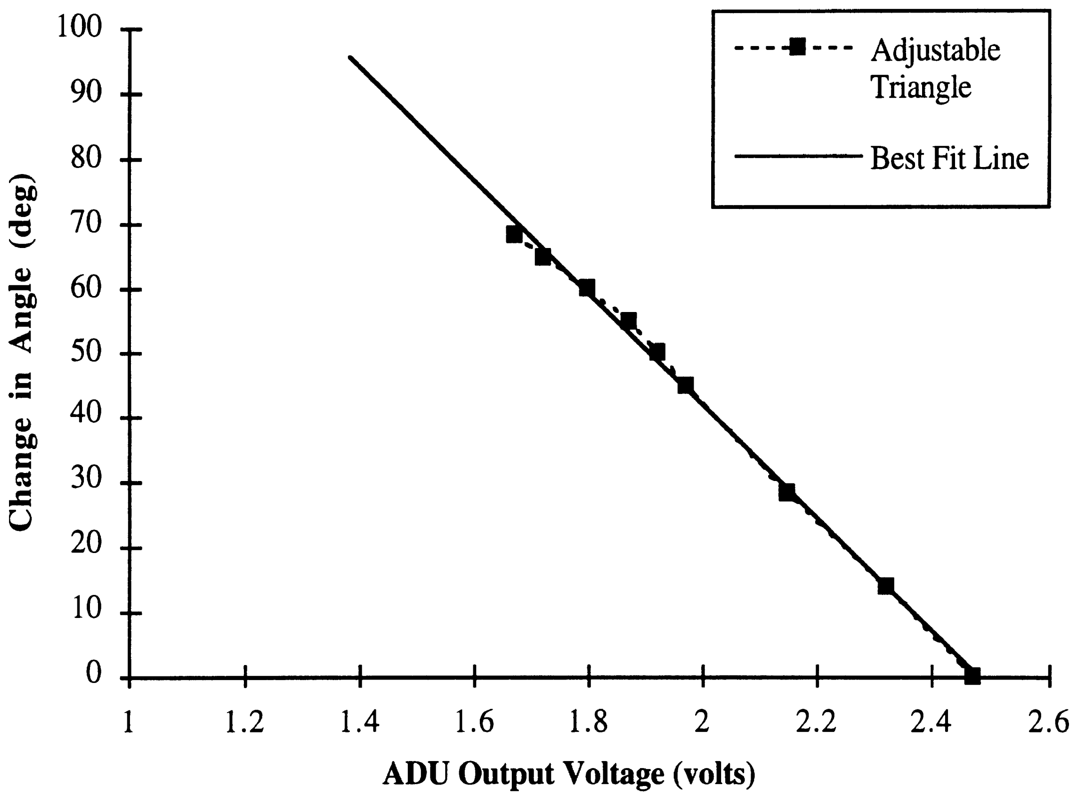


Figure D7-4. Change in flexion/extension angle vs voltage.

D8.
PEDAL TRAVEL

To determine the accelerator pedal travel, a string potentiometer is attached to the pedal base directly behind the accelerator pedal, and its cable is hooked at the pivot point behind the center of the pedal. This is illustrated in Figure D8-1. The potentiometer output is connected to a strip chart, which measures the change in voltage as the pedal moves.

To calculate the actual pedal travel, the x and z coordinates of a point on the pedal near the string potentiometer attachment were measured with an anthropometer at several different pedal displacements and the distances from the undepressed pedal were calculated. Voltage readings from the strip chart were taken simultaneously. The results are listed in Table D8-1 and a plot of pedal travel vs potentiometer voltage is presented in Figure D8-2. The best fit line for this plot is:

$$T = 204.9259v - 0.739233$$

where v is the voltage read from the strip chart and T is the pedal travel in mm.

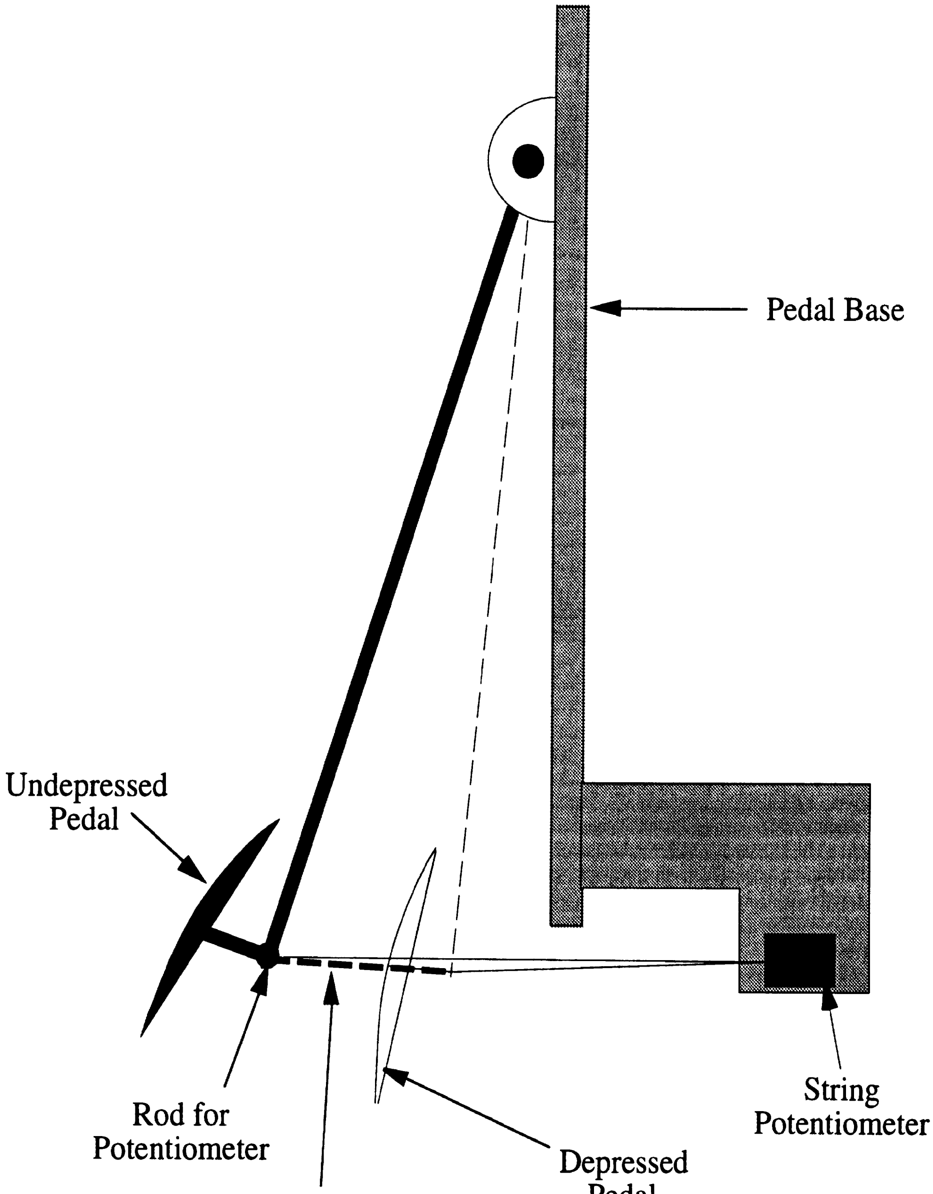


Figure D8-1. Pedal travel calibration.

Table D8-1
Pedal Travel Calibration

Distance from Undepressed Pedal		String Pot Voltage	Change in Voltage	Total Pedal Travel (mm)
x (mm)	z (mm)			
0.0	0.0	2.47	0.00	0.0
3.0	-1.0	2.49	0.02	3.2
8.0	-1.0	2.50	0.04	8.1
11.0	-2.5	2.53	0.06	11.3
13.0	-3.0	2.56	0.09	13.3
21.5	-4.0	2.57	0.11	21.9
42.0	-16.0	2.67	0.21	44.9
61.0	-18.0	2.77	0.31	63.6
82.0	-20.0	2.88	0.41	84.4
104.5	-20.0	2.99	0.52	106.4
127.0	-19.0	3.10	0.63	128.4
147.0	-18.0	3.20	0.73	148.1
167.0	-13.0	3.29	0.83	167.5

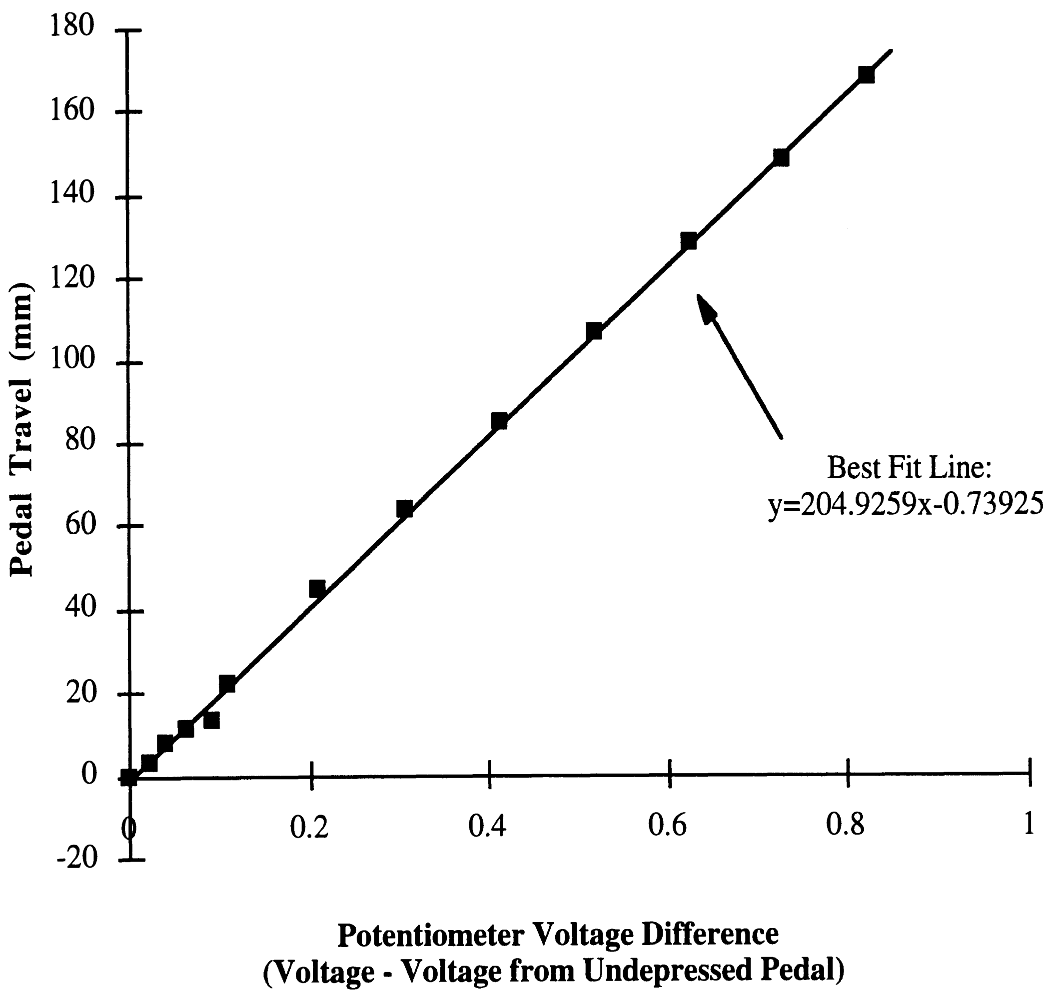


Figure D8-2. Pedal travel vs voltage difference.

D9.
EQUIVALENT CHANGE IN MANIKIN FOOT ANGLE

To determine the equivalent change in manikin foot angle for 95th percentile male leg lengths and 95th percentile seating accommodation, the relation between manikin foot angle and voltage from the pedal string potentiometer was first determined. Manikin foot angle was measured by placing the manikin foot so that the heel touched the AHP. The BOF was then lowered until it rested on the accelerator pedal. An inclinometer was placed on the top surface of the manikin heel to determine the angle at the undepressed pedal position, as shown in Figure D9-1. Then, keeping the manikin heel at the AHP, the BOF was lowered further so that the accelerator pedal was depressed. A protractor was attached at the pivot point of the pedal linkage, to aid in taking readings at regular intervals. The protractor scale angle, the angle on the inclinometer, and the voltage from the strip chart were recorded simultaneously at several pedal displacements.

The relation between change in manikin foot angle and potentiometer voltage was determined separately for each seat height. The results for the low, mid, and high seat heights are listed in Tables D9-1, D9-2, and D9-3, respectively. A plot of foot angle vs voltage for the low, mid, and high seat heights is given in Figure D9-2. As shown in Figure D9-2, the best fit curves for these plots are similar. Therefore the three trials were averaged together. A plot of the average foot angle vs voltage is given in Figure D9-3.

The formula for the best fit curve is:

$$\gamma = 39.65v^3 - 71.63v^2 + 74.26v + .2705$$

where v is the voltage from the strip chart, and γ is the resulting change in manikin foot angle.

In a similar fashion, the equivalent change in manikin foot angle for 50th percentile male leg lengths and 50th percentile seating accommodation was determined. Instead of placing the manikin heel on the AHP, which was calibrated for the 95th percentile adult population, the BOF was placed on the pedal, and then the heel was adjusted until the correct initial foot angle was reached.

To determine this initial foot angle, the 50th percentile seating accommodation curve from SAE J1517 was drawn. A two dimensional manikin was then placed on the curve at one of the specified seat heights and the x and y coordinates of the BOF were recorded. From those coordinates and the coordinates of the AHP, the foot pitch angle was calculated. The 2-d manikin was then placed on the curve at the other two seat heights, and those angles were calculated.

Once the manikin heel was in the correct position on the accelerator pedal, the BOF was lowered so that the accelerator pedal was depressed. The manikin foot angle and the potentiometer voltage were recorded at several pedal displacements. The results for the low, mid, and high seat heights are listed in Tables D9-4, D9-5, and D9-6, respectively. A plot of foot angle vs voltage for the low, mid, and high seat heights is given in Figure D9-4. Again, the best fit curves for these plots are similar, so the three trials were averaged together. A plot of the average foot angle vs voltage is given in Figure D9-5.

The formula for the best fit curve is:

$$\gamma = 75.41v^3 - 75.70v^2 + 60.70v + .2134$$

where v is the voltage from the strip chart, and γ is the resulting change in manikin foot angle.

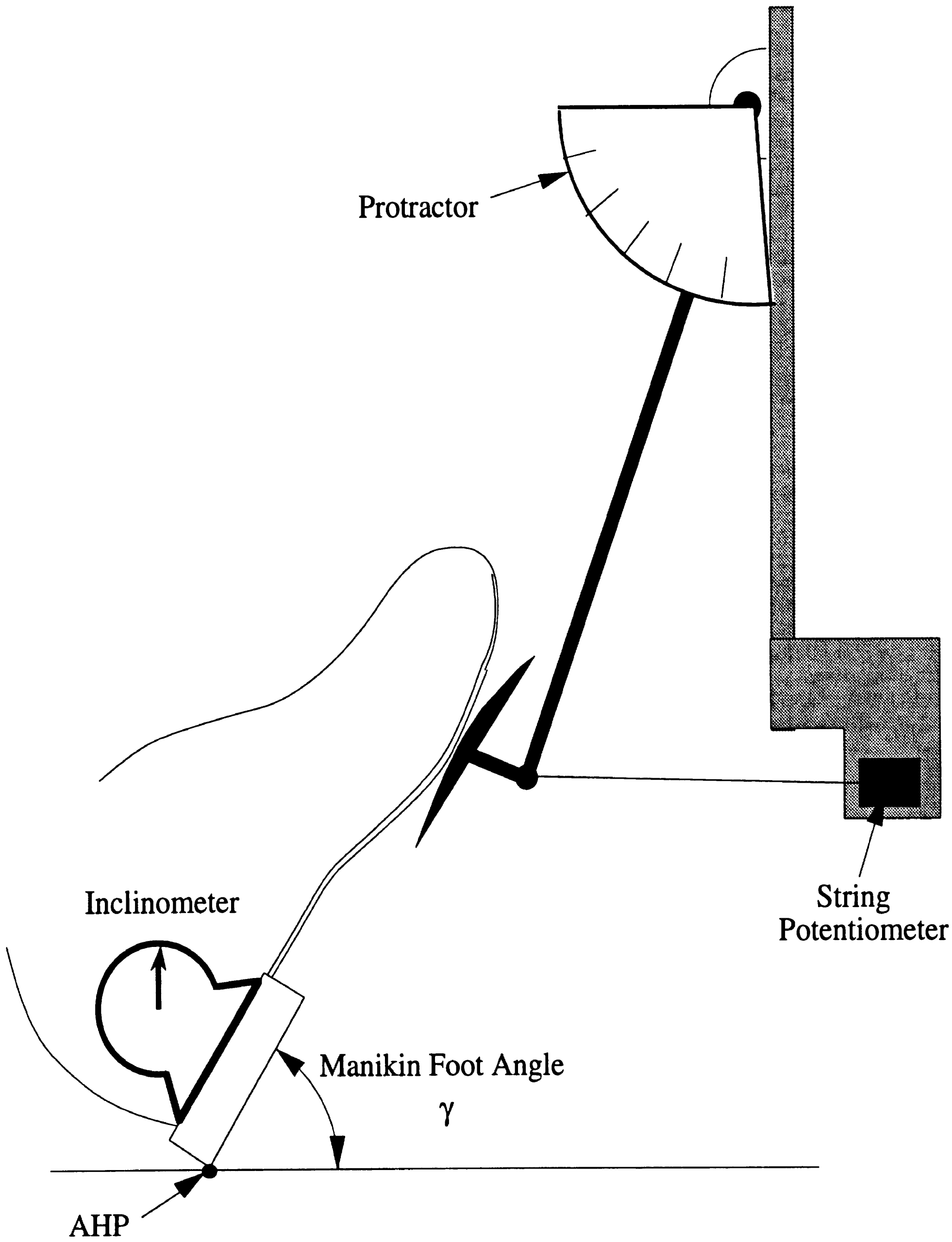


Figure D9-1. Manikin foot angle measurement.

Table D9-1
Manikin Foot Angle Calibration for the Low Seat Height

Scale Reading (deg)	String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
0	2.47	0.00	50.5	0.0
1	2.49	0.02	49.5	1.0
2	2.51	0.04	48.0	2.5
3	2.53	0.06	46.0	4.5
4	2.56	0.08	45.0	5.5
5	2.58	0.11	43.0	7.5
10	2.68	0.21	39.0	11.5
15	2.78	0.31	34.0	16.5
20	2.89	0.41	29.5	21.0
25	2.99	0.52	26.0	24.5
30	3.10	0.63	23.5	27.0
35	3.20	0.73	20.0	30.5
40	3.30	0.83	15.5	35.0

Table D9-2
Manikin Foot Angle Calibration for the Mid Seat Height

Scale Reading (deg)	String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
0	2.47	0.00	62.0	0.0
1	2.49	0.02	61.0	1.0
2	2.51	0.04	60.0	2.0
3	2.53	0.06	58.5	3.5
4	2.55	0.08	57.5	4.5
5	2.57	0.10	56.5	5.5
10	2.67	0.20	50.5	11.5
15	2.78	0.31	45.0	17.0
20	2.89	0.42	41.5	20.5
25	2.99	0.52	38.0	24.0
30	3.10	0.63	35.0	27.0
35	3.20	0.73	32.5	29.5
40	3.30	0.83	27.5	34.5

Table D9-3
Manikin Foot Angle Calibration for the High Seat Height

Scale Reading (deg)	String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
0	2.47	0.00	72.5	0.0
1	2.50	0.03	70.5	2.0
2	2.52	0.04	69.0	3.5
3	2.54	0.07	68.0	4.5
4	2.56	0.09	66.0	6.5
5	2.58	0.11	65.0	7.5
10	2.68	0.21	59.5	13.0
15	2.79	0.32	54.5	18.0
20	2.90	0.42	50.0	22.5
25	3.00	0.53	46.5	26.0
30	3.06	0.59	43.5	29.0
35	3.21	0.74	40.5	32.0
40	3.30	0.83	37.0	35.5

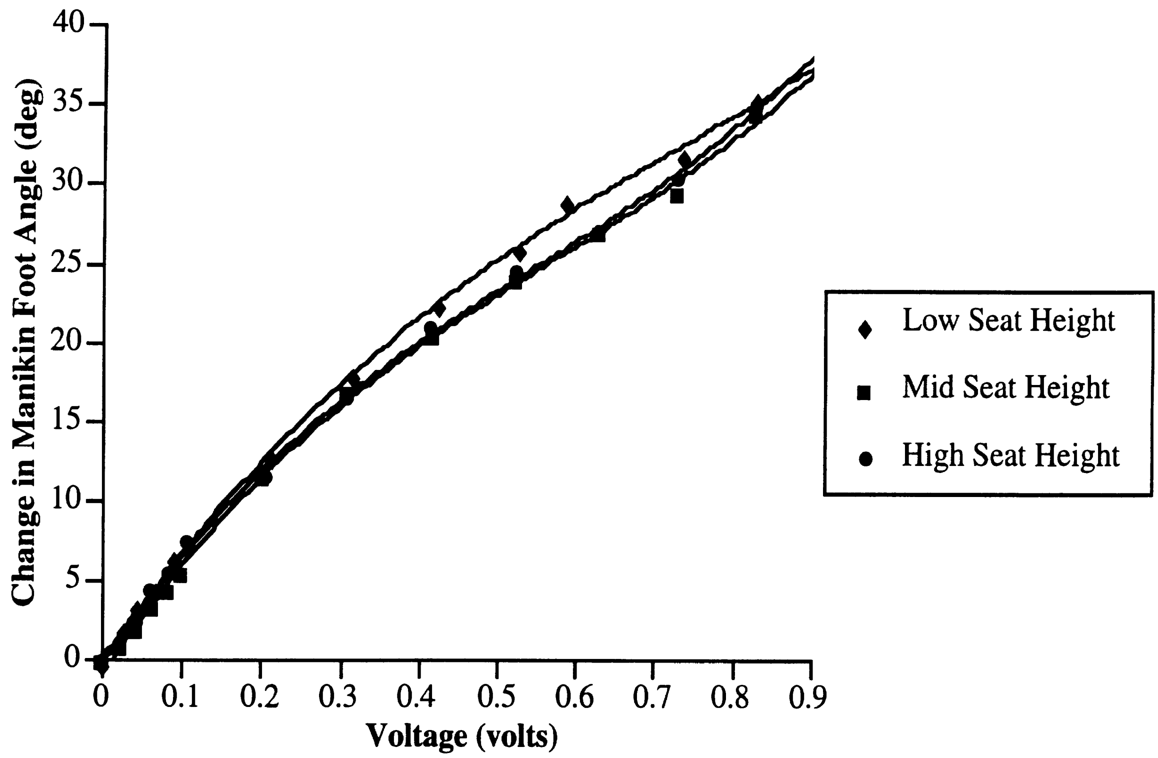


Figure D9-2. Change in 95th%ile manikin foot angle vs potentiometer voltage.

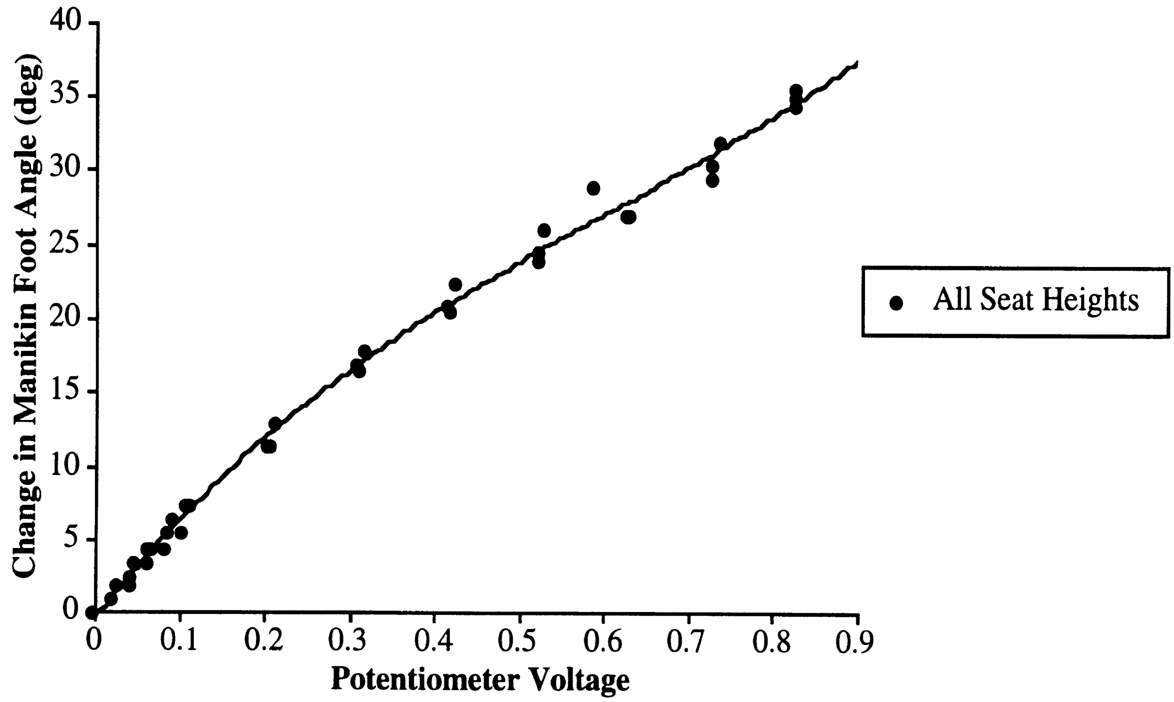


Figure D9-3. Change in 95th%ile manikin foot angle vs potentiometer voltage.

Table D9-4
50th%ile Manikin Foot Angle Calibration for the Low Seat Height

String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
2.47	0.00	54	0
2.50	0.03	55	1
2.52	0.05	56	2
2.54	0.07	57	3
2.57	0.10	58	4
2.61	0.14	60	6
2.66	0.19	62	8
2.71	0.24	64	10
2.77	0.30	66	12
2.83	0.36	68	14
2.89	0.42	70	16
2.95	0.48	72	18
2.99	0.52	74	20
3.05	0.58	76	22
3.07	0.60	78	24
3.11	0.64	80	26
3.17	0.70	86	32

Table D9-5
50th%ile Manikin Foot Angle Calibration for the Mid Seat Height

String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
2.47	0.00	47	0
2.49	0.02	48	1
2.51	0.04	49	2
2.52	0.05	50	3
2.55	0.08	51	4
2.56	0.09	52	5
2.59	0.12	53	6
2.60	0.13	54	7
2.65	0.18	56	9
2.70	0.23	58	11
2.76	0.29	60	13
2.82	0.35	62	15
2.87	0.40	64	17
2.92	0.45	66	19
2.96	0.49	68	21
2.98	0.51	69	22
3.01	0.54	70	23
3.05	0.58	73	26

Table D9-6
50th%ile Manikin Foot Angle Calibration for the High Seat Height

String Pot Voltage	Change in Voltage	Manikin Foot Angle (deg)	Change in Foot Angle (deg)
2.47	0.00	37.0	0.0
2.50	0.03	38.5	1.5
2.51	0.04	39.5	2.5
2.53	0.06	40.5	3.5
2.55	0.08	41.5	4.5
2.57	0.10	42.5	5.5
2.59	0.12	43.5	6.5
2.63	0.16	45.5	8.5
2.68	0.21	47.5	10.5
2.73	0.26	49.5	12.5
2.78	0.31	51.5	14.5
2.79	0.32	52.5	15.5
2.83	0.36	53.5	16.5
2.96	0.49	58.5	21.5
3.07	0.60	63.5	26.5

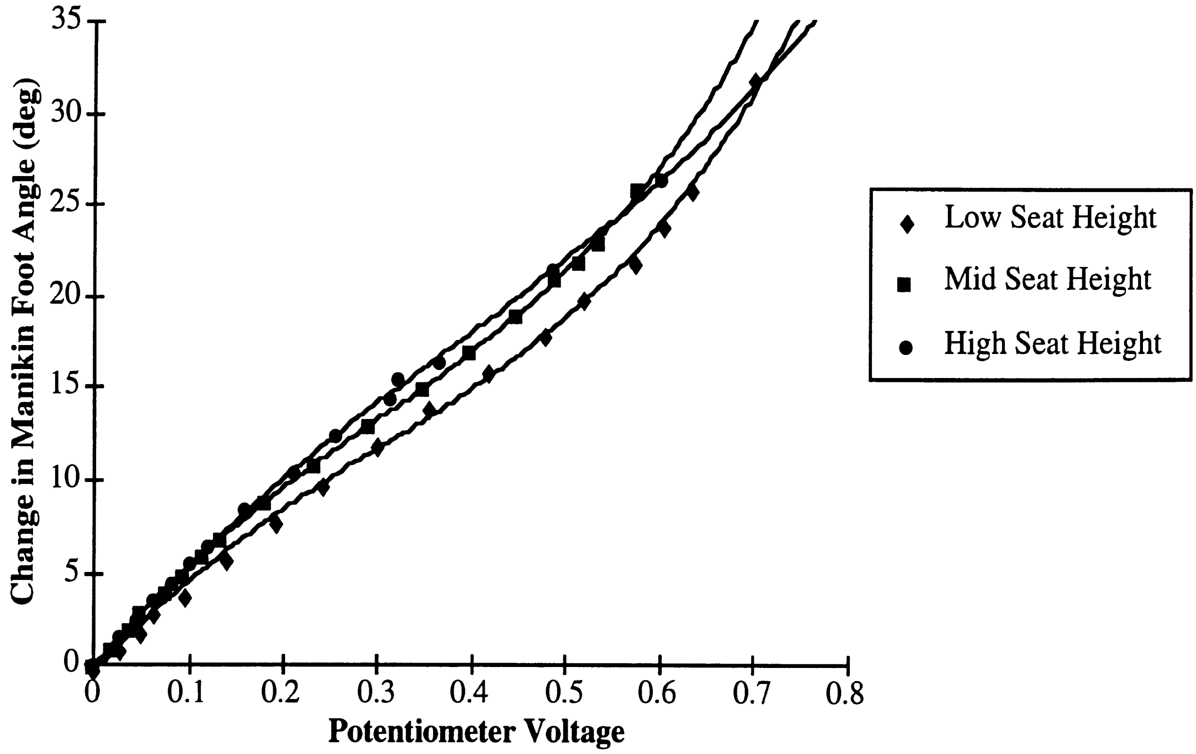


Figure D9-4. Change in 50th%ile manikin foot angle vs potentiometer voltage.

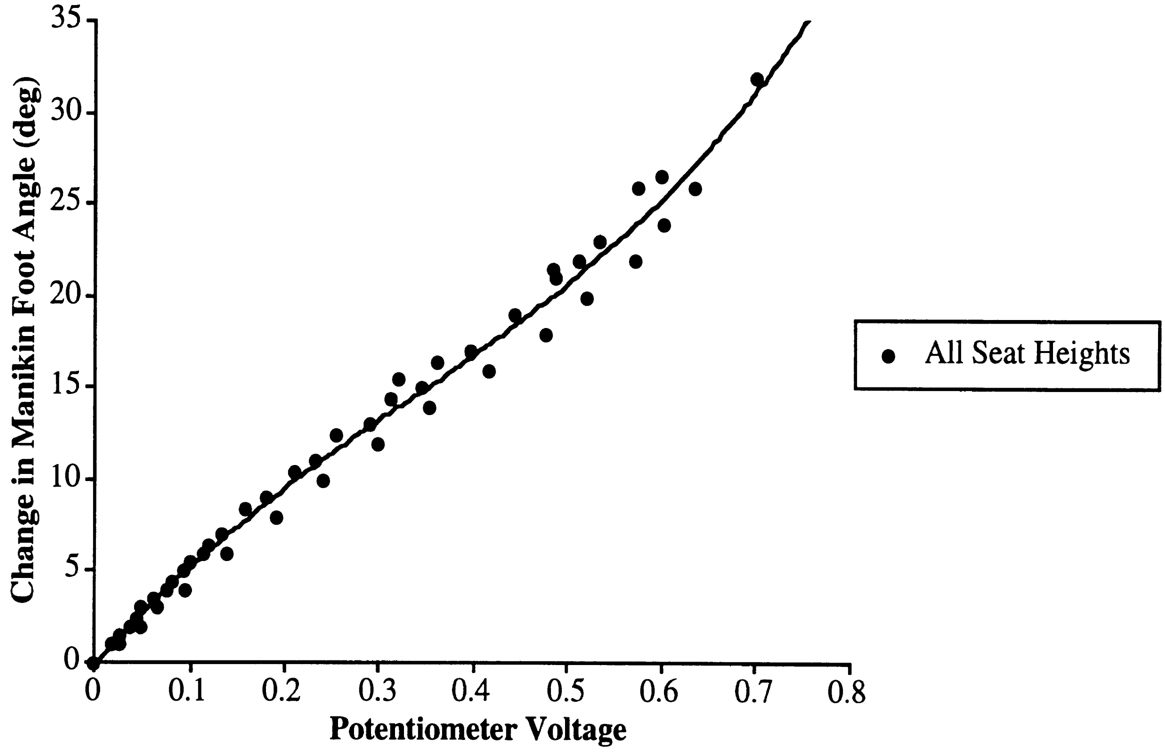


Figure D9-5. Change in 50th%ile manikin foot angle vs potentiometer voltage.

D10.
RESTING FOOT FORCE

The resting foot force on the pedal is measured by a load cell that attaches to the pedal base plate. The load cell is a strain-gauged load beam. A bolt is attached to the end of the load beam and contacts the back of the pedal linkage with the pedal in the undepressed position, as illustrated in Figure D10-1. The load cell is connected to the strip chart so that as forces are applied to the pedal, the strip chart records the change in voltage from the load cell.

The resting foot force device (RFFD), consisting of the load cell and the blocked pedal linkage was calibrated by applying known forces to the pedal arm parallel to the bolt, at the point where the bolt contacts the pedal linkage. The change in voltage on the strip chart was simultaneously recorded. Three trials were conducted to calibrate the RFFD. It was observed that the initial voltage on the unloaded pedal linkage varied in each trial. Therefore, the initial voltage is subtracted from subsequent readings. The results of the calibration are listed in Table D10-1. A plot of force vs change in voltage is given in Figure D10-2. The best fit curve for this plot is:

$$F_b = 5.85114v^3 - 12.997v^2 + 20.106v - 0.23884$$

where v is the change in voltage from the strip chart and F_b is the force on the bolt in kg.

To calculate the resting foot force at the point where the force is being applied to the pedal by the subject, F, it is assumed that that force is applied perpendicular to the surface of the pedal pad at the point of foot (shoe) contact, as shown in Figure D10-3. Five zones on the pedal were marked as illustrated in Figure D10-4. The coordinates and the angles of the tangents to the center points of these zones were measured at the mid seat height accelerator pedal angle, as shown in Figure D10-5, and are listed in Table D10-2.

Summing the moments about the pedal arm pivot point:

$$F(d_2) - F_b(d_3) = 0$$

where d_2 is the perpendicular distance from the resting foot force to the pedal arm pivot point and d_3 is the distance from the point where the bolt meets the pedal arm to the pedal arm pivot point. The values of d_2 are independent of accelerator pedal angle (i.e. seat height). Therefore, although the measurements in Table D10-2 were taken from the mid seat height, they can be utilized for all seat heights.

Solving the previous equation for resting foot force:

$$F = (F_b d_3) / (d_2)$$

F_b is determined from the calibration equation above. d_3 was manually measured and found to be 74.06 mm. d_2 is calculated using the following equation:

$$d_2 = d_1 * \mathrm{SIN}(\theta)$$

where:

$$\theta = 180 - \text{angle } P - \text{angle } d_1$$

where d_1 is the distance from the point of contact on the pedal to the pedal arm pivot point, angle d1 is the angle of d1 to the horizontal and angle P is the angle perpendicular to the pedal at the point of contact. d_1 and angle d_1 are calculated knowing the coordinates of the contact and pivot points and using the equations of a right triangle. Angle P is taken to be the angle of the line perpendicular to the tangent of the center of the pedal zone where the foot makes contact.

Finally, the equivalent force at the center of the pedal is determined. In the force equation above, F becomes F_e, the equivalent force. d_2 changes to the distance from the center of the pedal to the pedal pivot point, d_4, which was calculated to be 242.2 mm. The equivalent foot force equation then becomes:

$$F_e = (F_b d_3) / (d_4)$$

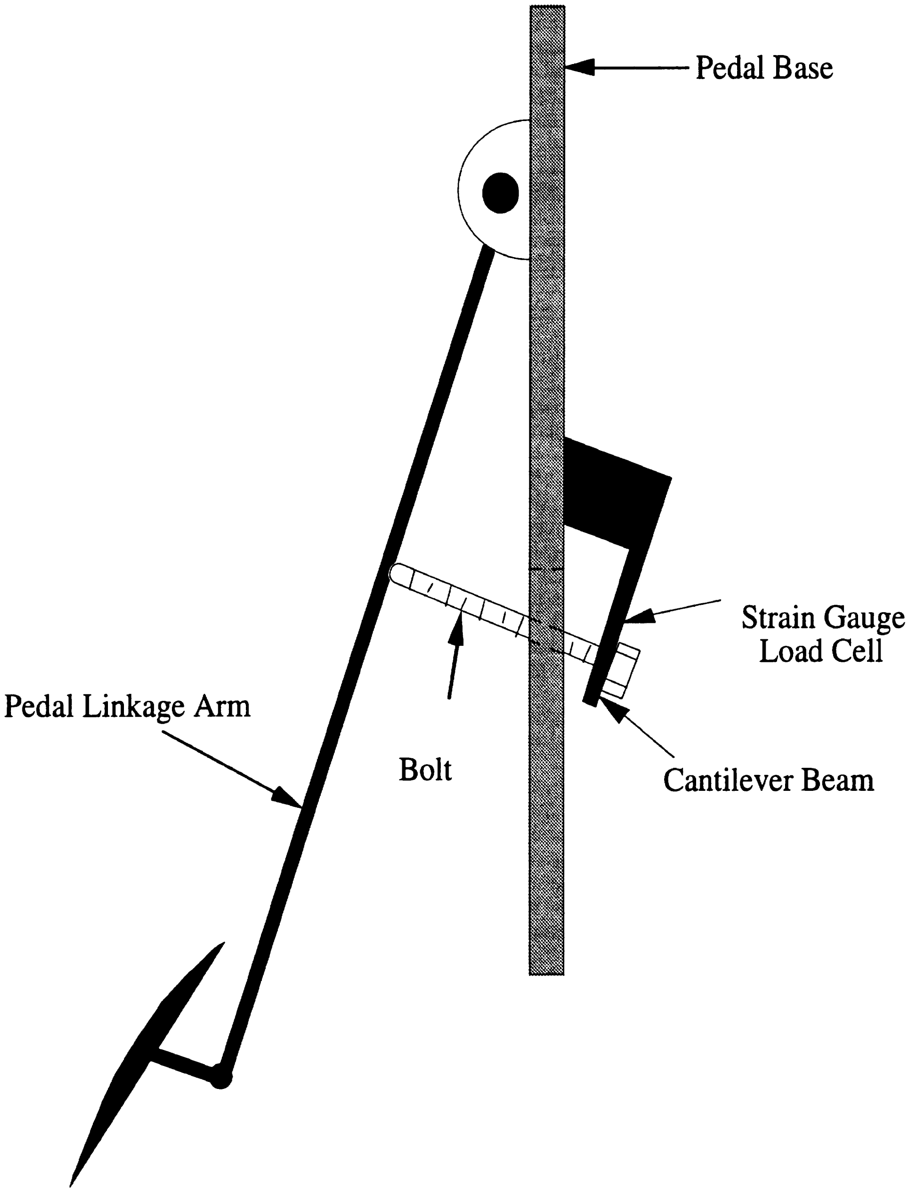


Figure 10-1. Resting foot force device.

Table D10-1
Resting Foot Force Calibration

Force (kg)	Force (lb)	Average Change in Voltage
0.00	0.00	0.000
0.10	0.22	0.005
0.20	0.44	0.008
0.30	0.66	0.010
0.40	0.88	0.013
0.50	1.10	0.017
1.00	2.20	0.035
1.50	3.30	0.055
2.00	4.40	0.078
2.50	5.50	0.100
3.00	6.60	0.132
3.50	7.70	0.170
4.00	8.80	0.209
4.50	9.90	0.238
5.00	11.00	0.276
5.50	12.10	0.315
6.00	13.20	0.356
6.50	14.30	0.429
7.00	15.40	0.470
7.50	16.50	0.522
8.00	17.60	0.553

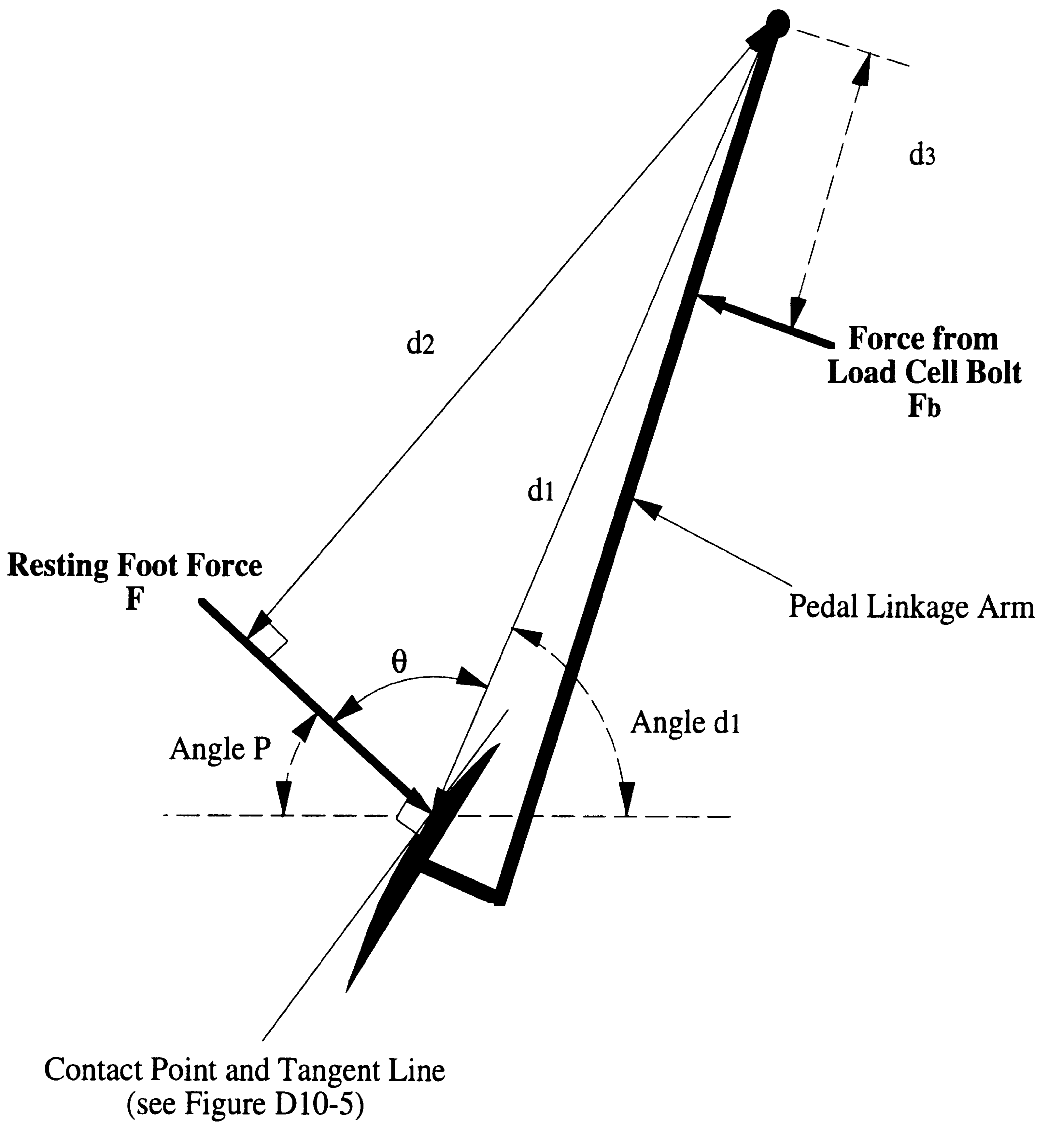


Figure D10-2. Pedal geometry.

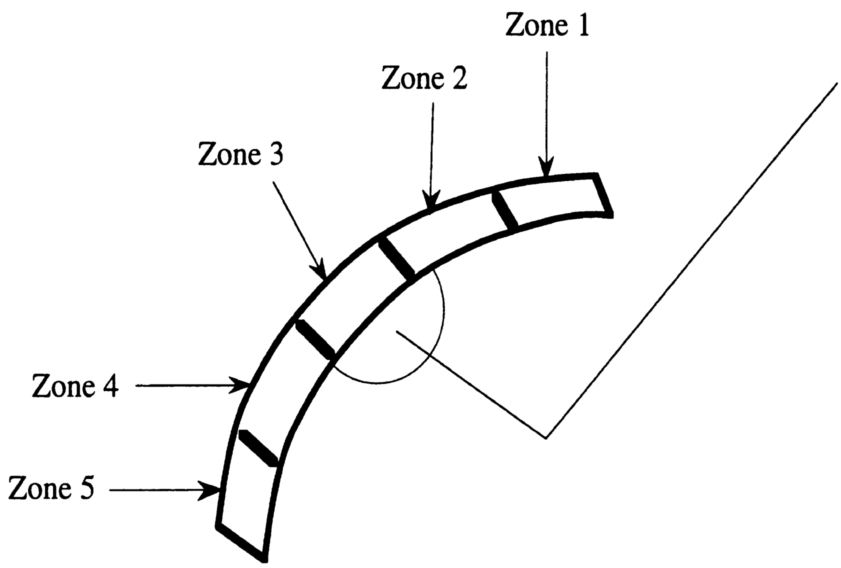


Figure D10-3. Pedal zones.

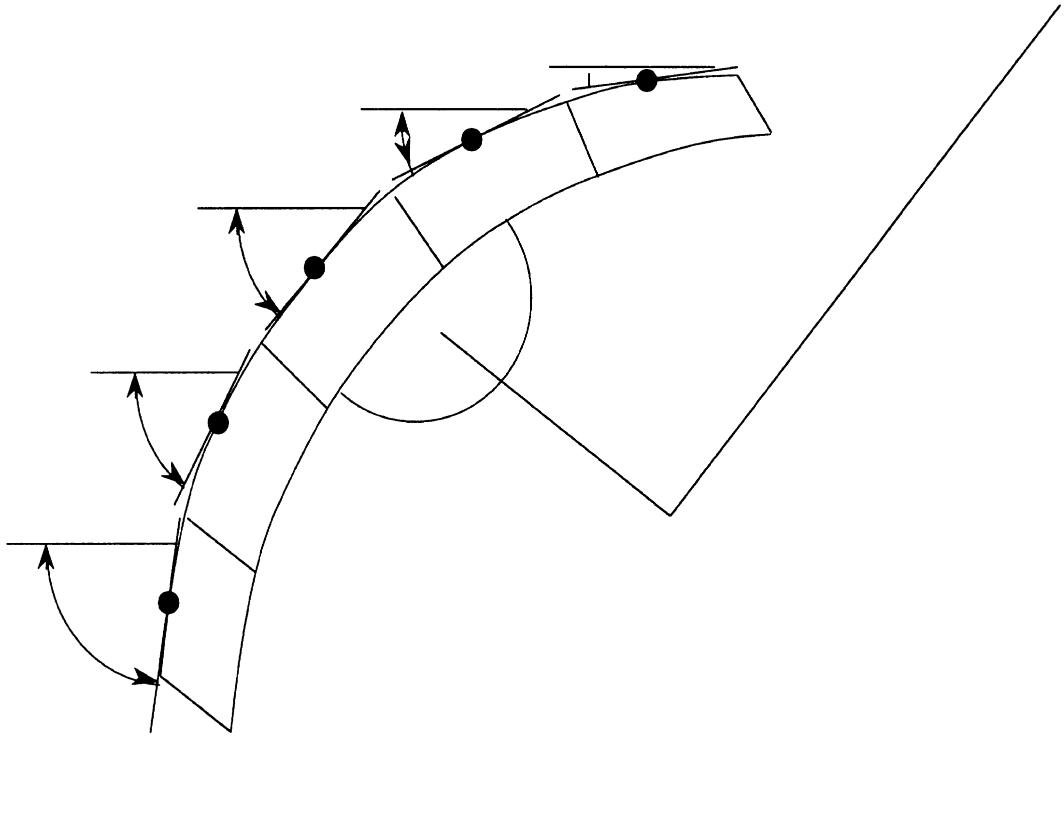


Figure D10-4. Zone center points and tangents used to determine magnitude and direction of applied RFF.

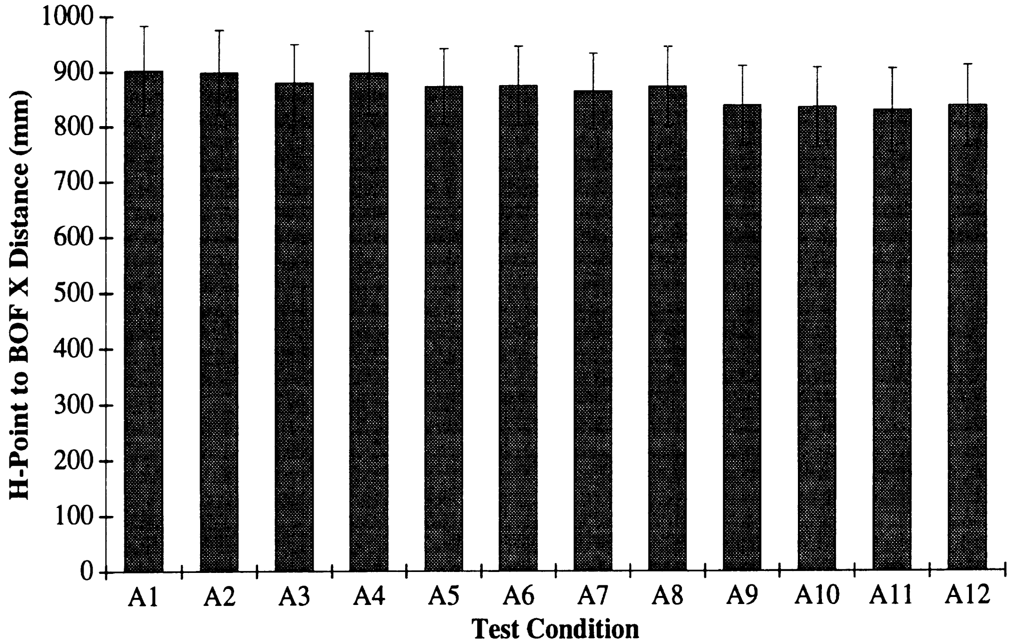
APPENDIX E

Distributions of Dependent Variables

Table E-1
Seat Position and Seatback Angle Results

Test						H-Point-to-BOF Distance (mm)			Seatback Angle (deg)		
Condition	SH	PA	PL	PF*	N	Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	902	81	785 - 1070 = 285	24.8	3.8	17.0 - 33.0 = 16.0
2	L	L	L	H	24	897	77	786 - 1039 = 253	24.5	3.4	17.5 - 32.0 = 14.5
3	L	H	S	H	24	878	70	785 - 1018 = 233	25.8	3.0	19.5 - 32.0 = 12.5
4	L	H	L	L	24	896	76	791 - 1026 = 235	25.5	3.5	20.0 - 33.5 = 13.5
5	M	L	S	L	24	871	69	767 - 1013 = 246	23.5	4.2	14.0 - 33.0 = 19.0
6	M	L	L	H	24	872	72	771 - 979 = 208	22.6	4.0	13.0 - 35.5 = 22.5
7	M	H	S	H	24	862	69	765 - 992 = 227	23.9	3.1	14.5 - 30.0 = 15.5
8	M	H	L	L	24	871	73	765 - 976 = 211	23.1	3.8	17.5 - 32.0 = 14.5
9	H	L	S	L	24	836	72	714 - 953 = 239	21.1	3.7	11.5 - 28.5 = 17.0
10	H	L	L	H	24	833	72	725 - 967 = 242	20.5	3.5	14.5 - 27.5 = 13.0
11	H	H	S	H	24	828	76	714 - 942 = 228	21.4	3.6	15.5 - 30.0 = 14.5
12	H	H	L	L	24	836	74	714 - 971 = 257	20.3	3.8	13.0 - 26.5 = 13.5
GROUP B											
1	L	L	S	H	24	882	62	798 - 1049 = 251	25.0	4.4	17.0 - 33.5 = 16.5
2	L	L	L	L	24	876	63	785 - 1066 = 281	25.8	4.3	17.0 - 33.0 = 16.0
3	L	H	S	L	24	876	70	785 - 1070 = 285	26.1	3.9	19.5 - 34.0 = 14.5
4	L	H	L	H	24	869	64	785 - 993 = 208	26.4	3.8	18.5 - 34.5 = 16.0
5	M	L	S	H	24	865	66	769 - 1052 = 283	23.0	4.6	14.0 - 35.0 = 21.0
6	M	L	L	L	24	863	66	765 - 1047 = 282	22.6	5.4	13.0 - 35.5 = 22.5
7	M	H	S	L	24	848	61	765 - 988 = 223	23.5	4.2	13.5 - 30.5 = 17.0
8	M	H	L	H	24	845	61	765 - 1024 = 259	23.6	4.1	17.5 - 34.0 = 16.5
9	H	L	S	H	24	820	67	715 - 1002 = 287	21.4	4.2	10.5 - 30.5 = 20.0
10	H	L	L	L	24	815	64	727 - 952 = 225	22.3	4.4	15.0 - 34.5 = 19.5
11	H	H	S	L	24	818	65	717 - 962 = 245	22.3	5.1	14.5 - 37.0 = 22.5
12	H	H	L	H	24	817	59	737 - 943 = 206	21.4	4.0	15.5 - 33.0 = 17.5

*Seat Height (SH): Low, Mid or High   Pan Angle (PA): Low or High   Pan Length (PL): Long or Short   Pedal Force (PF): Light or Heavy



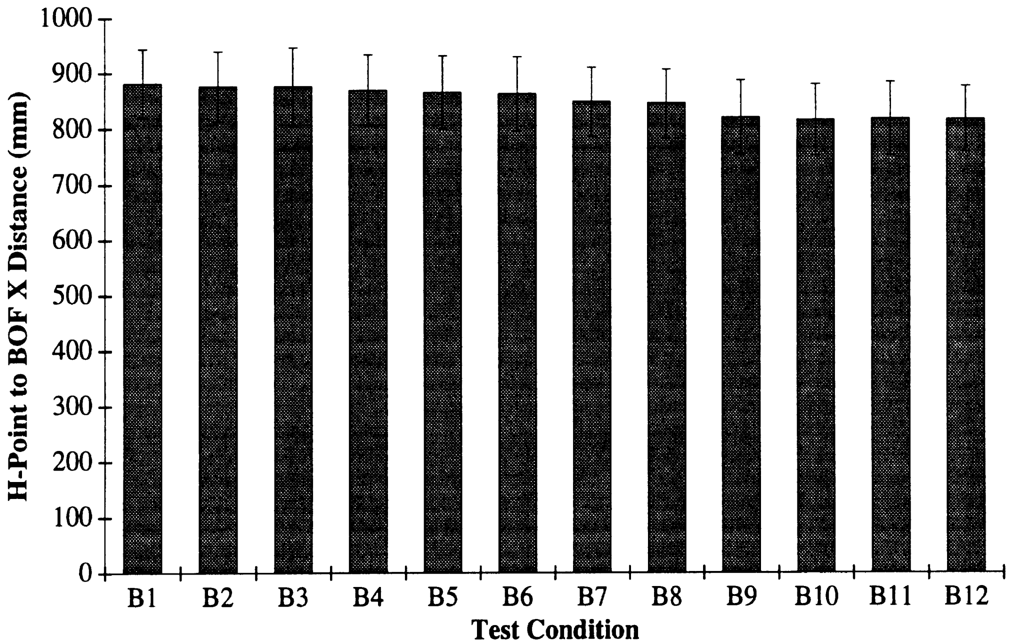
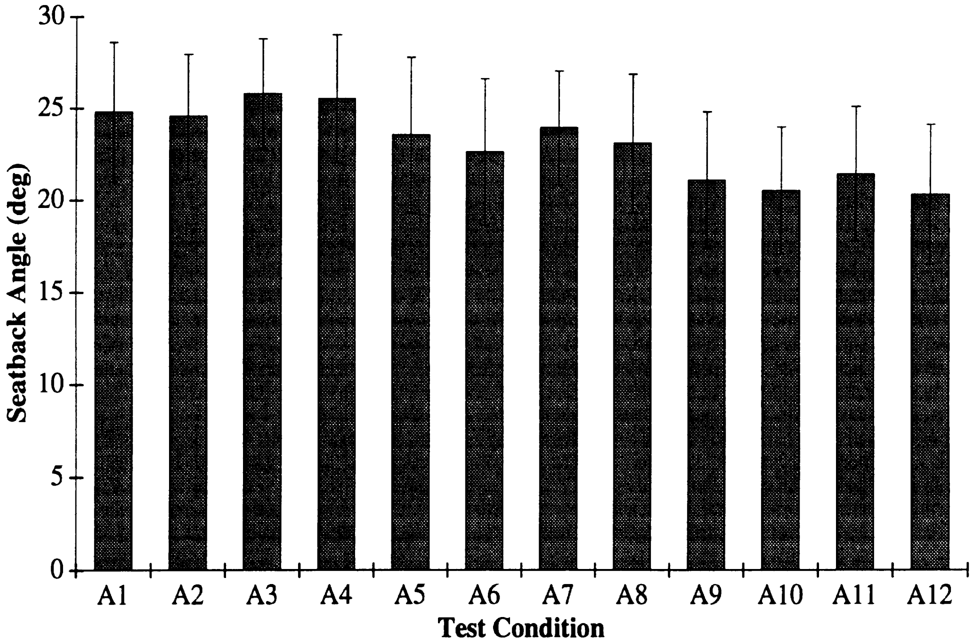


Figure E-1: Overall mean H-point to BOF distance by test condition.



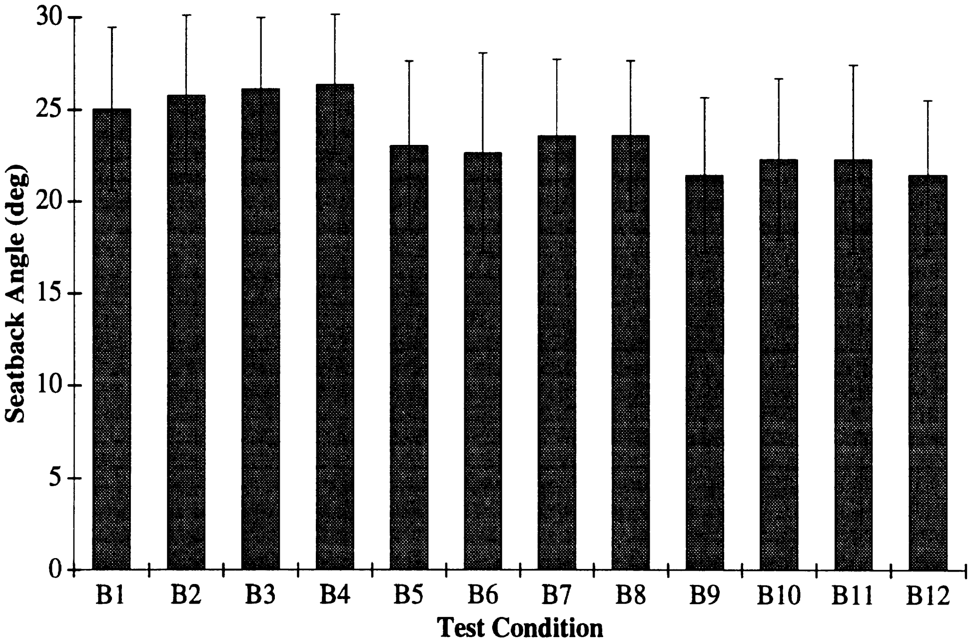


Figure E-2: Overall mean seatback angle by test condition

Table E-2
Right Heel Position Results

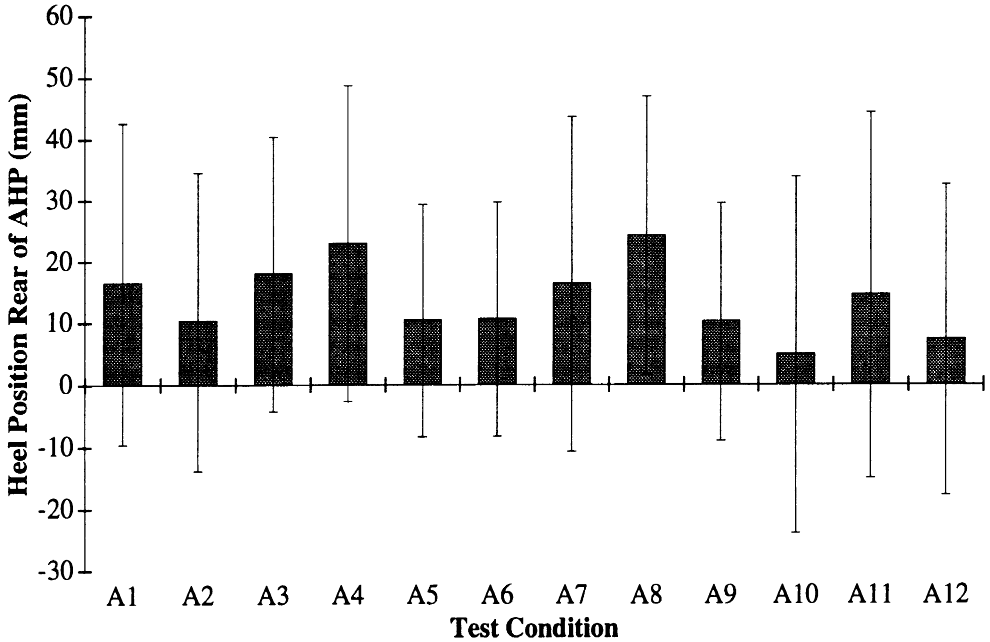
Test Condition	SH	PA	PL	PF*	N	Heel Position Rear of AHP (mm) Mean	s.d.	Range	Heel Position Left of Accel CL (mm) Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	16	26	(-35) - 62 = 97	44.9	39.9	(-1) - 154 = 155.0
2	L	L	L	H	24	10	24	(-43) - 62 = 105	40.8	39.4	(-11) - 144 = 155.0
3	L	H	S	H	24	18	22	(-31) - 60 = 91	48.0	39.1	4 - 144 = 140.0
4	L	H	L	L	24	23	26	(-23) - 65 = 88	42.4	34.6	(-1) - 129 = 130.0
5	M	L	S	L	24	10	19	(-28) - 42 = 70	49.9	41.0	(-6) - 152 = 158.0
6	M	L	L	H	24	11	19	(-38) - 40 = 78	45.0	40.6	4 - 144 = 140.0
7	M	H	S	H	24	16	27	(-41) - 67 = 108	38.9	32.3	9 - 149 = 140.0
8	M	H	L	L	24	24	23	(-13) - 65 = 78	42.9	41.0	(-4) - 139 = 143.0
9	H	L	S	L	24	10	19	(-28) - 47 = 75	43.1	36.6	(-4) - 139 = 143.0
10	H	L	L	H	24	5	29	(-58) - 50 = 108	40.7	28.8	7 - 124 = 117.0
11	H	H	S	H	24	15	30	(-41) - 85 = 126	40.3	30.2	9 - 119 = 110.0
12	H	H	L	L	24	7	25	(-53) - 52 = 105	44.6	34.7	(-1) - 129 = 130.0
GROUP B											
1	L	L	S	H	24	17	26	(-28) - 67 = 95	34.8	23.9	(-6) - 84 = 90.0
2	L	L	L	L	24	26	33	(-41) - 110 = 151	35.1	27.9	(-21) - 99 = 120.0
3	L	H	S	L	24	32	28	(-33) - 97 = 130	30.4	24.8	(-1) - 94 = 95.0
4	L	H	L	H	24	27	21	(-13) - 67 = 80	40.7	28.4	(-14) - 99 = 113.0
5	M	L	S	H	24	12	21	(-23) - 47 = 70	29.8	22.1	(-19) - 84 = 103.0
6	M	L	L	L	24	17	26	(-36) - 60 = 96	31.5	26.3	(-11) - 89 = 100.0
7	M	H	S	L	24	24	25	(-31) - 67 = 98	28.5	23.7	(-14) - 82 = 96.0
8	M	H	L	H	24	25	22	(-23) - 72 = 95	29.6	23.7	(-21) - 84 = 105.0
9	H	L	S	H	24	10	20	(-23) - 72 = 95	38.3	26.5	(-19) - 94 = 113.0
10	H	L	L	L	24	9	27	(-48) - 85 = 133	29.6	24.3	(-6) - 74 = 80.0
11	H	H	S	L	24	18	25	(-31) - 67 = 98	39.1	23.1	(-6) - 89 = 95.0
12	H	H	L	H	24	10	21	(-38) - 47 = 85	29.0	22.5	(-1) - 84 = 85.0

Seat Height (SH): Low, Mid or High   Pan Angle (PA): Low or High   Pan Length (PL): Long or Short   Pedal Force (PF): Light or Heavy

Table E-3
Right Foot Orientation Results

Test Condition	SH	PA	PL	PF*	N	Foot Pitch Angle re Horizontal (deg)			Foot Rotation Angle (deg)		
						Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	60	7	47.0 - 78.0 = 31	10.1	10.0	(-2.0) - 37.0 = 39.0
2	L	L	L	H	24	60	7	46.0 - 73.0 = 27	9.7	9.4	(-1.0) - 33.5 = 34.5
3	L	H	S	H	24	58	7	47.0 - 70.0 = 23	9.6	10.3	(-1.0) - 38.0 = 39.0
4	L	H	L	L	24	58	7	47.0 - 71.0 = 24	10.4	9.1	(-1.0) - 35.0 = 36.0
5	M	L	S	L	24	53	6	44.0 - 68.5 = 24.5	11.7	9.8	0 - 38.0 = 38.0
6	M	L	L	H	24	52	6	43.0 - 69.0 = 26	10.9	9.4	0 - 34.0 = 34.0
7	M	H	S	H	24	49	8	35.0 - 65.0 = 30	9.4	8.7	0 - 34.0 = 34.0
8	M	H	L	L	24	50	6	41.0 - 62.0 = 21	9.6	10.1	0 - 37.0 = 37.0
9	H	L	S	L	24	43	6	34.0 - 54.0 = 20	10.1	10.0	(-2.0) - 35.0 = 37.0
10	H	L	L	H	24	43	8	32.5 - 59.0 = 26.5	9.9	8.2	0 - 34.0 = 34.0
11	H	H	S	H	24	41	7	25.0 - 51.0 = 26	10.1	8.0	0 - 30.0 = 30.0
12	H	H	L	L	24	42	7	7.0 - 61.0 = 54	11.6	8.5	(-3.0) - 43.0 = 46.0
GROUP B											
1	L	L	S	H	24	58	8	46.0 - 74.0 = 28	6.9	6.3	(-5.0) - 21.0 = 26.0
2	L	L	L	L	24	58	9	39.0 - 77.0 = 38	6.7	8.8	(-8.0) - 28.0 = 36.0
3	L	H	S	L	24	56	8	37.0 - 76.0 = 39	6.2	7.1	(-5.0) - 24.0 = 29.0
4	L	H	L	H	24	55	6	44.0 - 67.0 = 23	7.3	6.8	(-4.0) - 23.0 = 27.0
5	M	L	S	H	24	51	6	42.0 - 65.0 = 23	6.6	7.9	(-5.0) - 26.0 = 31.0
6	M	L	L	L	24	52	6	39.0 - 62.0 = 23	6.8	8.2	(-4.0) - 24.0 = 38.0
7	M	H	S	L	24	50	7	38.5 - 70.0 = 31.5	6.6	6.6	(-4.0) - 24.0 = 28.0
8	M	H	L	H	24	48	5	39.0 - 64.0 = 25	7.0	8.1	(-8.0) - 23.0 = 31.0
9	H	L	S	H	24	41	5	30.0 - 51.0 = 21	7.3	7.2	(-2.0) - 25.0 = 27.0
10	H	L	L	L	24	43	7	30.0 - 60.0 = 30	6.7	8.0	(-7.0) - 25.0 = 32.0
11	H	H	S	L	24	41	6	30.0 - 54.0 = 24	6.6	7.1	(-4.0) - 25.0 = 29.0
12	H	H	L	H	24	41	5	33.0 - 54.0 = 21	7.8	6.6	0 - 24.0 = 24.0

*Seat Height (SH): Low, Mid or High   Pan Angle (PA): Low or High   Pan Length (PL): Long or Short   Pedal Force (PF): Light or Heavy



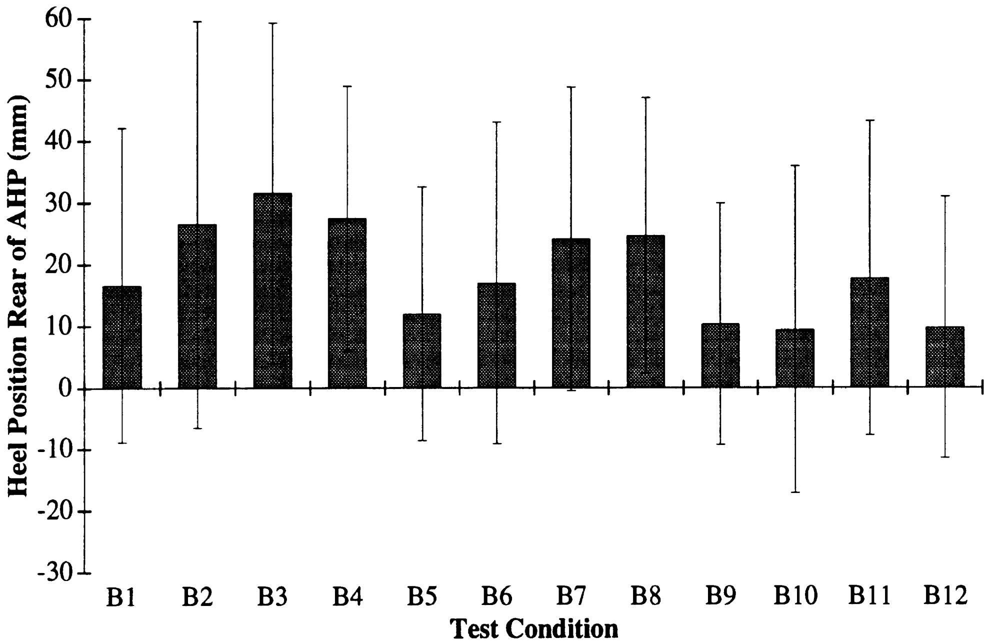
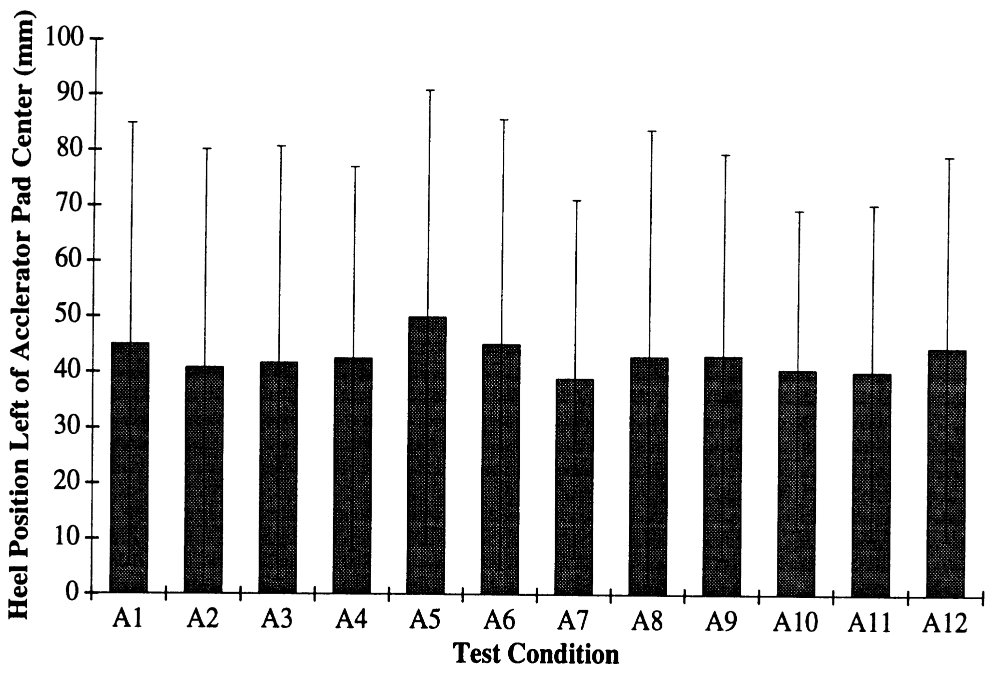


Figure E-3: Overall mean right heel position rear of AHP by test condition.



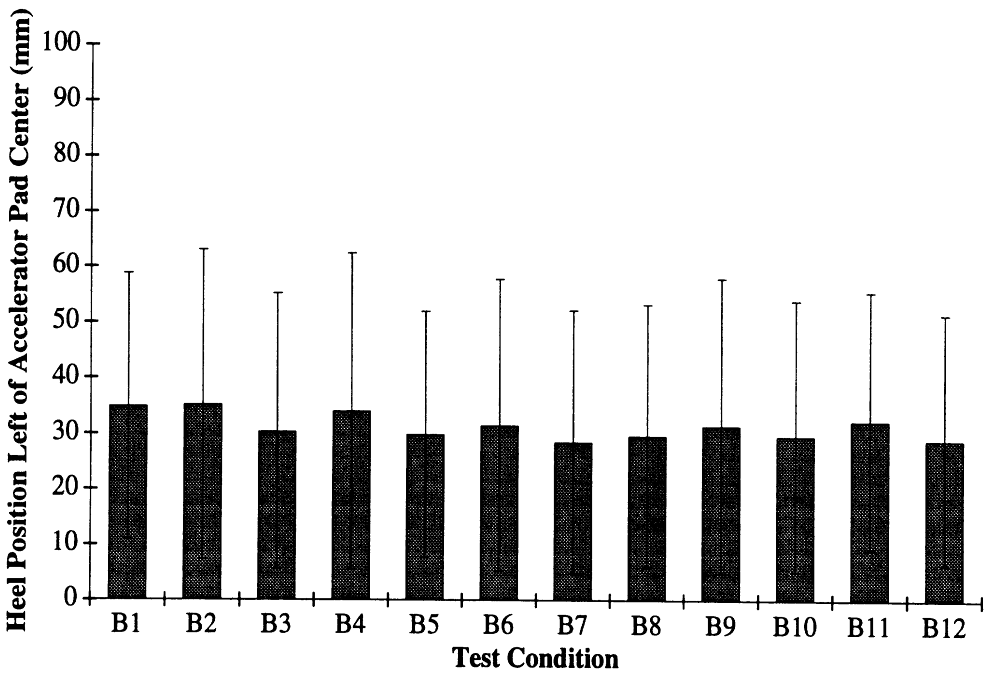
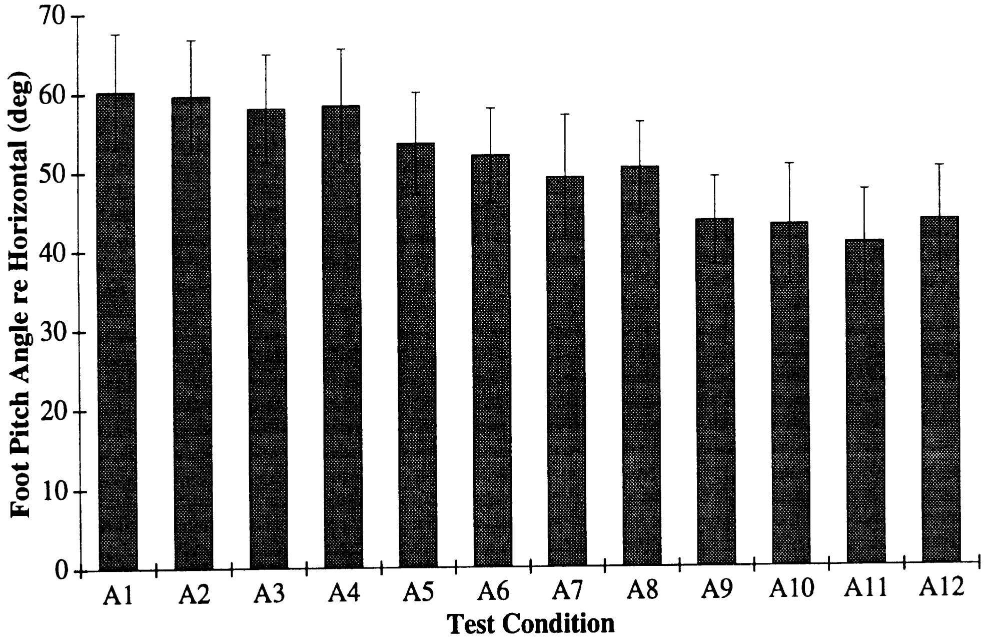


Figure E-4: Overall mean right heel position left of accelerator pad center by test condition.



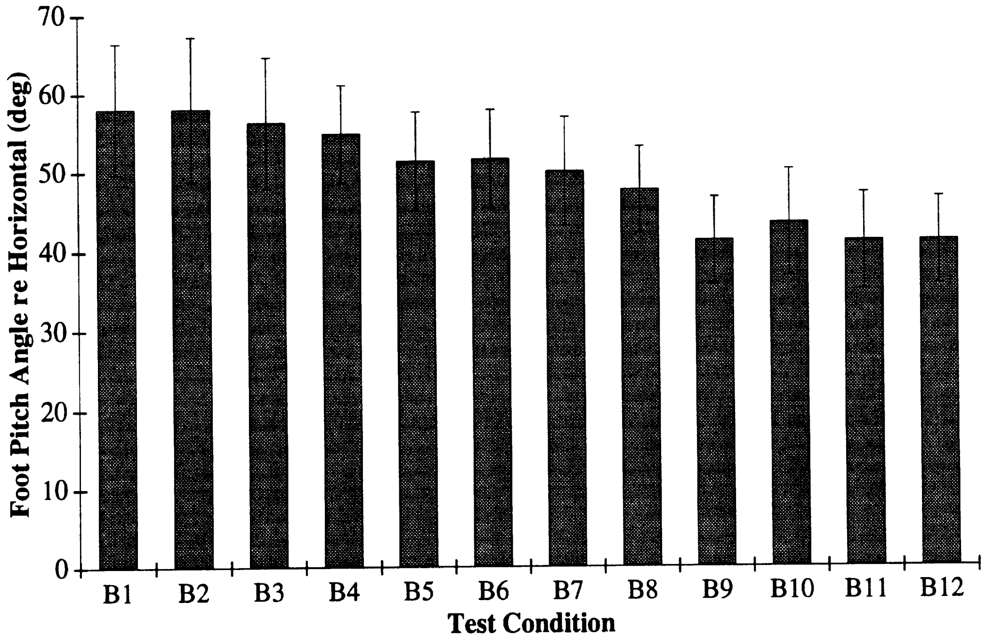
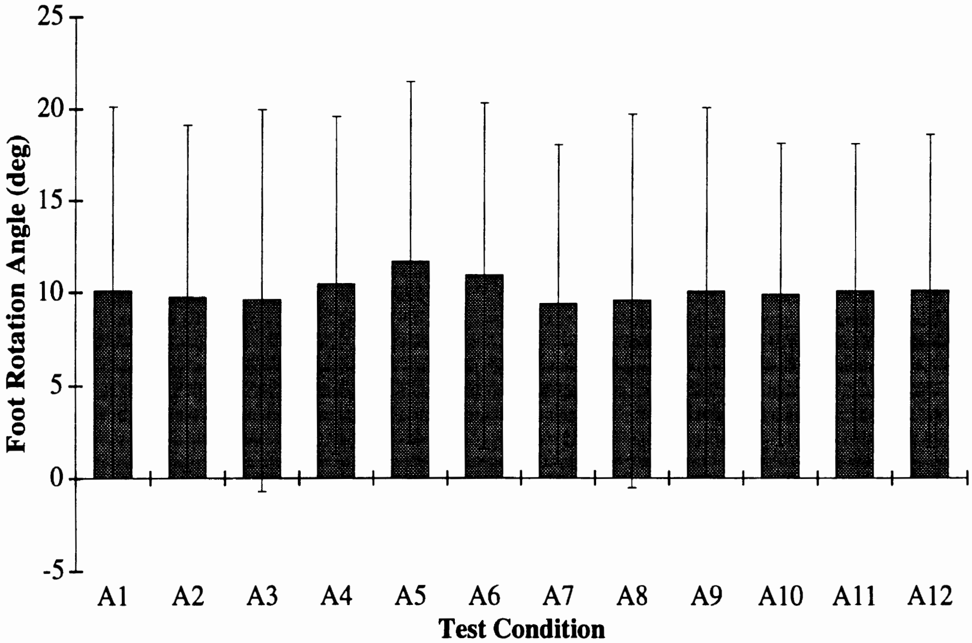


Figure E-5: Overall mean foot pitch angle re horizontal by test condition.



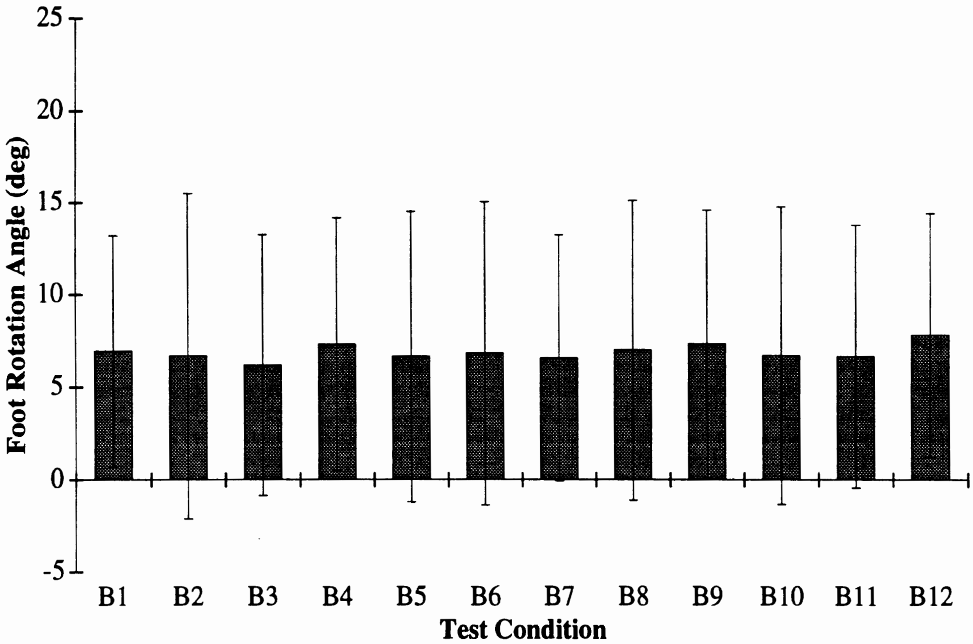
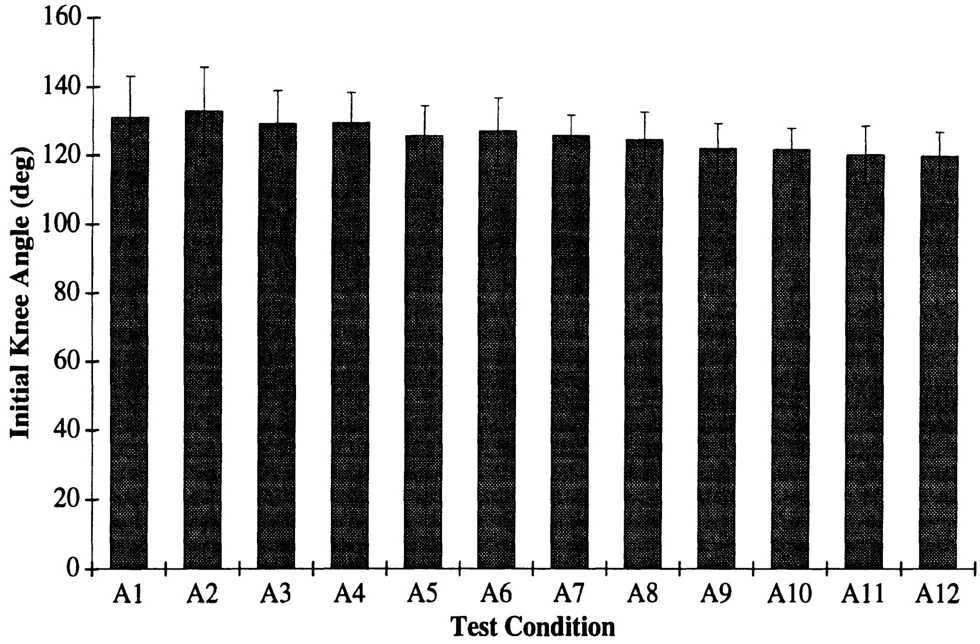


Figure E-6: Overall mean foot rotation angle by test condition.

Table E-4
Leg Orientation Angle Results

Test Condition	SH	PA	PL	PF*	N	Knee Angle (deg) Mean	Knee Angle (deg) s.d.	Thigh Angle re Horizontal (deg) Mean	Thigh Angle re Horizontal (deg) s.d.	Leg Angle re Horizontal (deg) Mean	Leg Angle re Horizontal (deg) s.d.	Angle Total (deg)
GROUP A												
1	L	L	S	L	24	131.0	12.0	13.8	7.2	34.2	7.7	179.0
2	L	L	L	H	24	132.8	12.8	13.0	6.9	33.2	7.5	179.1
3	L	H	S	H	24	129.1	9.6	14.0	6.2	36.6	5.8	179.7
4	L	H	L	L	24	129.4	8.9	13.6	6.0	36.3	5.8	179.3
5	M	L	S	L	24	125.6	8.7	9.9	5.0	43.6	6.1	179.1
6	M	L	L	H	24	126.9	9.8	10.4	5.7	43.1	6.3	180.4
7	M	H	S	H	24	125.7	6.0	8.9	4.8	45.4	4.4	179.9
8	M	H	L	L	24	124.6	7.9	10.3	4.7	46.2	5.1	181.1
9	H	L	S	L	24	122.0	7.3	5.1	5.2	53.7	6.0	180.8
10	H	L	L	H	24	121.7	6.3	4.5	4.5	53.6	5.5	179.7
11	H	H	S	H	24	120.3	8.3	5.4	5.2	55.0	6.0	180.6
12	H	H	L	L	24	119.9	7.0	4.7	4.2	55.4	5.1	180.0
GROUP B												
1	L	L	S	H	24	129.0	10.7	14.6	7.6	35.3	6.7	178.9
2	L	L	L	L	24	125.4	13.1	16.4	7.4	36.7	7.0	178.5
3	L	H	S	L	24	125.5	7.8	15.8	6.6	38.1	5.1	179.3
4	L	H	L	H	24	125.7	8.5	17.3	7.0	38.3	6.5	181.3
5	M	L	S	H	24	126.9	9.8	9.1	6.9	43.7	6.4	179.6
6	M	L	L	L	24	124.9	8.7	10.6	6.2	44.1	6.2	179.6
7	M	H	S	L	24	122.4	7.1	10.8	5.1	46.4	4.9	179.5
8	M	H	L	H	24	121.4	7.3	11.6	4.8	47.8	5.0	180.8
9	H	L	S	H	24	120.4	7.6	5.2	5.2	54.6	5.5	180.2
10	H	L	L	L	24	119.5	7.0	6.1	4.8	55.0	5.5	180.7
11	H	H	S	L	24	117.7	7.4	5.5	5.2	56.0	5.8	179.2
12	H	H	L	H	24	118.0	6.5	5.8	5.4	56.3	5.2	180.1



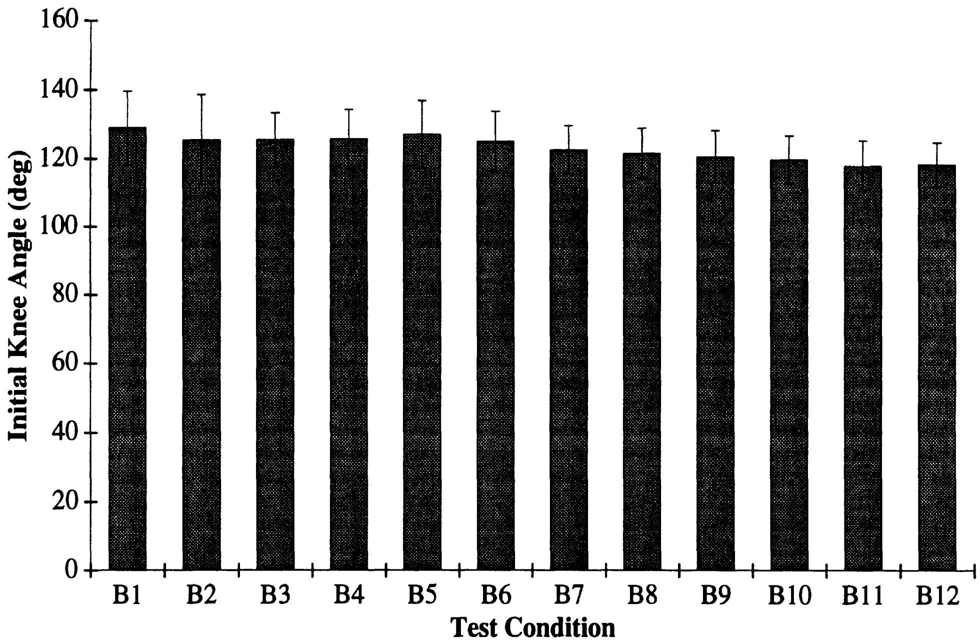
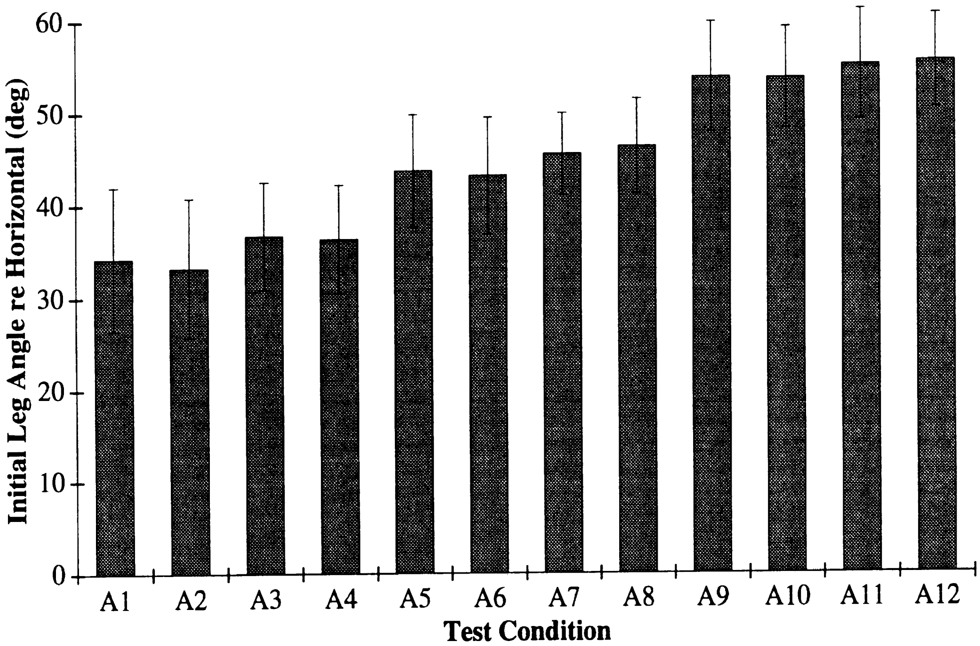


Figure E-7: Overall mean initial knee angle by test condition.



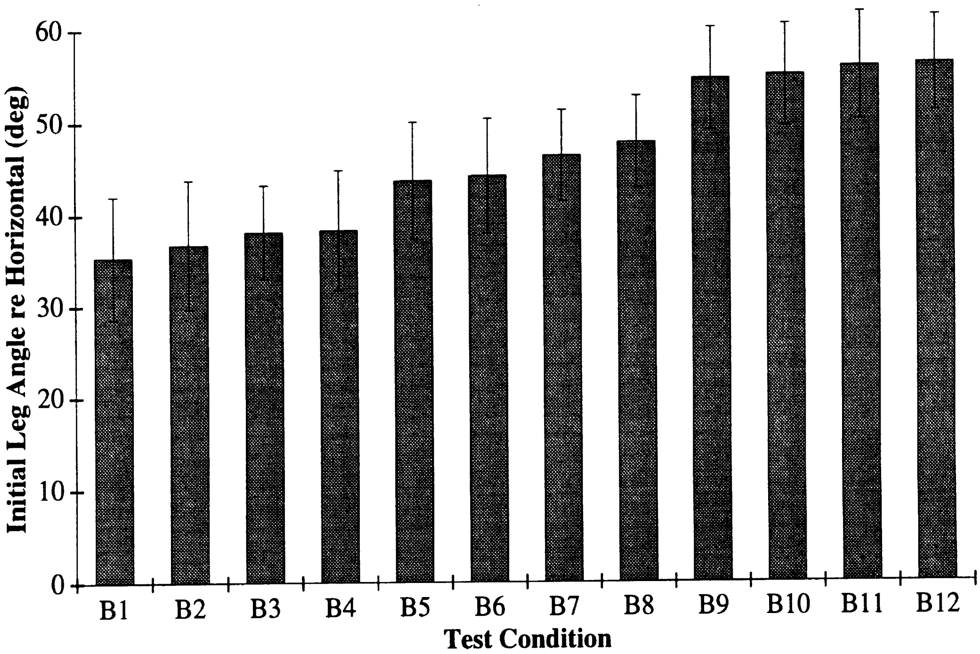
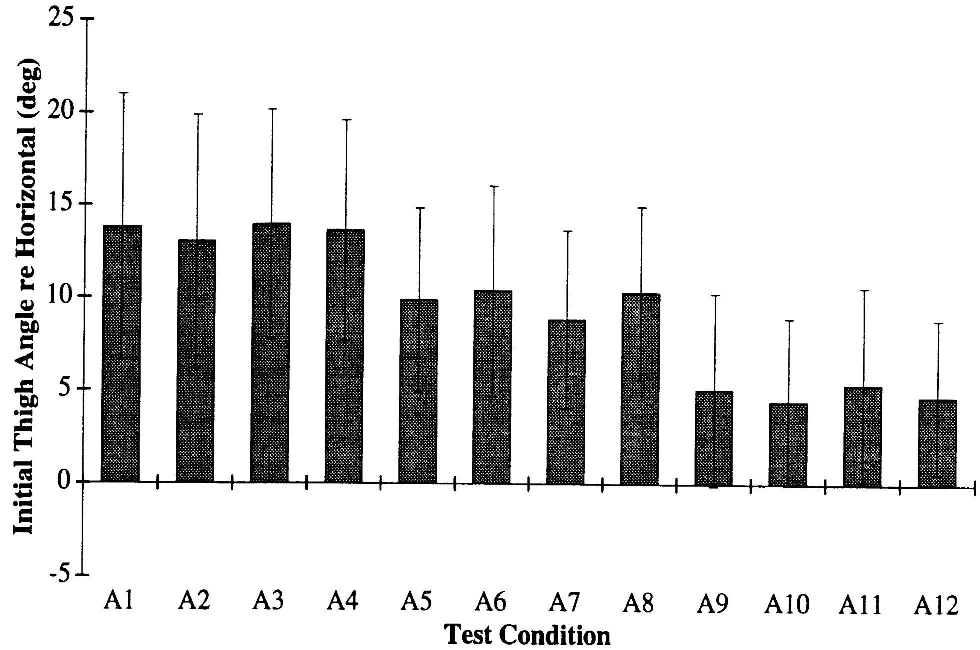


Figure E-8: Overall mean initial leg angle re horizontal by test condition.



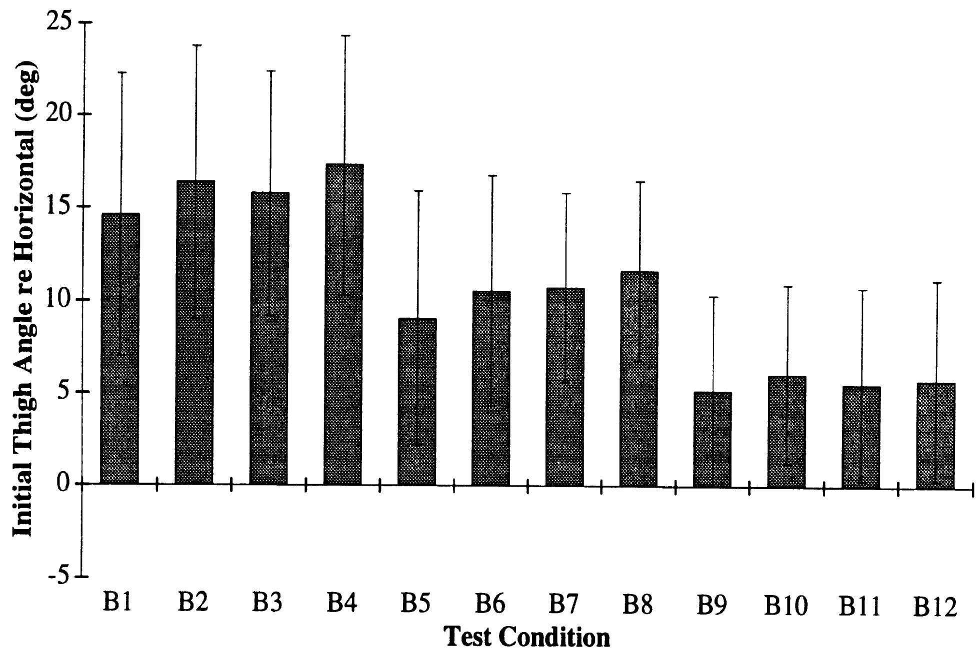


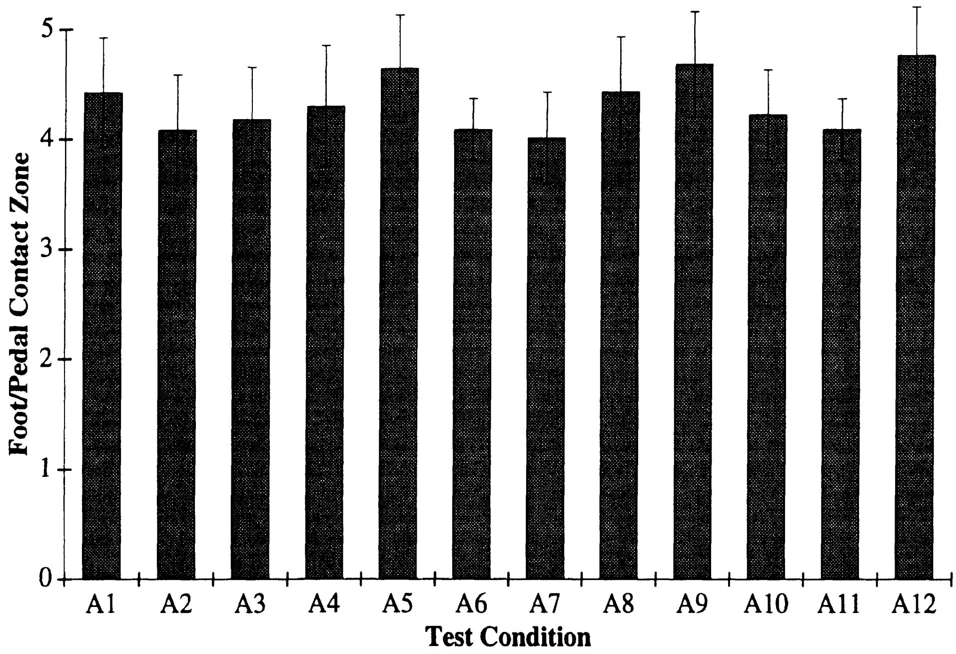
Figure E-9: Overall mean initial thigh angle re horizontal by test condition.

Table E-5
Foot/Pedal Contact Zone and Initial Ankle Angle Results

Test						Foot/ Pedal Contact Zone			Initial Ankle Angle (deg)		
Condition	SH	PA	PL	PF*	N	Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	4.4	0.10	4 - 5 = 1	88.0	8.6	68.5 - 102.5 = 34.0
2	L	L	L	H	24	4.1	0.10	3 - 5 = 2	89.7	8.1	72.5 - 103.5 = 31.0
3	L	H	S	H	24	4.2	0.10	3 - 5 = 2	88.7	8.0	77.0 - 104.5 = 27.5
4	L	H	L	L	24	4.3	0.11	3 - 5 = 2	87.9	8.9	69.5 - 104.5 = 35.0
5	M	L	S	L	24	4.6	0.10	4 - 5 = 1	85.4	6.4	71.5 - 96.5 = 25.0
6	M	L	L	H	24	4.1	0.06	4 - 5 = 1	87.5	6.6	76.5 - 98.5 = 22.0
7	M	H	S	H	24	4.0	0.09	3 - 5 = 2	88.1	8.2	70.5 - 104.5 = 34.0
8	M	H	L	L	24	4.4	0.10	4 - 5 = 1	86.0	6.4	69.5 - 97.5 = 28.0
9	H	L	S	L	24	4.7	0.10	4 - 5 = 1	85.3	5.7	75.5 - 98.5 = 23.0
10	H	L	L	H	24	4.2	0.08	4 - 5 = 1	85.9	9.1	68.5 - 104.0 = 35.5
11	H	H	S	H	24	4.1	0.06	4 - 5 = 1	89.2	12.7	73.5 - 132.0 = 58.5
12	H	H	L	L	24	4.8	0.09	4 - 5 = 1	85.2	11.1	64.5 - 121.5 = 57.0
GROUP B											
1	L	L	S	H	24	4.0	0.07	3 - 5 = 2	89.5	9.0	73.5 - 101.5 = 28.0
2	L	L	L	L	24	4.3	0.11	3 - 5 = 2	87.8	9.9	68.5 - 108.0 = 39.5
3	L	H	S	L	24	4.2	0.10	3 - 5 = 2	88.9	10.9	64.5 - 117.5 = 53.0
4	L	H	L	H	24	4.0	0.11	3 - 5 = 2	90.3	9.7	66.5 - 109.5 = 43.0
5	M	L	S	H	24	4.0	0.07	3 - 5 = 2	87.6	9.0	71.5 - 103.5 = 32.0
6	M	L	L	L	24	4.5	0.12	3 - 5 = 2	86.8	7.5	73.5 - 104.5 = 31.0
7	M	H	S	L	24	4.4	0.10	4 - 5 = 1	86.2	7.6	67.5 - 98.0 = 30.5
8	M	H	L	H	24	4.1	0.08	3 - 5 = 2	87.1	7.5	72.5 - 105.0 = 32.5
9	H	L	S	H	24	4.2	0.08	4 - 5 = 1	86.9	8.2	70.5 - 106.5 = 36.0
10	H	L	L	L	24	4.7	0.10	4 - 5 = 1	84.1	7.6	67.0 - 94.5 = 27.5
11	H	H	S	L	24	4.6	0.10	4 - 5 = 1	85.5	7.3	72.5 - 96.5 = 24.0
12	H	H	L	H	24	4.1	0.07	4 - 5 = 1	87.1	9.2	69.5 - 116.5 = 47.0

Table E-6
Resting Foot Force Resutls

Test Condition	SH	PA	PL	PF*	N	Resting Foot Force at Point of Contact (lb)			Equivalent Resting Foot Force at Pedal Center (lb)		
						Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	4.5	2.4	0.56 - 9.9 = 9.3	5.1	2.8	0.6 - 10.8 = 10.2
2	L	L	L	H	24	4.7	2.6	1.3 - 11.3 = 10.0	5.2	3.0	1.4 - 13.3 = 11.9
3	L	H	S	H	24	4.2	2.6	1.4 - 12.9 = 11.5	4.6	2.9	1.5 - 13.1 = 11.6
4	L	H	L	L	24	3.7	1.8	0.9 - 7.6 = 6.7	4.2	2.0	1.1 - 8.3 = 7.2
5	M	L	S	L	24	4.6	2.3	.03 - 9.4 = 9.4	5.2	2.6	.03 - 11.0 = 11.0
6	M	L	L	H	24	4.5	1.8	1.3 - 8.6 = 7.3	4.9	2.0	1.4 - 9.4 = 8.0
7	M	H	S	H	24	4.3	1.9	1.4 - 8.0 = 6.6	4.7	2.1	1.5 - 8.7 = 7.2
8	M	H	L	L	24	3.8	2.2	0.6 - 7.7 = 7.1	4.2	2.5	0.6 - 9.1 = 8.5
9	H	L	S	L	24	5.0	2.6	1.0 - 12.0 = 11.0	5.7	3.1	1.1 - 14.0 = 12.9
10	H	L	L	H	24	4.4	2.0	1.4 - 10.3 = 8.9	4.9	2.2	1.7 - 11.2 = 9.5
11	H	H	S	H	24	4.7	2.1	1.7 - 10.5 = 8.8	5.1	2.3	1.9 - 11.4 = 9.5
12	H	H	L	L	24	4.9	2.3	1.2 - 8.5 = 7.3	5.6	2.6	1.3 - 9.9 = 8.6
GROUP B											
1	L	L	S	H	24	4.4	2.6	0.8 - 11.4 = 10.6	4.8	2.9	0.8 - 12.5 = 11.7
2	L	L	L	L	24	3.8	2.5	0.7 - 8.5 = 7.8	4.3	2.8	0.7 - 9.9 = 9.2
3	L	H	S	L	24	4.0	2.2	0.5 - 8.6 = 8.1	4.4	2.4	0.5 - 9.4 = 8.9
4	L	H	L	H	24	4.0	2.0	1.2 - 9.4 = 8.2	4.3	2.2	1.2 - 11.0 = 9.8
5	M	L	S	H	24	4.8	2.4	1.5 - 10.1 = 8.6	5.2	2.7	1.7 - 11.3 = 9.6
6	M	L	L	L	24	4.8	2.4	1.0 - 8.6 = 7.6	5.5	2.8	1.1 - 10.1 = 9.0
7	M	H	S	L	24	4.2	2.1	1.2 - 7.9 = 6.7	4.8	2.4	1.3 - 8.7 = 7.4
8	M	H	L	H	24	4.1	2.8	0.8 - 11.8 = 11.0	4.5	3.0	1.0 - 12.9 = 11.9
9	H	L	S	H	24	4.4	2.1	1.0 - 8.8 = 7.8	4.8	2.3	1.2 - 9.6 = 8.4
10	H	L	L	L	24	5.1	3.1	0.7 - 11.5 = 10.8	5.8	3.5	0.8 - 12.6 = 11.8
11	H	H	S	L	24	4.1	2.4	0.6 - 9.9 = 9.3	4.7	2.7	0.7 - 11.6 = 10.9
12	H	H	L	H	24	4.5	2.5	1.0 - 10.9 = 9.9	4.9	2.7	1.1 - 12.0 = 10.9



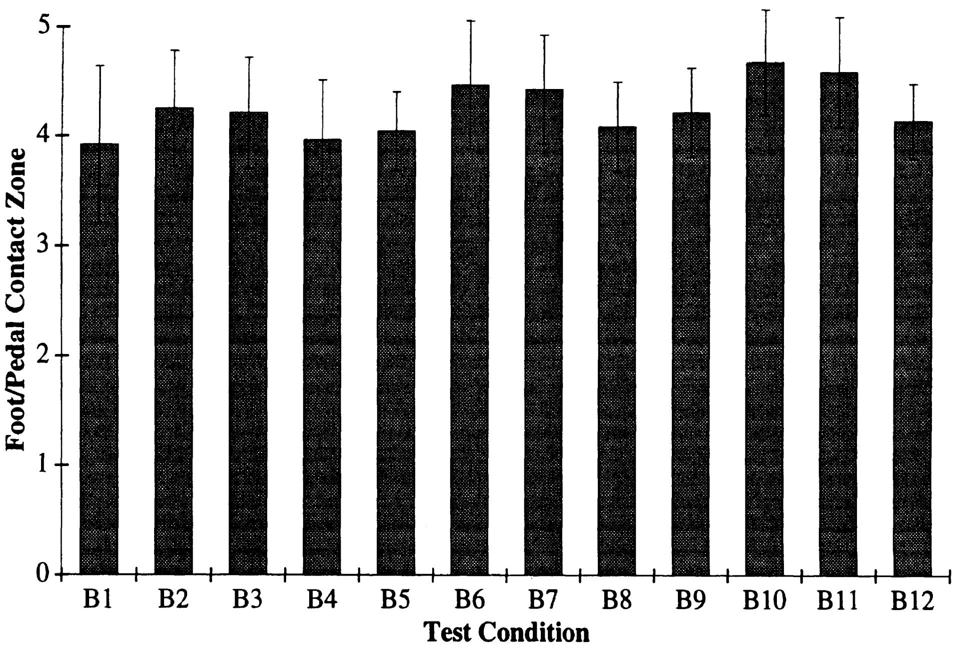
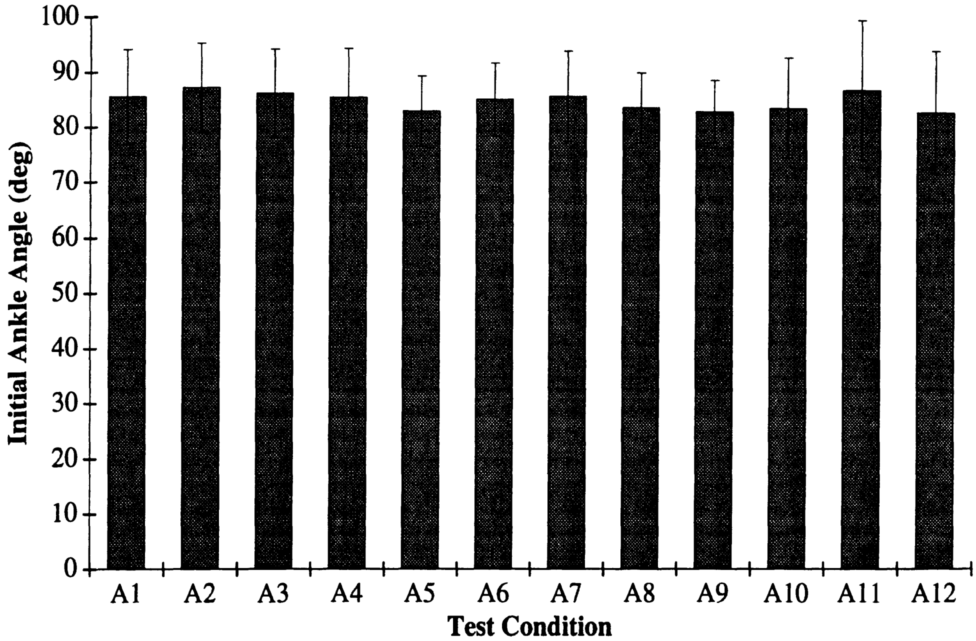


Figure E-10: Overall mean foot/pedal contact zone by test condition.



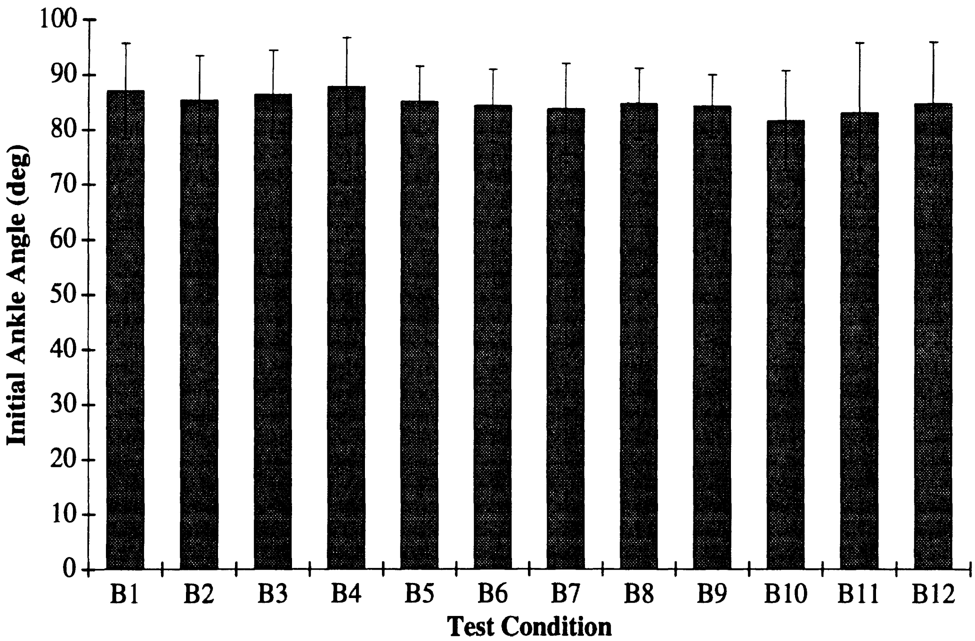
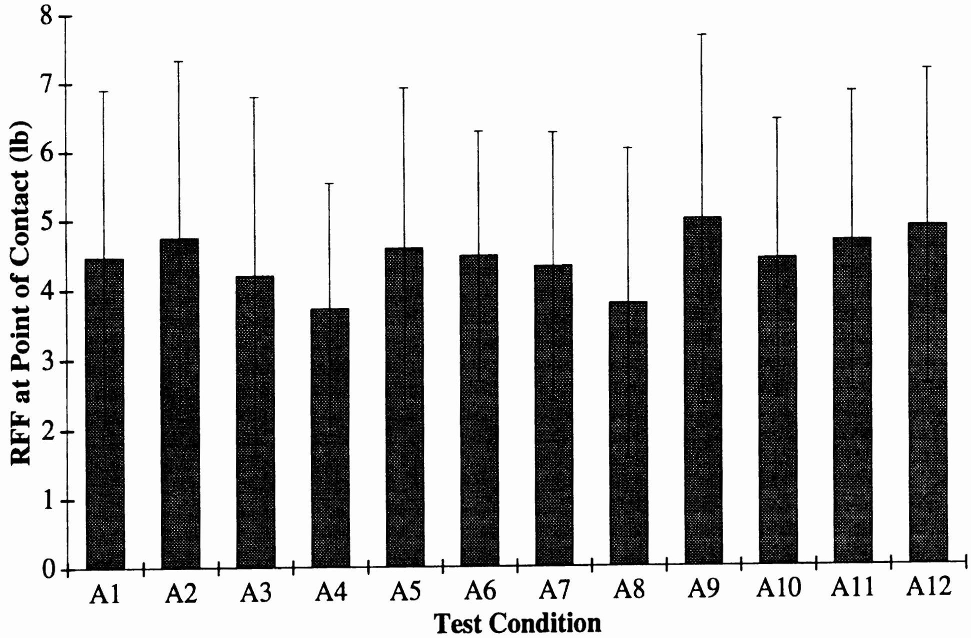


Figure E-11: Overall mean initial ankle angle by test condition.



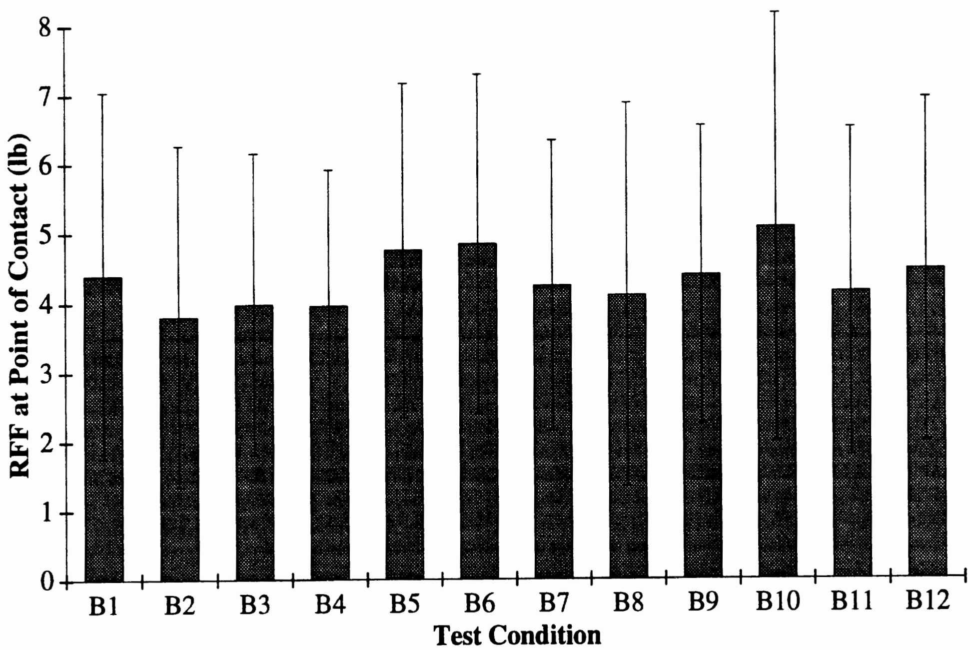
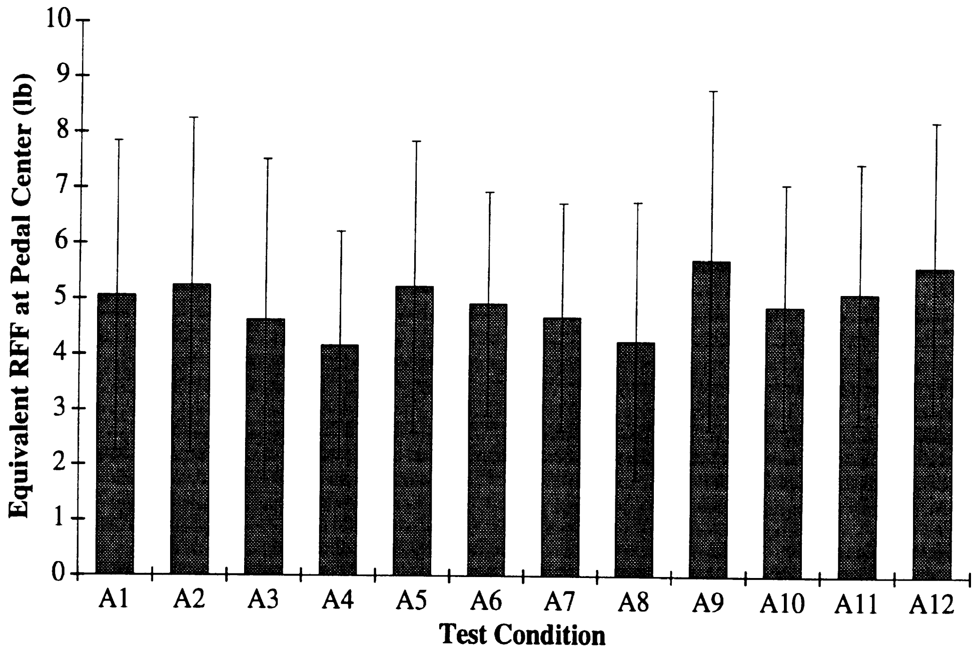


Figure E-12: Overall mean RFF at point of contact by test condition.



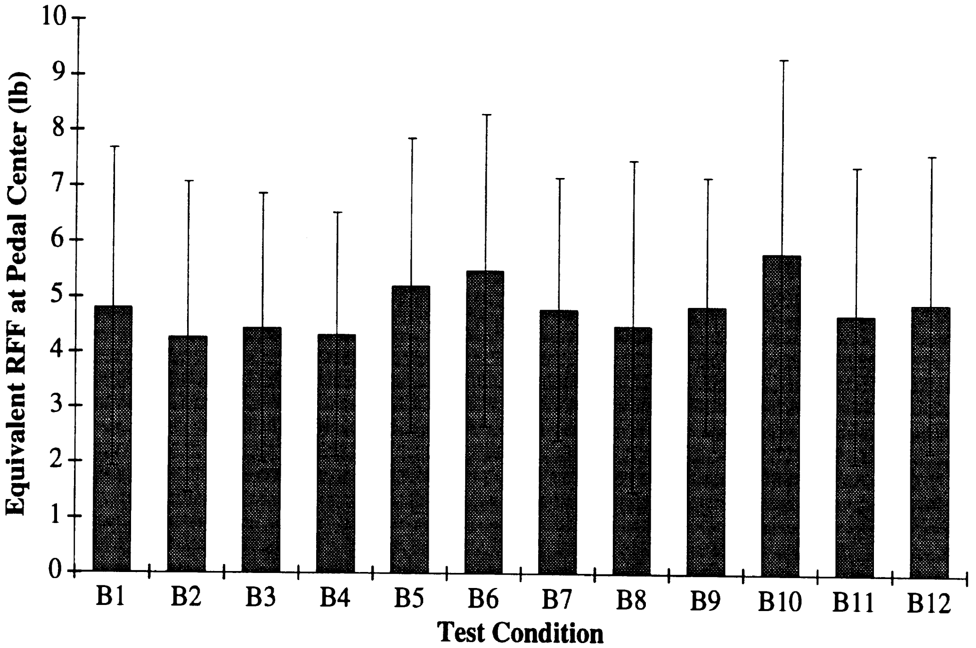
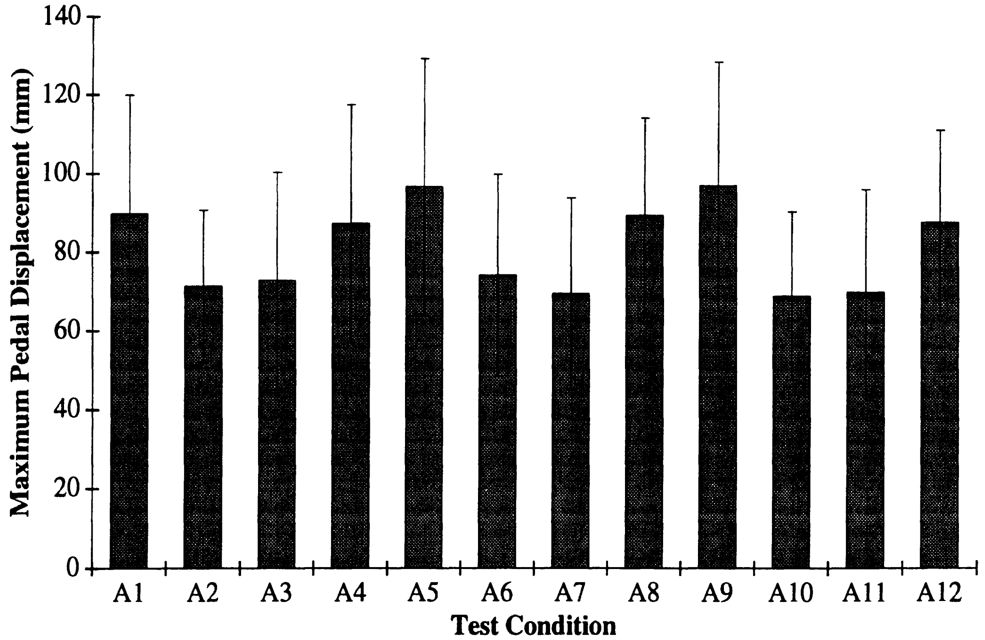


Figure E-13: Overall mean equivalent RFF at pedal center by test condition.

Table E-7
Maximum Pedal Displacement and Associated Ankle Extension Results

Test Condition	SH	PA	PL	PF*	N	Maximum Pedal Displacement (mm)			Change in Ankle Extension Angle at MPD (deg)		
						Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	90	30	40 - 147 = 107.0	27	9	14.0 - 58.4 = 44.4
2	L	L	L	H	24	71	19	34 - 106 = 72.0	21	5	11.4 - 31.8 = 20.4
3	L	H	S	H	24	73	28	34 - 137 = 103.0	21	6	12.2 - 31.4 = 19.2
4	L	H	L	L	24	87	30	40 - 147 = 107.0	25	8	10.1 - 42.7 = 32.6
5	M	L	S	L	24	97	33	40 - 147 = 107.0	30	9	13.5 - 53.2 = 39.7
6	M	L	L	H	24	74	26	36 - 122 = 86.0	23	7	12.2 - 39.2 = 27.0
7	M	H	S	H	24	69	24	36 - 132 = 96.0	21	7	8.3 - 35.8 = 27.5
8	M	H	L	L	24	89	25	30 - 132 = 102.0	26	7	9.2 - 38.4 = 29.2
9	H	L	S	L	24	97	32	55 - 163 = 108.0	29	7	16.6 - 43.2 = 26.6
10	H	L	L	H	24	69	21	14 - 102 = 88.0	21	8	7.0 - 34.9 = 27.9
11	H	H	S	H	24	70	26	30 - 126 = 96.0	21	8	7.9 - 35.8 = 27.9
12	H	H	L	L	24	88	24	46 - 132 = 86.0	26	7	12.2 - 36.6 = 24.4
GROUP B											
1	L	L	S	H	24	75	32	20 - 132 = 112.0	21	8	7.4 - 36.6 = 29.2
2	L	L	L	L	24	95	29	55 - 157 = 102.0	26	7	15.3 - 40.1 = 24.8
3	L	H	S	L	24	91	33	50 - 173 = 123.0	25	7	14.4 - 40.1 = 25.7
4	L	H	L	H	24	72	34	34 - 159 = 125.0	18	7	5.3 - 32.7 = 27.4
5	M	L	S	H	24	72	33	20 - 153 = 133.0	21	8	4.8 - 42.3 = 37.5
6	M	L	L	L	24	97	31	40 - 178 = 138.0	28	7	12.7 - 44.9 = 32.2
7	M	H	S	L	24	93	34	40 - 173 = 133.0	26	7	15.7 - 40.1 = 24.4
8	M	H	L	H	24	74	33	26 - 143 = 117.0	20	8	6.6 - 35.8 = 29.2
9	H	L	S	H	24	78	34	26 - 153 = 127.0	24	10	5.7 - 43.2 = 37.5
10	H	L	L	L	24	100	34	61 - 178 = 117.0	29	8	18.3 - 52.3 = 34.0
11	H	H	S	L	24	96	34	50 - 173 = 123.0	27	7	16.2 - 42.3 = 26.1
12	H	H	L	H	24	74	30	20 - 126 = 106.0	22	9	7.9 - 40.1 = 32.2



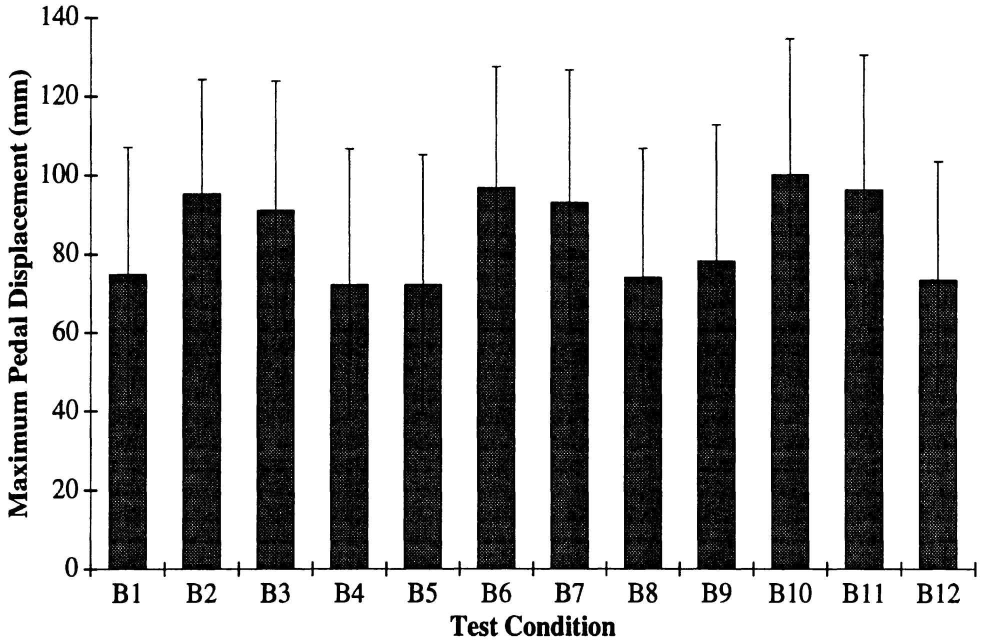


Figure E-14: Overall mean maximum pedal displacement by test condition.

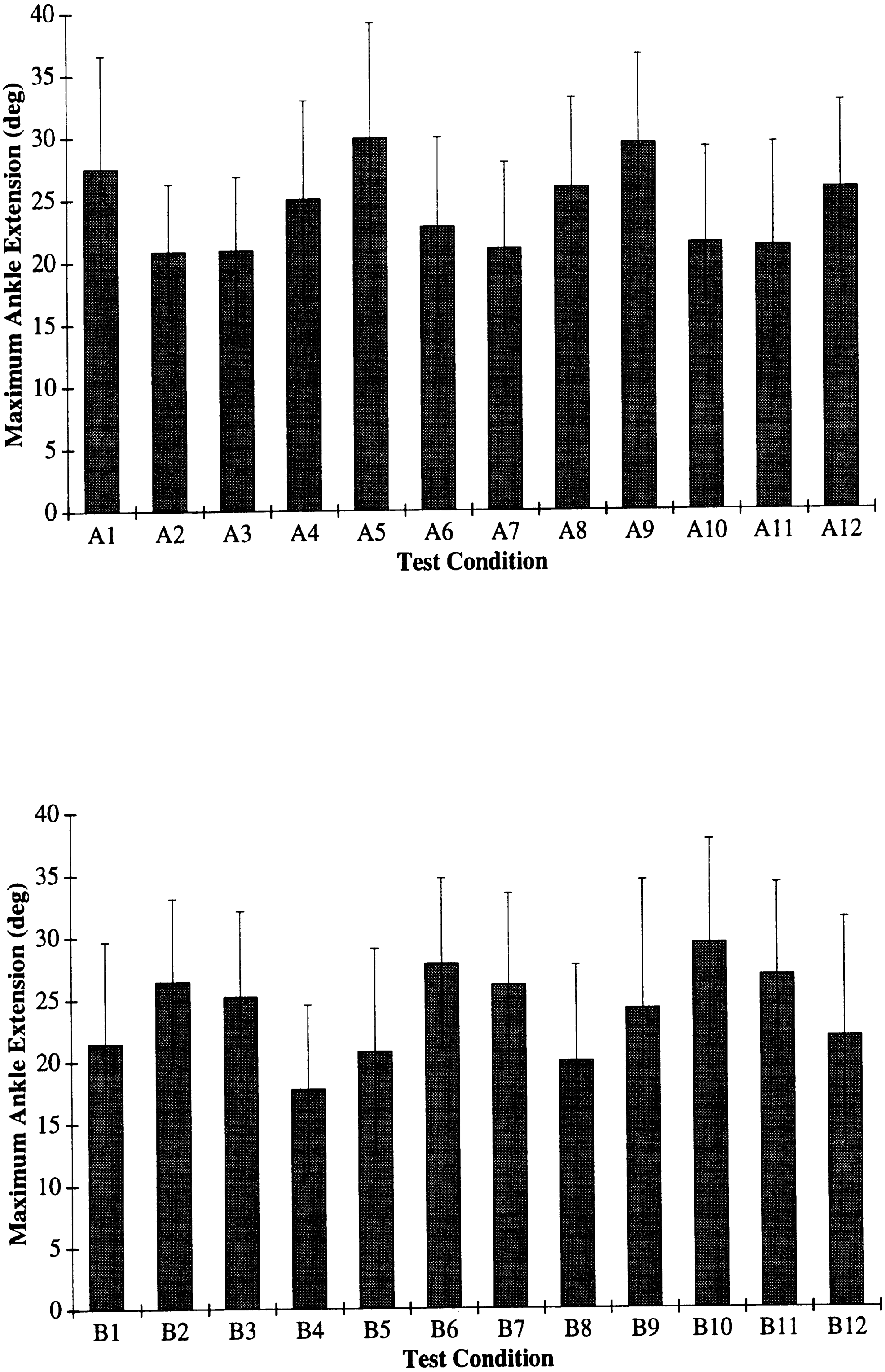
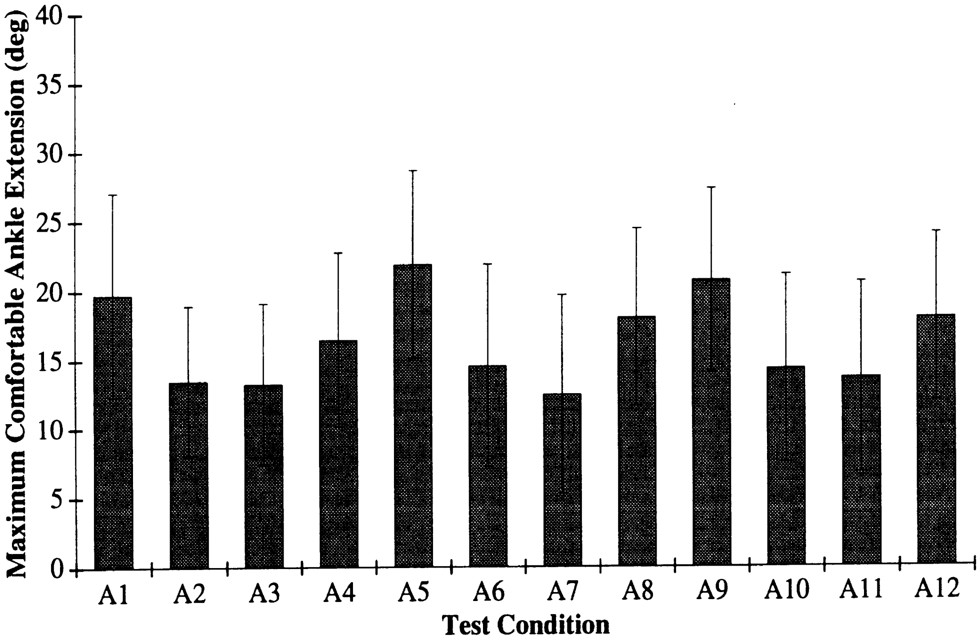


Figure E-15: Overall mean maximum ankle extension by test condition.

Table E-8
Maximum Comfortable Pedal Displacement and Associated Ankle Extension Results

Test Condition	SH	PA	PL	PF*	N	Maximum Comfortable Pedal Displacement (mm)			Change in Ankle Extension Angle at MCPD (deg)		
						Mean	s.d.	Range	Mean	s.d.	Range
GROUP A											
1	L	L	S	L	24	60	23	29 - 103 = 74.0	20	7	7.9 - 35.5 = 27.6
2	L	L	L	H	24	45	16	18 - 75 = 57.0	13	5	4.1 - 24.4 = 20.3
3	L	H	S	H	24	43	19	10 - 85 = 75.0	13	6	0.5 - 27.9 = 27.4
4	L	H	L	L	24	54	21	26 - 104 = 78.0	16	6	7.4 - 29.8 = 22.4
5	M	L	S	L	24	69	28	34 - 142 = 108.0	22	7	11.9 - 41.7 = 29.8
6	M	L	L	H	24	46	19	7 - 107 = 100.0	15	7	0.2 - 34.9 = 34.7
7	M	H	S	H	24	42	20	10 - 94 = 84.0	12	7	4.3 - 30.7 = 26.4
8	M	H	L	L	24	58	24	26 - 104 = 78.0	18	6	7.9 - 29.7 = 21.8
9	H	L	S	L	24	66	33	39 - 201 = 162.0	21	7	11.4 - 37.8 = 26.4
10	H	L	L	H	24	47	25	14 - 132 = 118.0	14	7	5.9 - 30.1 = 24.2
11	H	H	S	H	24	44	17	16 - 91 = 75.0	14	7	2.2 - 32.4 = 30.2
12	H	H	L	L	24	58	15	36 - 89 = 53.0	18	6	4.0 - 31.3 = 27.3
GROUP B											
1	L	L	S	H	24	52	21	17 - 90 = 73.0	16	7	5.6 - 31.7 = 26.1
2	L	L	L	L	24	72	29	42 - 141 = 99.0	21	7	10.5 - 39.4 = 28.9
3	L	H	S	L	24	68	26	29 - 124 = 95.0	20	7	3.2 - 34.0 = 30.8
4	L	H	L	H	24	50	27	20 - 123 = 103.0	13	7	1.6 - 31.5 = 29.9
5	M	L	S	H	24	51	26	14 - 118 = 104.0	15	7	5.4 - 36.9 = 31.5
6	M	L	L	L	24	73	29	21 - 159 = 138.0	22	6	8.5 - 30.7 = 22.2
7	M	H	S	L	24	68	28	31 - 139 = 108.0	20	8	11.7 - 35.6 = 23.9
8	M	H	L	H	24	48	23	7 - 91 = 84.0	13	7	0.3 - 27.3 = 27.0
9	H	L	S	H	24	51	25	14 - 115 = 101.0	17	8	3.7 - 36.8 = 33.1
10	H	L	L	L	24	72	29	36 - 153 = 117.0	23	7	14.9 - 41.4 = 26.5
11	H	H	S	L	24	71	31	33 - 151 = 118.0	21	8	12.1 - 39.8 = 27.7
12	H	H	L	H	24	50	22	17 - 103 = 86.0	16	7	5.6 - 30.1 = 24.5



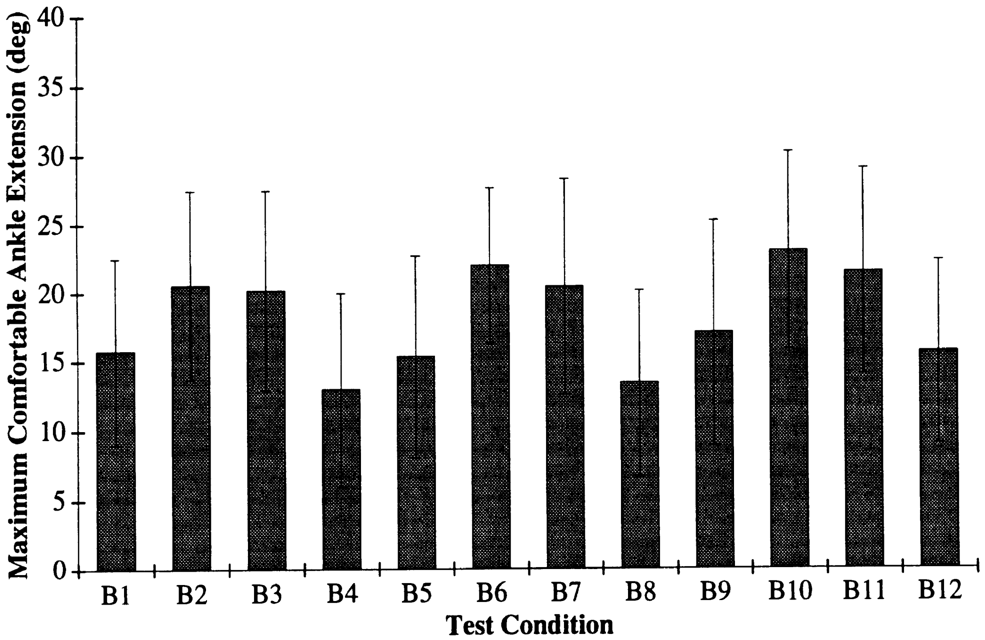
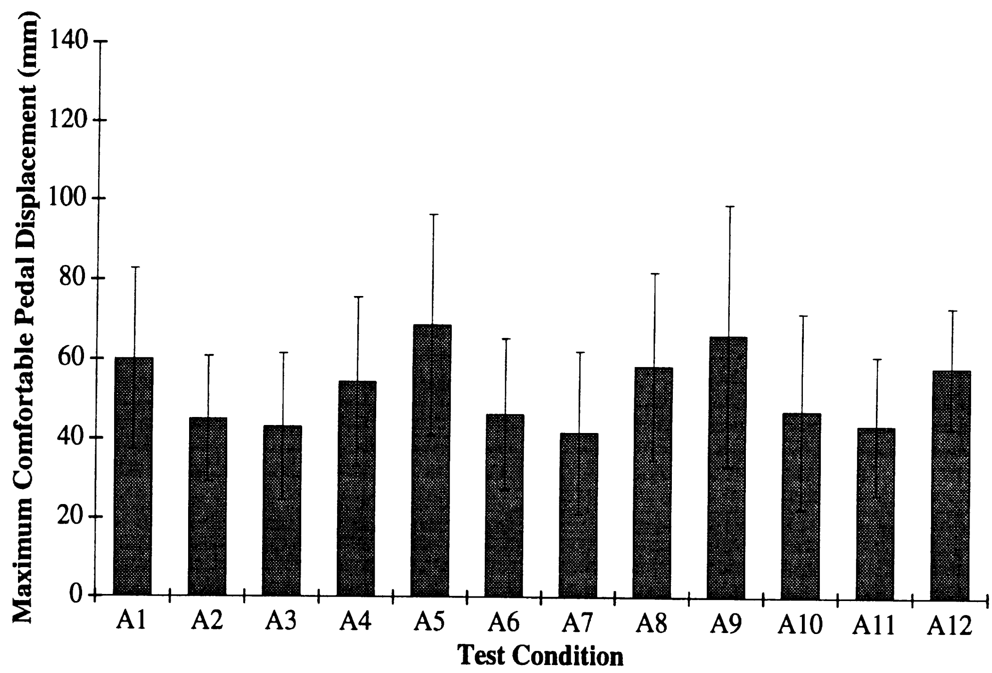


Figure E-17: Overall mean maximum comfortable ankle extension by test condition.



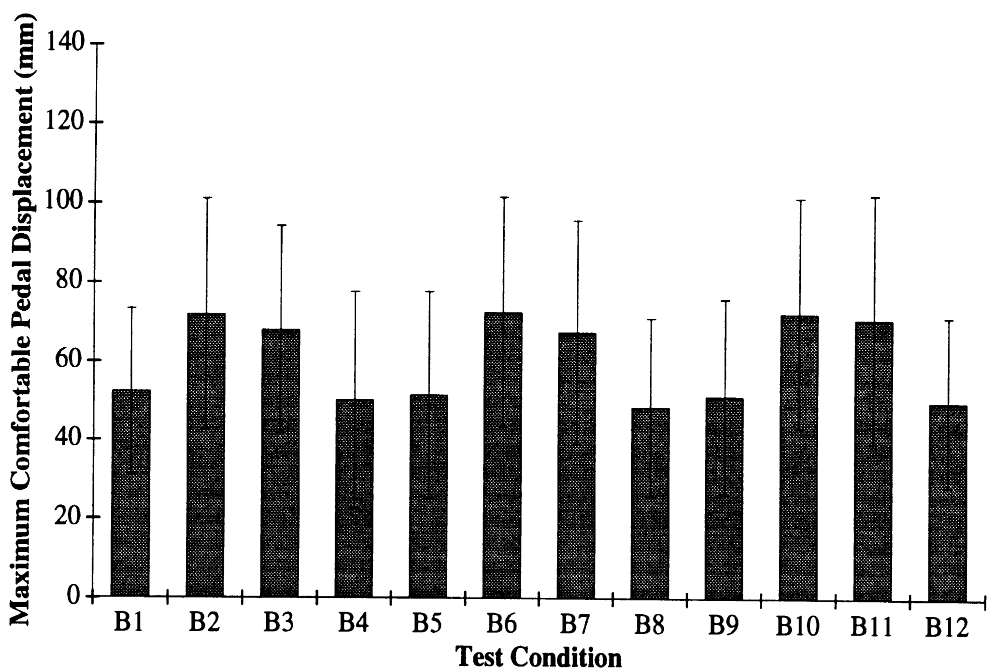
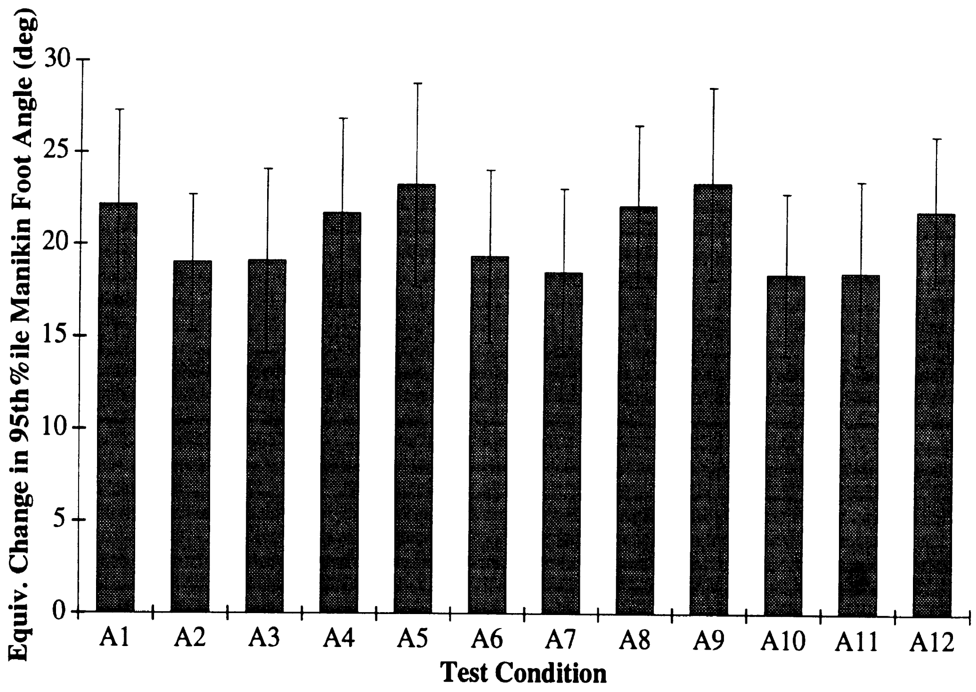


Figure E-16: Overall mean maximum comfortable pedal displacement by test condition

Table E-9
Equivalent Change in 95th%ile Manikin Foot Angle Results

Test Condition	SH	PA	PL	PF*	N	Change in Manikin Foot Angle for MPD (mm)			Change in Manikin Foot Angle for MCPD (mm)			Difference in Mean Angle (mm)
						Mean	s.d.	Range	Mean	s.d.	Range	
GROUP A												
1	L	L	S	L	24	22	5	12.6 - 31.4 = 18.8	17	5	9.6 - 24.7 = 15.1	5.5
2	L	L	L	H	24	19	4	11.0 - 25.1 = 14.1	13	4	6.4 - 19.9 = 13.5	5.5
3	L	H	S	H	24	19	5	11.0 - 29.8 = 18.8	13	4	3.8 - 21.8 = 18.0	6.2
4	L	H	L	L	24	22	5	12.6 - 31.4 = 18.8	15	4	8.8 - 24.9 = 16.1	6.2
5	M	L	S	L	24	23	6	12.6 - 31.4 = 18.8	18	5	11.0 - 30.6 = 19.6	4.9
6	M	L	L	H	24	19	5	11.5 - 27.6 = 16.1	14	4	2.9 - 24.4 = 21.5	5.7
7	M	H	S	H	24	19	5	11.5 - 29.2 = 17.7	13	5	3.8 - 23.2 = 19.4	6.0
8	M	H	L	L	24	22	4	9.9 - 29.2 = 19.3	16	5	8.8 - 24.9 = 16.1	5.9
9	H	L	S	L	24	23	5	15.9 - 34.1 = 18.2	18	6	12.2 - 41.7 = 29.5	5.5
10	H	L	L	H	24	18	4	5.1 - 24.4 = 19.3	14	5	5.1 - 29.1 = 24.0	4.7
11	H	H	S	H	24	19	5	9.9 - 28.2 = 18.3	13	4	5.8 - 22.7 = 16.9	5.4
12	H	H	L	L	24	22	4	14.0 - 29.2 = 15.2	16	3	11.5 - 22.5 = 11.0	5.4
GROUP B												
1	L	L	S	H	24	19	6	7.0 - 29.2 = 22.2	15	5	6.2 - 22.6 = 16.4	4.3
2	L	L	L	L	24	23	5	15.9 - 33.1 = 17.2	19	5	12.9 - 30.5 = 17.6	4.3
3	L	H	S	L	24	22	6	15.0 - 36.0 = 21.0	18	5	9.7 - 27.9 = 18.2	4.2
4	L	H	L	H	24	19	6	11.0 - 33.4 = 22.4	14	6	7.0 - 27.7 = 20.7	4.5
5	M	L	S	H	24	19	6	7.0 - 32.4 = 25.4	15	6	5.1 - 27.0 = 21.9	4.2
6	M	L	L	L	24	23	5	12.6 - 36.8 = 24.2	19	5	7.4 - 33.4 = 26.0	4.4
7	M	H	S	L	24	23	6	12.6 - 36.0 = 23.4	18	5	10.3 - 30.2 = 19.9	4.7
8	M	H	L	H	24	19	6	8.8 - 30.8 = 22.0	14	5	3.1 - 22.8 = 19.7	5.1
9	H	L	S	H	24	20	6	8.8 - 32.4 = 23.6	15	5	5.1 - 26.6 = 21.5	5.3
10	H	L	L	L	24	24	6	17.2 - 36.8 = 19.6	19	5	11.5 - 32.4 = 20.9	5.0
11	H	H	S	L	24	23	6	15.0 - 36.0 = 21.0	19	6	10.7 - 32.1 = 21.4	4.7
12	H	H	L	H	24	19	6	7.0 - 28.2 = 21.2	14	5	6.2 - 24.7 = 18.5	4.6



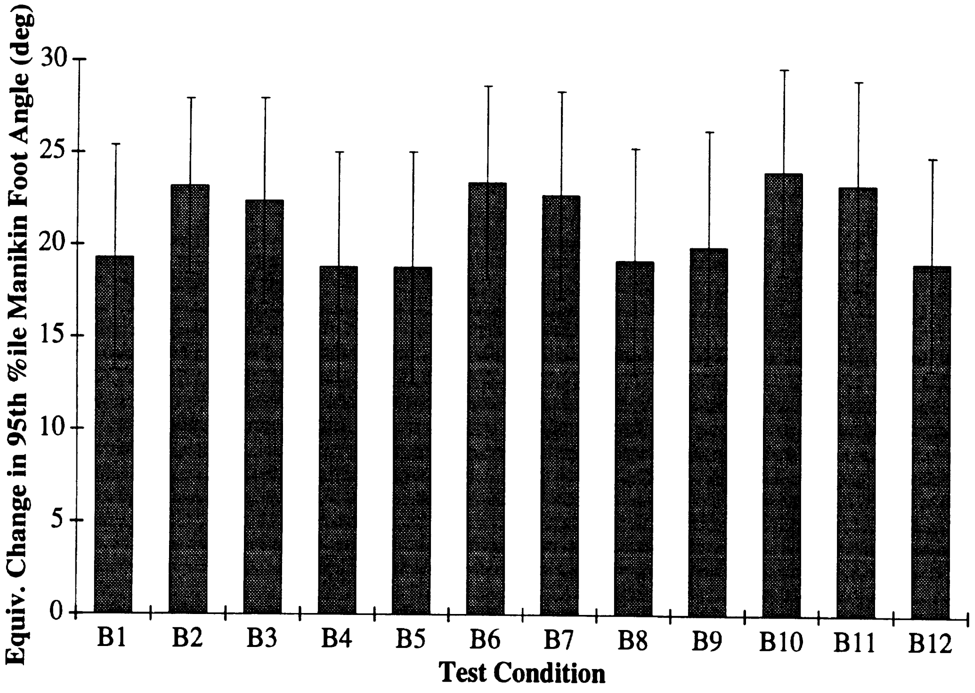
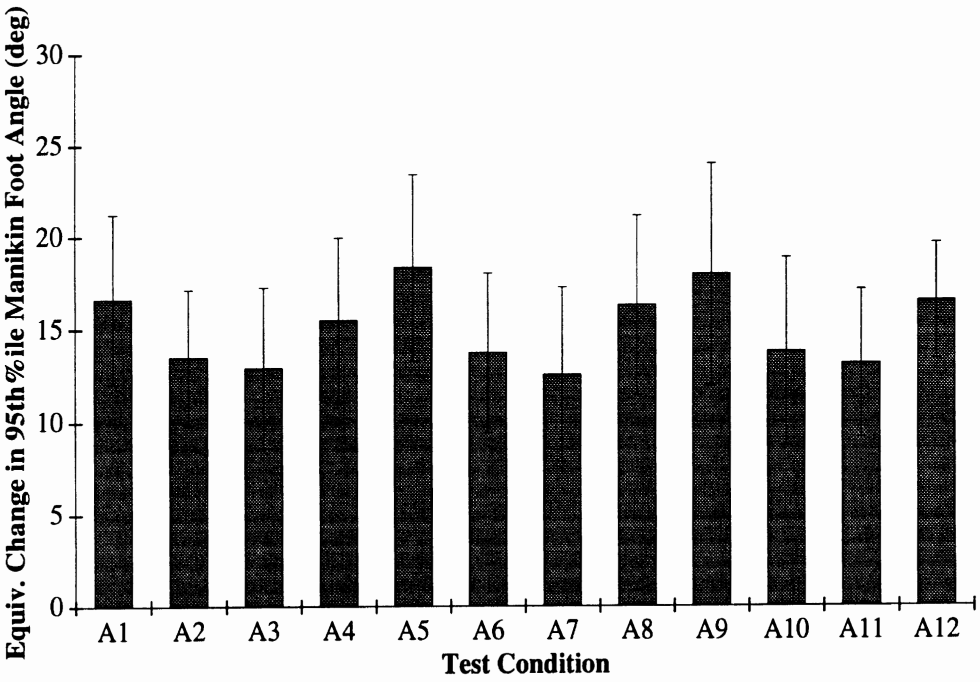


Figure E-18: Overall mean equivalent change in 95th%ile manikin foot angle for MPD by test condition.



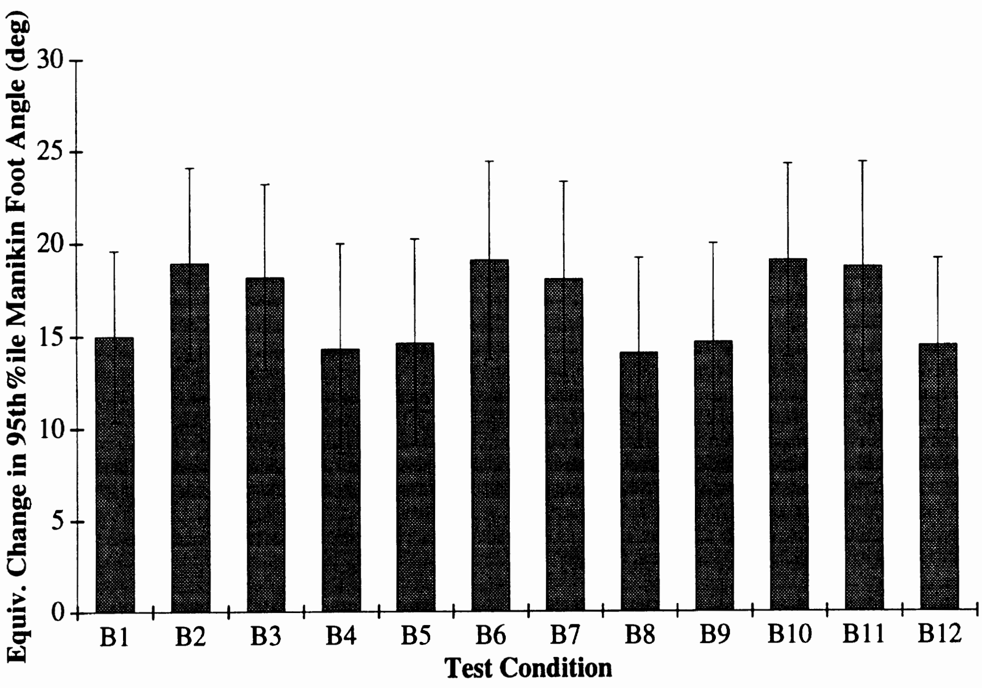
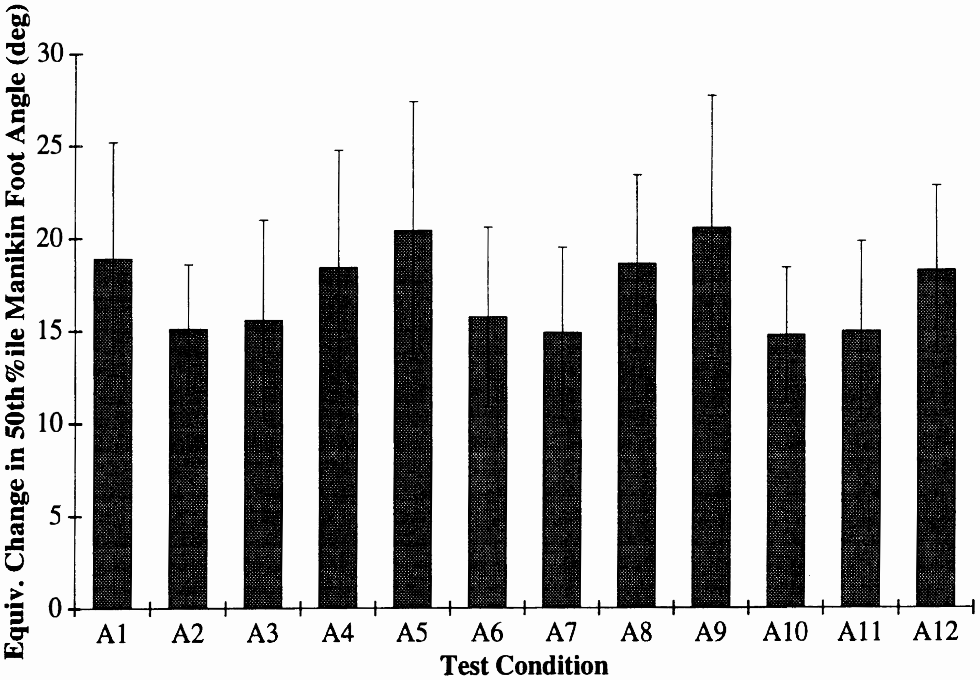


Figure E-19: Overall mean equivalent change in 95th%ile manikin foot angle for MCPD by test condition.

Table E-10
Equivalent Change in 50th%ile Manikin Foot Angle Results

Test Condition	SH	PA	PL	PF*	N	Change in Manikin Foot Angle for MPD (mm)			Change in Manikin Foot Angle for MCPD (mm)			Difference in Mean Angle (mm)
						Mean	s.d.	Range	Mean	s.d.	Range	
GROUP A												
1	L	L	S	L	24	19	6	9.5 - 32.4 = 22.9	13	4	7.2 - 20.9 = 13.7	5.9
2	L	L	L	H	24	15	3	8.3 - 21.5 = 13.2	10	3	4.7 - 15.7 = 11	4.8
3	L	H	S	H	24	16	5	8.3 - 29.2 = 20.9	10	4	2.6 - 17.5 = 14.9	5.7
4	L	H	L	L	24	18	6	9.5 - 32.4 = 22.9	12	4	6.6 - 21.2 = 14.6	6.4
5	M	L	S	L	24	20	7	9.5 - 32.4 = 22.9	15	6	8.3 - 30.8 = 22.5	5.5
6	M	L	L	H	24	16	5	8.7 - 25.2 = 16.5	10	4	1.9 - 20.6 = 18.7	5.2
7	M	H	S	H	24	15	5	8.7 - 28.0 = 19.3	10	4	2.6 - 19.2 = 16.6	5.3
8	M	H	L	L	24	19	5	8.7 - 28.0 = 19.3	13	4	6.6 - 21.2 = 14.6	5.8
9	H	L	S	L	24	21	7	12.1 - 38.5 = 26.4	14	4	9.2 - 26.2 = 17	6.8
10	H	L	L	H	24	15	4	6.1 - 20.6 = 14.5	11	5	6.1 - 27.8 = 21.7	3.9
11	H	H	S	H	24	15	5	7.4 - 26.3 = 18.9	10	3	4.2 - 18.5 = 14.3	4.9
12	H	H	L	L	24	18	5	10.7 - 28.0 = 17.3	13	3	8.7 - 18.3 = 9.6	5.5
GROUP B												
1	L	L	S	H	24	16	6	5.2 - 28.0 = 22.8	12	4	4.5 - 18.4 = 13.9	4.3
2	L	L	L	L	24	20	7	12.1 - 36.1 = 24	15	6	9.8 - 30.6 = 20.8	4.6
3	L	H	S	L	24	20	7	11.4 - 43.0 = 31.6	15	5	7.3 - 25.8 = 18.5	5.2
4	L	H	L	H	24	16	7	8.3 - 36.9 = 28.6	11	5	5.2 - 25.4 = 20.2	4.5
5	M	L	S	H	24	15	7	5.2 - 34.5 = 29.3	11	5	3.7 - 24.2 = 20.5	4.1
6	M	L	L	L	24	20	7	9.5 - 45.0 = 35.5	16	6	5.5 - 36.9 = 31.4	4.9
7	M	H	S	L	24	20	8	9.5 - 43.0 = 33.5	15	5	7.7 - 30.0 = 22.3	5.3
8	M	H	L	H	24	16	7	6.6 - 31.1 = 24.5	11	4	2.1 - 18.6 = 16.5	5.0
9	H	L	S	H	24	17	7	6.6 - 34.5 = 27.9	12	4	5.0 - 23.6 = 18.6	5.2
10	H	L	L	L	24	22	9	13.2 - 45.0 = 31.8	16	6	8.7 - 34.5 = 25.8	6.0
11	H	H	S	L	24	21	8	11.4 - 43.0 = 31.6	15	6	8.0 - 33.8 = 25.8	5.3
12	H	H	L	H	24	16	6	5.2 - 29.3 = 24.1	11	4	4.5 - 20.9 = 16.4	4.4



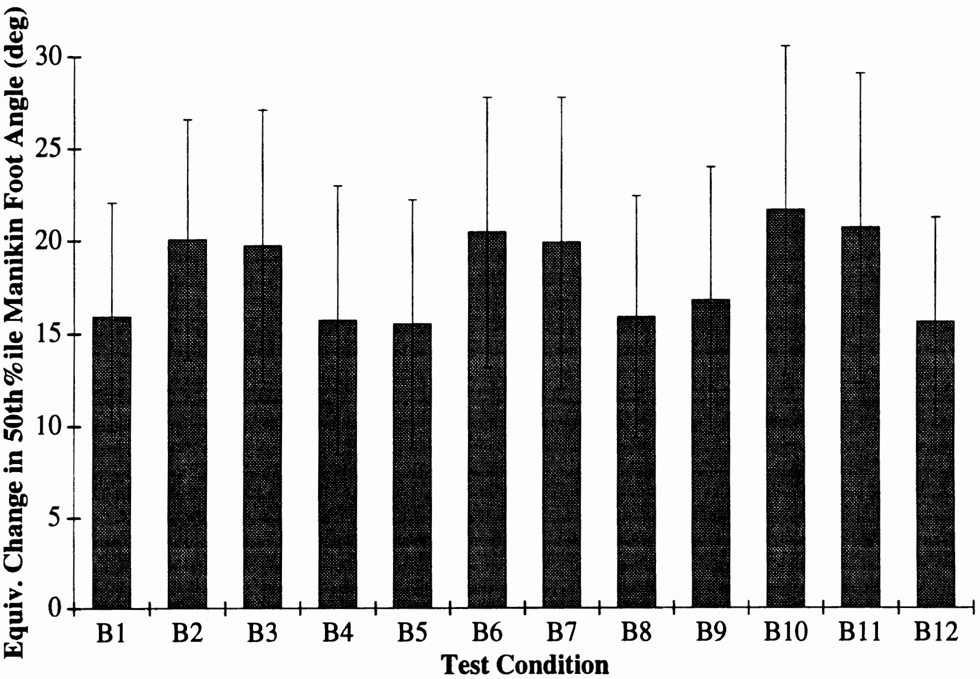
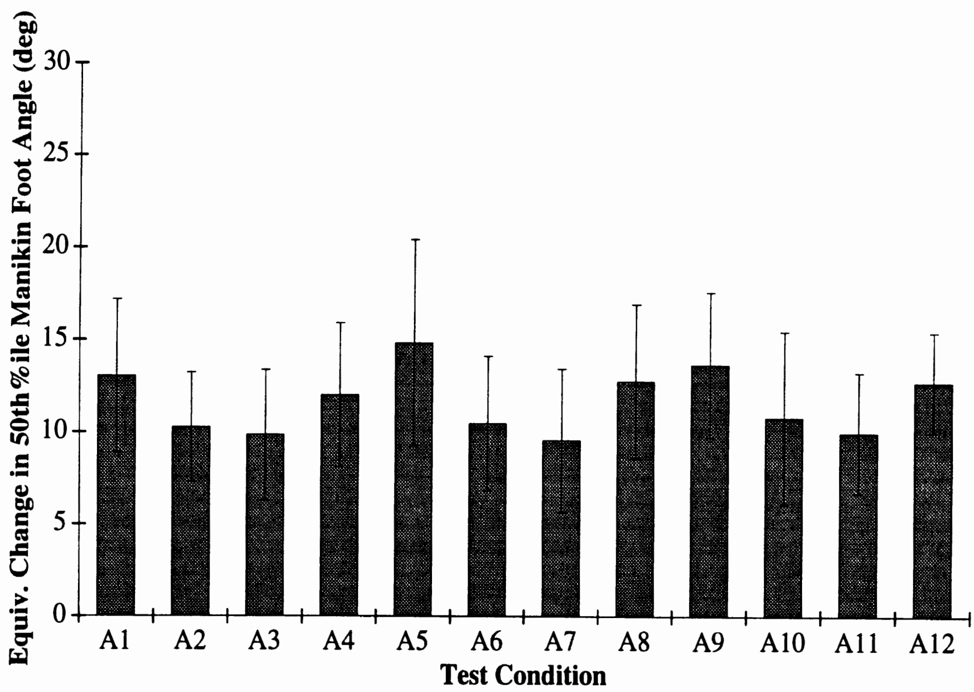


Figure E-20: Overall mean equivalent change in 50th%ile manikin foot angle for MPD by test condition.



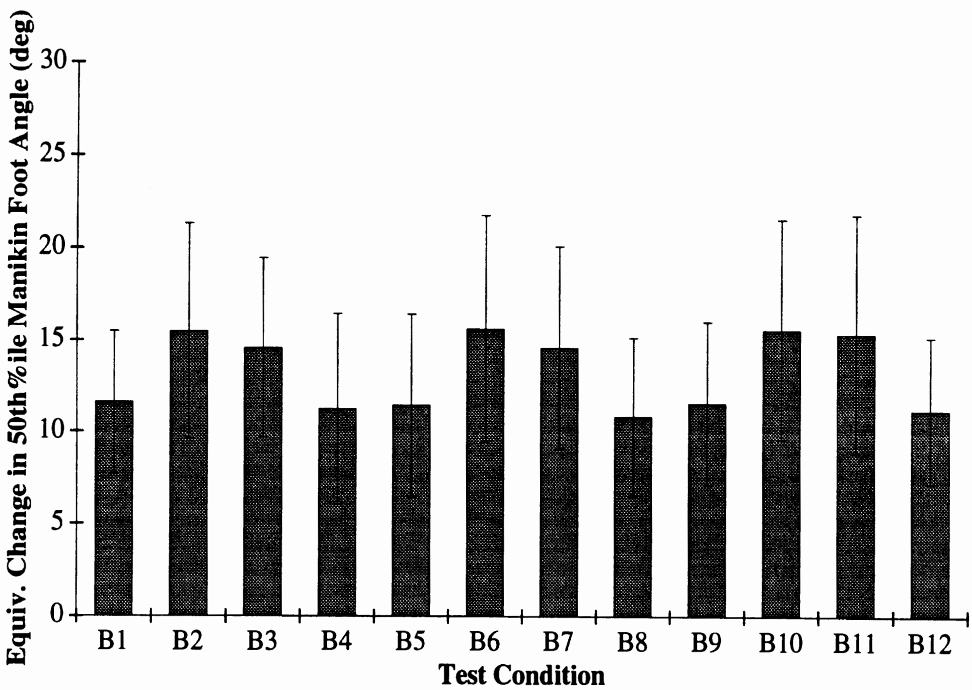
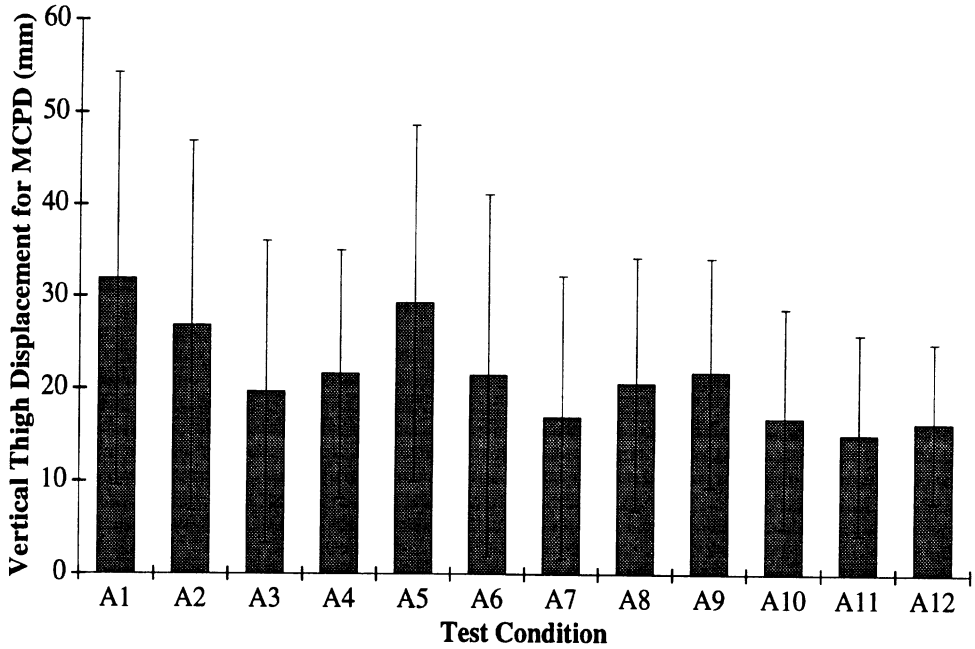


Figure E-21: Overall mean equivalent change in 50th%ile manikin foot angle for MCPD by test condition.

Table E-11
Downward Thigh Displacement, Change in Knee Angle and FSR Pressure Results

Test Condition	SH	PA	PL	PF*	N	Downward Thigh Displacement (mm)		Change in Knee Angle (deg)		Peak Pressure at Front FSR (psi)		Peak Pressure at Back FSR (psi)	
						Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
GROUP A													
1	L	L	S	L	24	32	22	9	6	0.73	0.78	0.91	0.39
2	L	L	L	H	24	27	20	5	6	0.64	0.86	0.90	0.46
3	L	H	S	H	24	20	16	5	4	2.04	2.28	1.39	0.54
4	L	H	L	L	24	22	13	5	4	1.33	1.32	1.14	0.40
5	M	L	S	L	24	29	19	8	6	1.21	1.36	1.11	0.37
6	M	L	L	H	24	22	20	5	7	0.79	0.99	0.99	0.41
7	M	H	S	H	24	17	15	4	5	1.90	1.83	1.38	0.41
8	M	H	L	L	24	21	14	5	5	1.29	0.89	1.18	0.39
9	H	L	S	L	24	22	12	5	4	1.66	1.71	1.26	0.39
10	H	L	L	H	24	17	12	4	5	1.13	1.18	1.28	0.47
11	H	H	S	H	24	15	11	4	4	1.82	1.64	1.40	0.45
12	H	H	L	L	24	16	9	4	2	1.33	0.70	1.26	0.38
GROUP B													
1	L	L	S	H	24	28	23	7	6	0.82	1.20	0.88	0.31
2	L	L	L	L	24	33	26	9	7	0.45	0.66	0.65	0.46
3	L	H	S	L	24	29	17	8	5	1.30	1.20	1.13	0.35
4	L	H	L	H	24	21	20	7	7	1.13	1.25	1.14	0.39
5	M	L	S	H	24	23	15	6	5	1.01	1.21	1.02	0.32
6	M	L	L	L	24	29	17	8	5	0.70	0.74	0.87	0.35
7	M	H	S	L	24	24	16	7	5	1.55	1.36	1.20	0.43
8	M	H	L	H	24	16	12	4	4	1.09	1.52	1.13	0.42
9	H	L	S	H	24	20	13	6	6	1.43	1.37	1.23	0.43
10	H	L	L	L	24	25	15	7	4	0.92	0.93	0.95	0.26
11	H	H	S	L	24	22	13	6	3	1.63	1.28	1.18	0.42
12	H	H	L	H	24	16	10	4	3	1.35	1.21	1.25	0.48



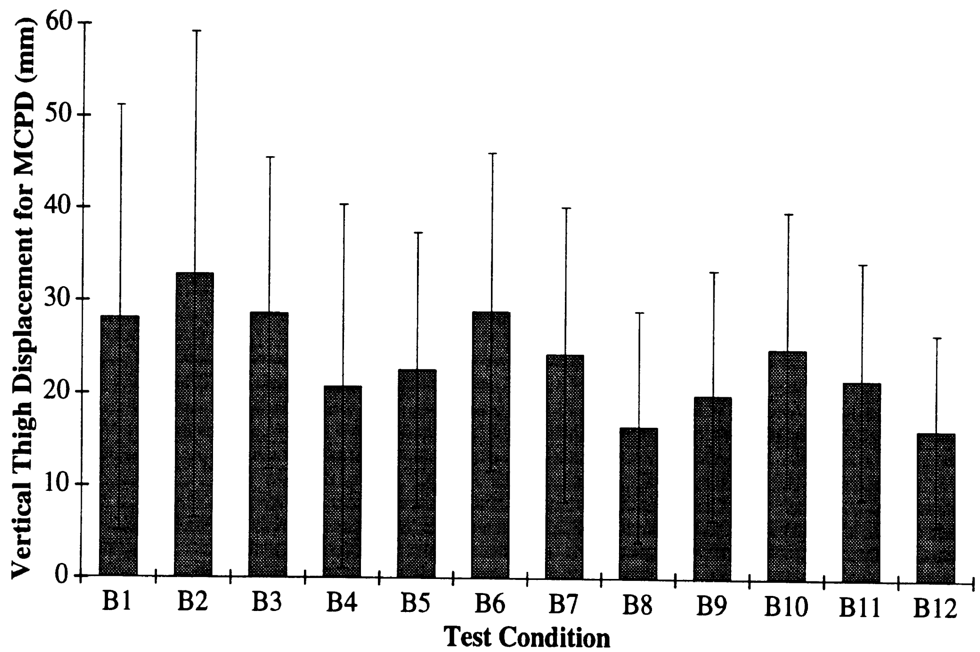


Figure E-22: Overall mean vertical thigh displacement for MCPD by test condition.

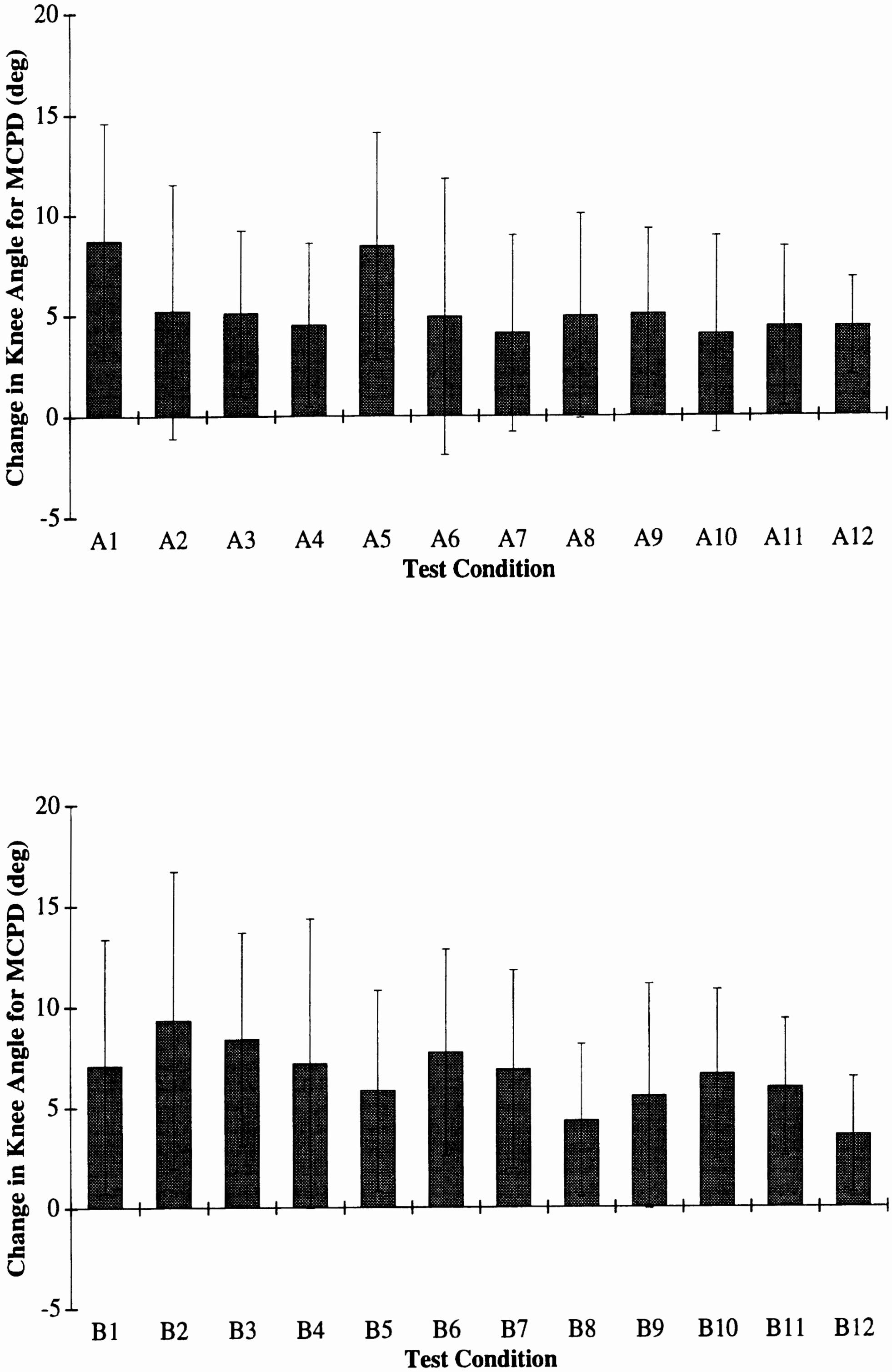
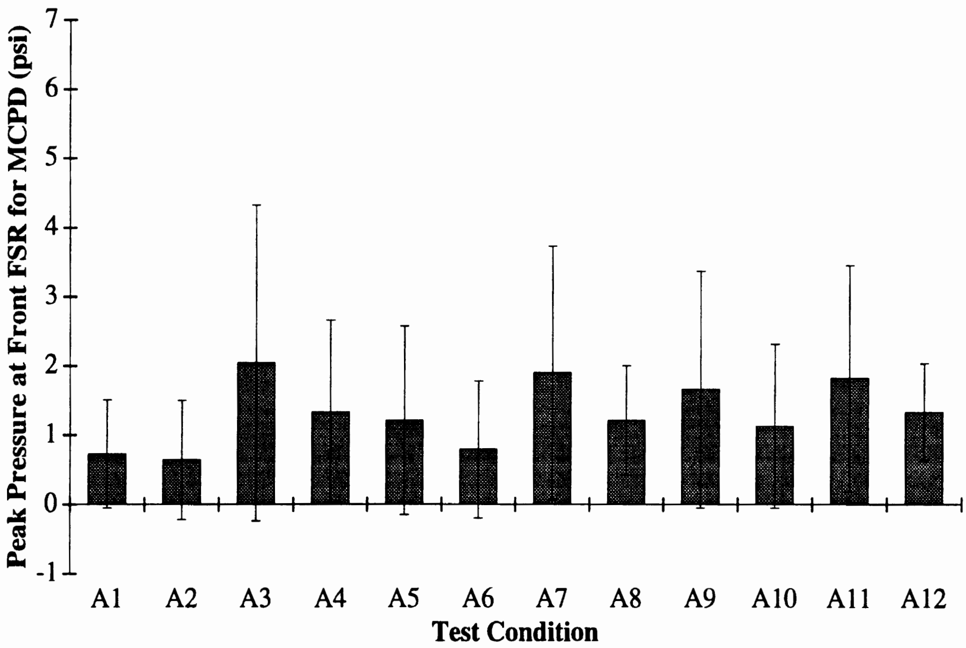


Figure E-23: Overall mean change in knee angle for MCPD by test condition.



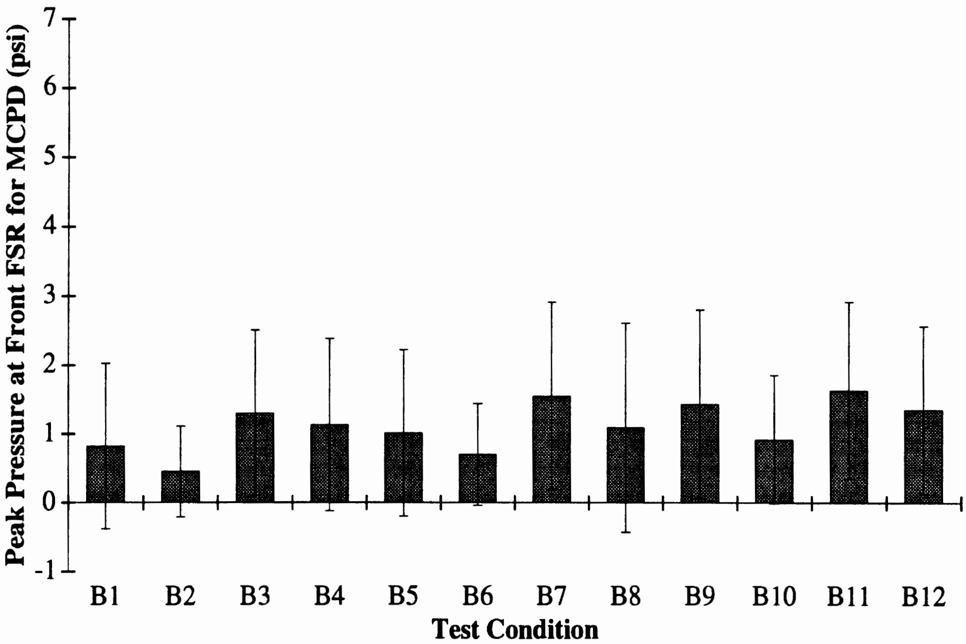
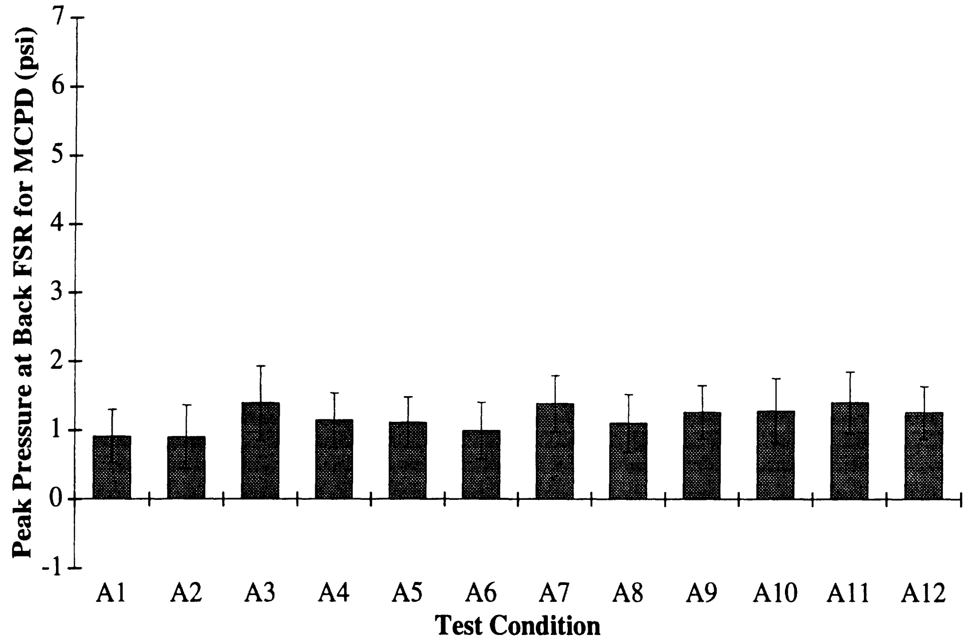


Figure E-24: Overall mean peak pressure at front FSR for MCPD by test condition.



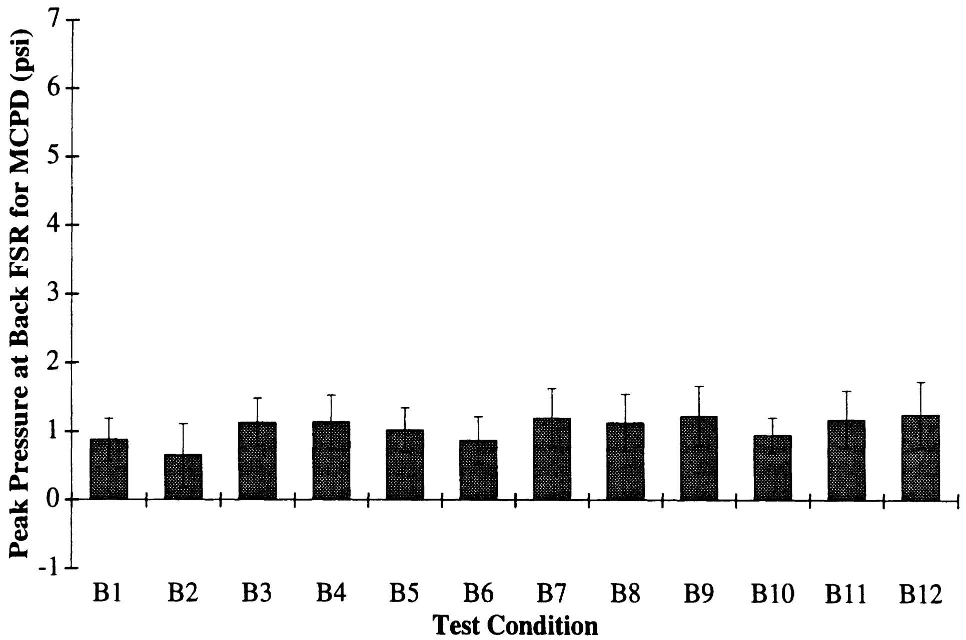
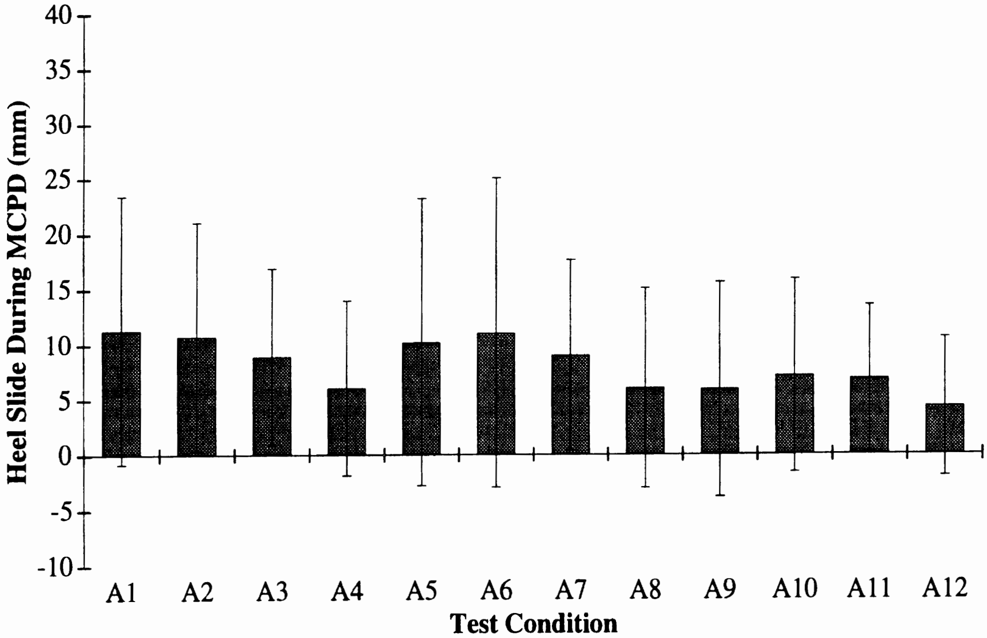


Figure E-25: Overall mean peak pressure at back FSR for MCPD by test condition.

Table E-12
Forward Heel Slide Results

Test Condition	SH	PA	PL	PF*	N	Forward Heel Slide Mean	s.d.	Range
GROUP A								
1	L	L	S	L	24	11	12	0 - 50 = 50
2	L	L	L	H	24	11	10	0 - 35 = 35
3	L	H	S	H	24	9	8	0 - 25 = 25
4	L	H	L	L	24	6	8	0 - 30 = 30
5	M	L	S	L	24	10	13	0 - 55 = 55
6	M	L	L	H	24	11	14	0 - 50 = 50
7	M	H	S	H	24	9	9	0 - 35 = 35
8	M	H	L	L	24	6	9	0 - 35 = 35
9	H	L	S	L	24	6	10	0 - 45 = 45
10	H	L	L	H	24	7	9	0 - 30 = 30
11	H	H	S	H	24	7	7	0 - 25 = 25
12	H	H	L	L	24	4	6	0 - 22 = 22
GROUP B								
1	L	L	S	H	24	13	14	0 - 50 = 50
2	L	L	L	L	24	11	19	0 - 70 = 70
3	L	H	S	L	24	12	16	0 - 60 = 60
4	L	H	L	H	24	17	17	0 - 60 = 60
5	M	L	S	H	24	13	13	0 - 50 = 50
6	M	L	L	L	24	9	14	-1 - 65 = 66
7	M	H	S	L	24	8	12	0 - 50 = 50
8	M	H	L	H	24	11	10	0 - 35 = 35
9	H	L	S	H	24	11	12	0 - 45 = 45
10	H	L	L	L	24	7	12	0 - 55 = 55
11	H	H	S	L	24	9	14	0 - 55 = 55
12	H	H	L	H	24	7	6	0 - 20 = 20

*Seat Height (SH): Low, Mid or High   Pan Angle (PA): Low or High   Pan Length (PL): Long or Short   Pedal Force (PF): Light or Heavy



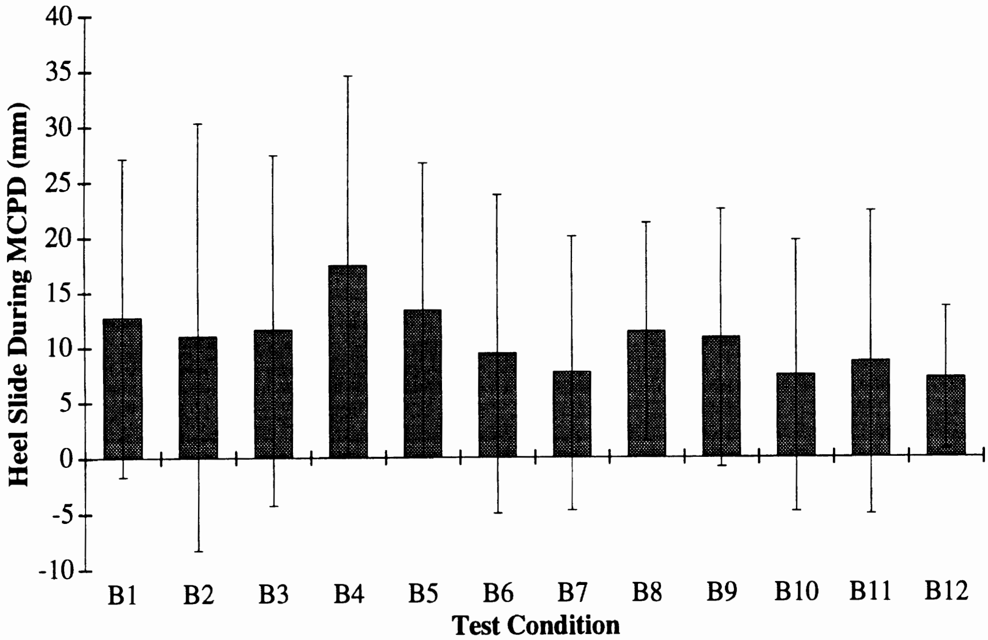


Figure E-26: Overall mean heel slide during MCPD by test condition.

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