Elderly Occupants: Posture, Body Shape, and Belt Fit

Matthew P. Reed
Sheila M. Ebert

University of Michigan Transportation Research Institute

Final Report

UMTRI-2013-26

August 2013

Technical Report Documentation Page

1. Report No. UMTRI-2013-26	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Elderly Occupants: Posture, Body Shape, and Belt Fit		5. Report Date August 2013 6. Performing Organization Code
7. Author(s) Reed, Matthew P. and Ebert, Sheila M.		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Michigan Transportation Research Institute 2901 Baxter Rd. Ann Arbor MI 48109		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A laboratory study was conducted to quantify the posture, body shape, and safety belt fit of 200 adults with a wide range of age, stature, and body weight. Body and belt landmark data were gathered as participants sat in a driver mockup that was adjusted to represent nine vehicle packages spanning a large range of the vehicle fleet and in a mockup of a rear passenger seat. Whole-body surface shape data were gathered in 22 postures using a laser scanner. The data analysis showed significant effects of occupant attributes on posture and belt fit. Vehicle and seat variables had important effects on posture and position but did not have strong effects on belt fit relative to occupant attributes, particularly body mass index. Age had significant effects on both posture and belt fit, although the effect of age was smaller than the effect of body mass index across the ranges in the participant population.

17. Key Word anthropometry, vehicle seats, posture	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 87	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	inches	25.4	millimeters	mm
Ft	feet	0.305	meters	m
Yd	yards	0.914	meters	m
Mi	miles	1.61	kilometers	km
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce	6.89	kilopascals	kPa

	per square inch			
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ACKNOWLEDGMENTS

This research was sponsored by the Toyota Collaborative Safety Research Center. We thank our collaborators at the CSRC who contributed significantly to this work, including Chuck Gulash, Megan Mackenzie, Jason Hallman, and Palani Palaniappan. Many people at UMTRI contributed to the success of this project, including Brian Eby, Charlie Bradley, Steven Thomas, and Stewart Simonett, who developed the mockups and fixtures. Laura Malik and Jamie Moore led the data collection, assisted by numerous student research assistants, including Alexis Baker, Olivia DeTroyer, Tiffany Fredrick, Mollie Pozolo, Rachel Palmer, Sarah Scholten, and Lindsay Youngren. These students were assisted in data processing and scan landmark extraction by Christian Calyore, David Hayashi, Danielle Hedden, Jordan MacDonald, Huibin Hu, Ryan Warner, and Mikhail Wise.

CONTENTS

EXECUTIVE SUMMARY

A laboratory study was conducted to quantify the posture, body shape, and safety belt fit of 200 adults with a wide range of age, stature, and body weight. Body and belt landmark data were gathered as participants sat in a driver mockup that was adjusted to represent nine vehicle packages spanning a large range of the vehicle fleet and in a mockup of a rear passenger seat. Whole-body surface shape data were gathered in 22 postures using a laser scanner. The data analysis showed significant effects of occupant attributes on posture and belt fit. Vehicle and seat variables had important effects on posture and position but did not have strong effects on belt fit relative to occupant attributes, particularly body mass index. Age had significant effects on both posture and belt fit, although the effect of age was smaller than the effect of body mass index across the ranges in the participant population.

INTRODUCTION

Vehicle occupant restraint systems, including seat belts, airbags, and knee bolsters, are optimized to provide protection for a wide range of occupants. However, most simulations and physical tests are conducted with adult occupant surrogates with a few sizes, namely midsize male, large male, and small female. These anthropomorphic test devices (ATDs), or crash test dummies, used for vehicle and restraint system testing are were constructed to represent approximately the 5th, 50th, and 95th-percentile values of stature and body weight for the U.S. population, but recent changes in body weight distribution in the U.S. mean that the midsize- and large-male ATDs are considerably lighter weight than the target population percentiles (Reed and Rupp 2013). For example, the reference body weight for the so-called "50th-percentile male" Hybrid-III ATD of 78.2 kg places it at approximately the 33rd percentile for U.S. adult men as of 2008, due to secular trends in body weight (Flegal et al. 2010).

The populations of the U.S., Japan, and many other countries are also "aging" at historically rapid rates, in the sense that the percentage of the population exceeding 60, 70, and 80 years is larger than at any previous time, and projected to continue to increase for decades. This trend poses challenges for occupant restraint design and vehicle safety more generally, because older occupants have a greater risk of injury than younger occupants in crashes (Glassbrenner and Starnes 2009, Kent et al. 2004, Ridella et al. 2012). An increased susceptibility to rib fractures accounts for much of the risk, but older occupants may also be at greater risk of abdominal injury than younger occupants (Yaguchi et al 2011, Frampton et al. 2012).

Previous UMTRI studies have led to widely used anthropometry and ergonomics guidelines for vehicle design and assessment. The Anthropometry of Motor Vehicle Occupants (AMVO) study, conducted in the 1980s, has been the standard for adult anthropometry for ATD development (Schneider et al. 1983). UMTRI driver posture and position studies conducted during the 1990s were used in the development of new SAE design standards (Manary et al. 1998; Flannagan et al. 1998). Related work has been used to develop ATD positioning procedures based on driver posture data (Manary et al. 1998; Reed et al. 2001). The Cascade Prediction Model, a set of statistical models based on driver posture data, has been widely used in the auto industry for predicting driving posture (Reed et al. 2000; Reed et al. 2001).

However, none of the previous work has specifically addressed whether age is associated with driving posture or belt fit, after accounting for body dimensions. For example, older drivers might sit more upright or closer to the steering wheel because of changes in body shape (e.g., thoracic kyphosis). The earlier driver posture and position studies were also conducted with relatively lean populations that did not reflect the effects of the increase in overweight and obesity. Finally, the laboratory studies on which the current SAE design tools and UMTRI ATD positioning procedures are not based on data from height-adjustable driver seats, although the results have been validated using data from vehicles with height-adjustable seats (Reed et al. 2001).

The current study was designed to determine the extent to which age, together with other occupant characteristics, including gender, stature, and body weight, affect driver and rear-seat passenger posture and belt fit. The study was conducted in a laboratory environment that allowed rapid presentation of a wide range of vehicle and belt geometry using methods similar to those employed in recent UMTRI studies. In addition, a whole-body laser scanner was used to obtain body shape data in a range of postures. Together, these data provide a detailed picture of how people with a wide range of characteristics sit in vehicles.

METHODS

Overview

The study protocol was approved by the University of Michigan Institutional Review Board (IRB) for Health Behavior and Health Sciences (IRB # HUM00054993). Participants were recruited through online advertisements, newspaper advertisements, flyers at senior centers and other facilities, and word of mouth. Written informed consent was obtained using a form approved by the IRB (Appendix A). The participant changed into test clothing and standard anthropometric measures were taken. Body landmark locations were recorded in a laboratory hardseat. Each participant was randomly assigned to either driver or passenger conditions. In the driver mockup, participants adjusted the seat to obtain a comfortable posture and donned the belt in 9 package configurations and 5 belt configurations. Posture and belt fit were recorded by digitizing landmark locations. Passenger trials were similar except that the participant made no adjustments and data were recorded with two foot positions. The body shape of each participant was measured in 22 postures using a whole-body laser scanner and specially constructed seating fixtures. Joint center locations were estimated using the surface landmarks. Surface landmark locations were extracted from surface scan data in software. Linear regression analysis was conducted to quantify the effects of vehicle, seat, and participant factors on posture and belt fit in the driver and passenger mockups. Custom software and methods were used fit a uniform template to the body scan data. A statistical shape model was developed that predicts body shape, surface landmarks, and joint center locations as a function of gender, stature, and body weight across a range of seated postures.

Standard Anthropometry

Table 1 lists standard anthropometric measures obtained from each participant. The methods (Appendix E) followed the ANSUR procedures (Gordon et al. 1989).

Table 1
Standard Anthropometric Dimensions

1	Weight	12	Maximum Hip Breadth
2	Stature (with shoes)	13	Buttock Knee Length
2.5	Stature (without shoes)	14	Buttock-Popliteal Length
3	Erect Sitting Height	15	Biacromial Breadth
4	Eye Height (Sitting)	16	Shoulder Breadth
5	Acromial Height (Sitting)	17	Chest Depth (on a scapula)
6	Knee Height	18	Chest Depth (on spine)
7	Tragion to Top of Head	19	Bispinous (BiASIS) Breadth
8	Head Length	20	Chest Circumference at Axilla
9	Head Breadth	21	Waist Circumference
10	Shoulder Elbow Length	22	Hip Circumference at Buttocks
11	Elbow-Hand Length	23	Upper Thigh Circumference

Driver Mockup

Figures 1 and 2 show the vehicle mockup used for testing. A steering wheel and instrument panel from a 2010 Toyota Corolla were modified for mounting in the laboratory and set up in the left-side drive configuration typical of U.S. vehicles. Accelerator and brake pedals were mounted to an adjustable arm attached to a moveable floor, so that the both the fore-aft and vertical relationship between the floor and the steering wheel could be changed to represent a wide range of vehicle configurations. The pedals were connected to springs so that pressing the pedals produced typical amounts of travel. A seat from a 2010 Toyota Highlander that provided adjustability for height, cushion angle, and seat back angle was installed on a rail system that provided additional fore-aft adjustability. Powered seat mechanisms provided 239 mm of continuous fore-aft adjustability along a track inclined 5 degrees from horizontal, 50 mm of vertical adjustability, and cushion angle adjustment from 11.5 to 17.5 degrees. As is typical of powered seats, cushion angle adjustment was constrained at the highest and lowest seat positions. Seat back angle was continuously adjustable and essentially unlimited (no participant hit the end of the range of travel). The head restraint was removed to provide better access to the participant for measurements.

A seat belt assembly with a sliding latchplate and retractor from the second row of a model year 2010 Toyota Sienna was mounted on customized fixtures designed to

permit adjustment of belt anchorage locations. A second-row belt was used to ensure sufficient webbing length for all package conditions. A rigid buckle stalk was attached to the seat with an adjustable fixture, as shown in Figure 2. The outboard lower anchorage was attached to the mockup, rather than to the seat, simulating a belt mounted to the vehicle body. The retractor and D-ring were mounted to a fixture allowing the D-ring location to be adjusted over a wide range. The belt webbing width was 45 mm.

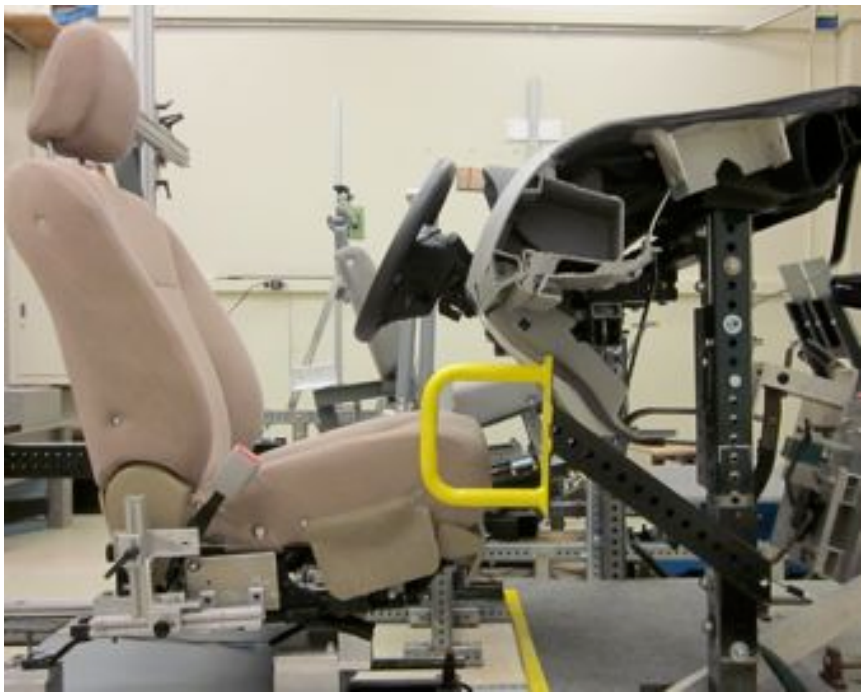


Figure 1. Driver mockup.

Figure 2. Additional images of driver mockup.

Testing was conducted in 9 package conditions (Figure 3) distinguished by values of steering wheel fore-aft position (SAE L6 or L11), steering wheel height above the heel surface (SAE H17), and seat height (SAE H30). The pedal plane angle was also changed according to SAE J1516 for each seat height. The steering wheel angle was varied at each seat height. Appendix F contains photos of all of the driver test conditions.

Table 2 lists the package conditions, labeled D1 through D9. Based on L6 and H30, the conditions span a large percentage of the U.S. passenger car and light truck vehicle fleet. Figure 4 shows the test conditions relative to 86 vehicles measured in previous UMTRI research.

Figure 5 shows the belt anchorage fixtures. The belt anchorage locations relative to seating reference point were the same for each condition, except that a total of five belt conditions were presented in package D5. Belt anchorage locations were characterized by a side-view lap belt angle measured according to FMVSS 210, except that the angle was measured on the vector from the anchorage to SgRP, rather than to a point forward of SgRP as specified in FMVSS 210 for moveable seats. This was done to preserve continuity with previous testing (Reed et al. 2012) conducted with a fixed-position seat as well as with the passenger conditions in the current study.

Table 2 lists the landmarks on the participant, belt, seat, and mockup that were recorded in each trial. The points include landmarks defining the position and orientation of the head, thorax, pelvis, upper extremities, and lower extremities. The recorded points on the belt allow the calculation of belt placement relative to the sternum, clavicle, and pelvis. The seat points are used to calculate driver-selected seat position (translated H-point location), seat cushion angle, and seat back angle. The points on the mockup are checked to verify that the test conditions were set as intended.

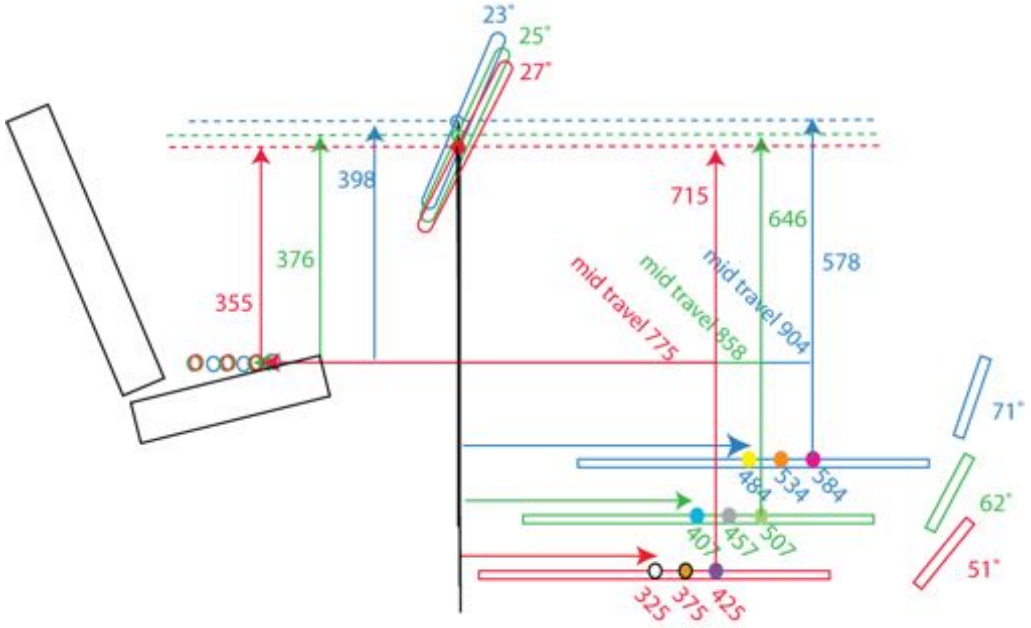


Figure 3. Illustration of package conditions in driver mockup (mm and deg). Steering wheel dimensions reference accelerator heel point. Not to scale. Accelerator pedal is displaced to the right for improved clarity.

Table 2
Driver Mockup Test Matrix

	H-point			Steering Wheel				Pedal	D-ring		Lower Anchorages	
		X re AHP		X					X			
	Z H30	Male	Female	L11	L6	Z (H17)	Ang.	Ang.	Fore-aft	Y & Z	Outboard	(buckle) Inboard
D1	180	902	755	584	650	578	23°	71°	mid	mid	52°	52°
D2*	180	882	735	534	600	578	23°	71°	mid	mid	52°	52°
D3	180	861	714	484	550	578	23°	71°	mid	mid	52°	52°
D4*	270	833	679	507	600	646	25°	62°	mid	mid	52°	52°
D5	270	813	658	457	550	646	25°	62°	mid	mid	52°	52°
D5	270	792	638	457	550	646	25°	62°	mid	mid	**30°**	**30°**
D5	270	759	630	457	550	646	25°	62°	mid	mid	**75°**	**75°**
D5	270	738	609	457	550	646	25°	62°	**EXT 1**	**EXT 1**	52°	52°
D5	270	718	589	457	550	646	25°	62°	**EXT 2**	**EXT 2**	52°	52°
D6*	270	902	755	407	500	646	25°	62°	mid	mid	52°	52°
D7	360	882	735	425	550	715	27°	51°	mid	mid	52°	52°
D8*	360	861	714	375	500	715	27°	51°	mid	mid	52°	52°
D9	360	833	679	325	450	715	27°	51°	mid	mid	52°	52°

*Conditions dropped in shorter matrix; units in mm unless noted

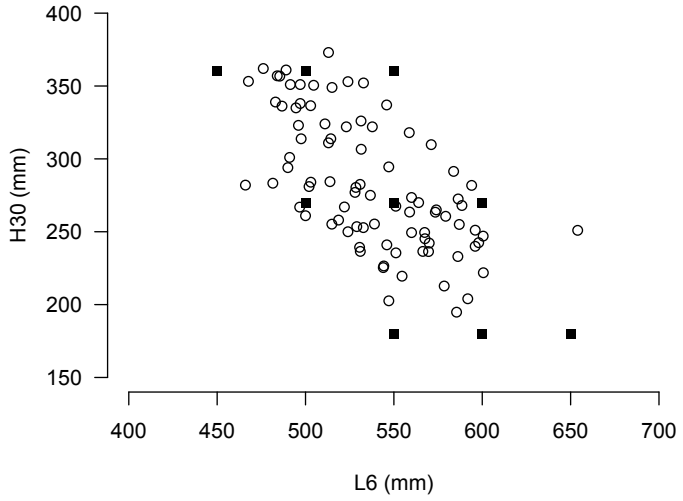


Figure 5. Driver packages used in the current study (filled squares) relative to 86 vehicles measured at UMTRI in recent research.

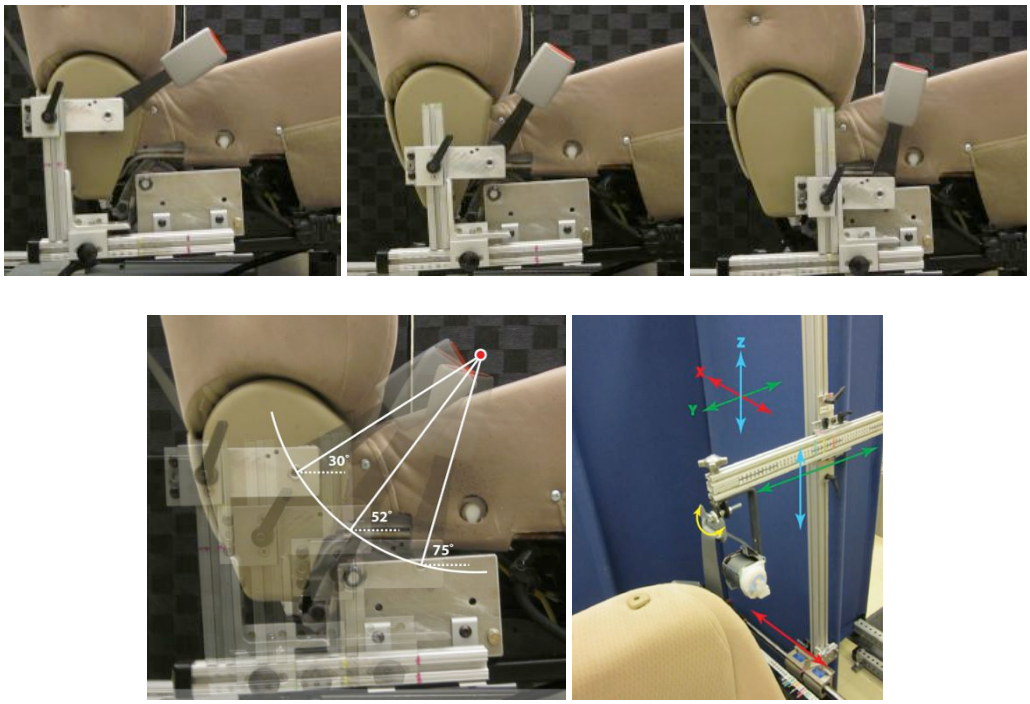


Figure 5. Belt anchorage fixtures.

Table 3
Driver Mockup Point List

C7 (Cervicale)	Accelerator Pedal
Back Of Head Max Rearward	Floor
Top Of Head Max Height	Origin
Tragion Lt [Near side]	Platform
Corner Eye Lt (Ectoorbitale)	Outboard_LA*
Center Eye Lt (Infraorbitale at Pupil Center)	Seat Cushion Fore
Glabella	Seat Cushion Aft
Suprasternale*	Seat Cushion Low
Substernale*	Seat Back Bottom
Medial Clavicle Lt*	Seat Back Top
Lateral Clavicle Lt*	D-ring*
Acromion Lt (Anterior)*	Steering Wheel Center
Elbow Lt (Lateral Humeral Epicondyle)	
Wrist Lt (Ulnar Styloid Process, Lateral)	Seat Cushion Fore (Pre)
ASIS Rt*	Seat Cushion Aft (Pre)
ASIS Lt*	Seat Cushion Low (Pre)
Suprapatella Lt	Seat Back Bottom (Pre)
Infrapatella Lt	Seat Back Top (Pre)
Knee Lt (Lateral Femoral Epicondyle)	Origin
Toe Lt (Bottom edge of sole, longest shoe pt)	TB Clavicle Outboard*
Ball of Foot Lateral Lt	TB Clavicle Inboard*
Ankle Lt (Lateral Malleolus)	TB Midline Top*
Heel Lt (Bottom edge of sole at midline)	TB Midline Bottom*
Suprapatella Rt	TB at Suprasternale Height*
Infrapatella Rt	LB Top ASIS Rt*
Knee Rt (Medial Femoral Epicondyle)	LB Bot ASIS Rt*
Ball of Foot Medial Rt	LB Top ASIS Lt*
Ankle Rt (Medial Malleolus)	LB Bot ASIS Lt*
Heel Rt (Bottom edge of sole at midline)	Stream Belts: Torso and Lap Belt*

*Points repeated in belt matrix (driver condition D5)

Passenger Mockup

Figure 6 shows the passenger mockup. The seat height and seat back angle could be adjusted by the experimenters to achieve the test conditions listed in Table 4. Seven package conditions were obtained using the same three seat heights (SAE H30) used in the driver mockup (180, 270, and 360 mm). The back angle (SAE A40) was set to 19, 23, or 27 degrees. A midrange belt configuration was used for all conditions except that five belt conditions similar to those used in the driver mockup were presented in the mid-range package condition (P4). In each condition, data on lower extremity postures were gathered with the participant's heels positioned three ways: forward (resting on the heels), resting with the soles flat on the floor

and the legs vertical, and pulled back as far as possible, simulating a short-coupled vehicle.

Table 5 lists the points gathered in each test condition. Figure 7 shows an investigator palpating the location of a participant's right anterior-superior iliac spine (ASIS) landmark location prior to measurement with the FARO Arm coordinate digitizer. Figure 8 illustrates the three foot positions.

Figure 6. Passenger mockup.

Table 4
Passenger Mockup Testing Matrix

	Seat		D-ring		Lower Anchorages		
	Back Angle	H-point Re Floor (H30) mm	X Fore-aft	Y & Z	Outboard	(buckle) Inboard	Feet
P1	19°	270	mid	mid	52°	52°	Heels
P1	19°	270	mid	mid	52°	52°	Flat
P1	19°	270	mid	mid	52°	52°	Back
P2*	19°	360	mid	mid	52°	52°	Heels
P2*	19°	360	mid	mid	52°	52°	Flat
P2*	19°	360	mid	mid	52°	52°	Back
P3	23°	180	mid	mid	52°	52°	Heels
P3	23°	180	mid	mid	52°	52°	Flat
P3	23°	180	mid	mid	52°	52°	Back
P4	23°	270	mid	mid	52°	52°	Heels
P4	23°	270	mid	mid	52°	52°	Flat
P4	23°	270	mid	mid	52°	52°	Back
P4	23°	270	mid	mid	**30°**	**30°**	Flat
P4	23°	270	mid	mid	**75°**	**75°**	Flat
P4	23°	270	**EXT 1**	**EXT 1**	52°	52°	Flat
P4	23°	270	**EXT 2**	**EXT 2**	52°	52°	Flat
P5	23°	360	mid	mid	52°	52°	Heels
P5	23°	360	mid	mid	52°	52°	Flat
P5	23°	360	mid	mid	52°	52°	Back
P6	27°	270	mid	mid	52°	52°	Heels
P6	27°	270	mid	mid	52°	52°	Flat
P6	27°	270	mid	mid	52°	52°	Back
P7*	27°	180	mid	mid	52°	52°	Heels
P7*	27°	180	mid	mid	52°	52°	Flat
P7*	27°	180	mid	mid	52°	52°	Back

* Conditions dropped in short matrix

Table 5
Passenger Mockup Point List

Dring*	Platform
Outboard LA*	Origin
Inboard LA*	Seat Cushion Fore
C7 (Cervicale)	Seat Cushion Aft
Back Of Head Max Rearward	Seat Back Bottom
Top Of Head Max Height	Seat Back Top
Tragion Rt (Near side)	Floor
Corner Eye Rt (Ectoorbitale)	Origin
Center Eye Rt (Infraorbitale at Pupil Center)	TB Clavicle Outboard*
Glabella	TB Clavicle Inboard*
Lateral Clavicle Lt*	TB Midline Top*
Medial Clavicle Lt*	TB Midline Bottom*
Suprasternale*	TB at Suprasternale Height*
Substernale*	LB Top ASIS Rt*†
Medial Clavicle Rt	LB Bot ASIS Rt*†
Lateral Clavicle Rt	LB Top ASIS Lt*†
Acromion Rt (Anterior)*	LB Bot ASIS Lt*†
Elbow Rt (Lateral Humeral Epicondyle)	Streams (in belt matrix)
Wrist Rt (Ulnar Styloid Process, Lateral)	
ASIS Rt†	
ASIS Lt†	
Suprapatella Lt†	
Infrapatella Lt†	
Knee Lt (Medial Femoral Epicondyle)†	
Suprapatella Rt†	
Infrapatella Rt†	
Knee Rt (Lateral Femoral Epicondyle)†	
Toe Rt (Bottom edge of sole, longest shoe pt)†	
Ball of Foot Lateral Rt†	
Ankle Rt (Lateral Malleolus)†	
Heel Rt (Bottom edge of sole at midline)†	

* Points repeated in belt matrix (passenger condition P4)
† Points repeated in different leg positions

Figure 7. Recording a participant's anterior-superior iliac spine landmark location.

Figure 8. Illustration of the three foot positions used in the passenger mockup: feet back, flat, and on heels.

Laboratory Hardseat

Body landmark locations were recorded in the laboratory hardseat shown in Figure 9. The hardseat allows access to posterior spine and pelvis landmarks that are inaccessible in an automotive seat. The hardseat has a 14.5-degree "cushion" (pan) angle and a 23-degree back angle designed to produce postures similar to those in an automotive seat. Postures were recorded using the two configurations of the hardseat shown in Figure 9. In one, foam wedges were used to induce a more-slouched posture. Table 6 lists the landmarks recorded in the hardseat.

Figure 9. Hardseat for postures 1 (left) and 2 (right).

Table 6
Hardseat Point List

Origin
Platform Tilt Table
Back if Head
Top Of Head (Vertex)
Head1 Marker
Tragion Rt
Corner Eye Rt (Ectoorbitale)
Center Eye Rt (Infraorbitale at Pupil Center)
Glabella
Head3 Marker
Center Eye Lt (Infraorbitale at Pupil Center)
Corner Eye Lt (Ectoorbitale)
Tragion Lt
Head2 Marker
Medial Clavicle Lt
Lateral Clavicle Lt
Acromion Lt (Anterior)
Acromion Lt Marker
Lateral Elbow Lt (Lat Humeral Epicondyle)
Lateral Elbow Lt Marker
Medial Elbow Lt (Med Humeral Epicondyle)
Medial Elbow Lt Marker
Lateral Wrist Lt (Ulnar Styloid Process)
Medial Wrist Lt (Radial Styloid Process)
Wrist Mid Top Lt Marker
Wrist Mid Bot Lt Marker
Lateral Hand Lt
Medial Hand Lt
C7 (Cervicale)
Suprasternale
Chest Top Marker
Substernale
Chest Bot Marker
Medial Clavicle Rt
Lateral Clavicle Rt
Acromion Rt (Anterior)
Acromion Rt Marker

Lateral Elbow Rt (Lat Humeral Epicondyle)
Lateral Elbow Rt Marker
Medial Elbow Rt (Med Humeral Epicondyle)
Medial Elbow Rt Marker
Lateral Wrist Rt (Ulnar Styloid Process)
Medial Wrist Rt (Radial Styloid Process)
Wrist Mid Top Rt Marker
Wrist Mid Bot Rt Marker
Lateral Hand Rt
Medial Hand Rt
ASIS Rt
ASIS Lt
Lateral Femoral Epicondyle Rt*
Lateral Femoral Epicondyle Rt Marker*
Lateral Fibular Head Rt
Medial Femoral Epicondyle Rt*
Medial Femoral Epicondyle Rt Marker*
Medial Tibial Condyle Rt
Suprapatella Rt*
Infrapatella Rt*
Heel Rt
Lateral Ankle Rt (Lat Malleolus)
Lateral Ankle Rt Marker
Ball of Foot Lateral Rt
Toe Rt (Longest Tibiale)
Ball of Foot Medial Rt
Medial Ankle Rt (Med Malleolus)
Medial Ankle Rt Marker
Lateral Femoral Epicondyle Lt*
Lateral Femoral Epicondyle Lt Marker*
Lateral Fibular Head Lt
Medial Femoral Epicondyle Lt*
Medial Femoral Epicondyle Lt Marker*
Medial Tibial Condyle Lt
Suprapatella Lt*
Infrapatella Lt*

Heel Lt
Lateral Ankle Lt (Lat Malleolus)
Lateral Ankle Lt Marker
Ball of Foot Lateral Lt
Toe Lt (Longest Tibiale)
Ball of Foot Medial Lt
Medial Ankle Lt (Med Malleolus)
Medial Ankle Lt Marker
Rib10 Lt Marker
Lateral Torso Ctr Lt Marker
Hip Top Lt Marker
Torso Mid Top Marker
Torso Mid Ctr Marker
Torso Mid Bot Marker
Rib10 Rt Marker
Lateral Torso Ctr Rt Marker
Hip Top Rt Marker
Suprasternale
Substernale
C7
C7 Marker
T4
T4 Marker
T8
T8 Marker
T12
T12 Marker
L1
L1 Marker
L2
L2 Marker
L3
L3 Marker
L4
L4 Marker
L5
L5 Marker
ASIS Rt*
ASIS Lt*
PSIS Rt*
PSIS Lt*

*Points repeated in posture 2

Whole-Body Scanning

Body surface contours were recorded using a VITUS XXL whole-body surface scanner and ScanWorX software (Human Solutions). The scanner, shown in Figure 10, uses red-light, eye-safe lasers mounted on four towers arranged in a square to project a horizontal line on the subject. Cameras mounted above and

below the lasers in each tower record images of the laser line as the heads travel synchronously from top to bottom. Scanning the entire volume requires 12 seconds. The ScanWorX software converts the camera images to range data and then to 3D coordinate data. Approximately 500000 surface data points are recorded with each scan. The system records grayscale information for each datapoint, enabling visual identification of surface features. This capability was exploited by placing optical markers on body landmarks of interest to enable their 3D locations to be obtained during scan data processing.

Figure 11 shows the process of palpating a landmark and applying a mark. The marks were created by a non-toxic, square ink stamp into which was placed a high-contrast white paint dot. This combination was developed to provide good contrast on a wide range of skin tones. A particular corner of the marker was defined as the location to be picked in the scan data. Figure 12 shows the marker locations on a standing scan, and Table 7 gives a description of each marker. Appendix D provides complete detail on the marker definitions and locations.

Figure 10. VITUS XXL scanner in UMTRI laboratory.

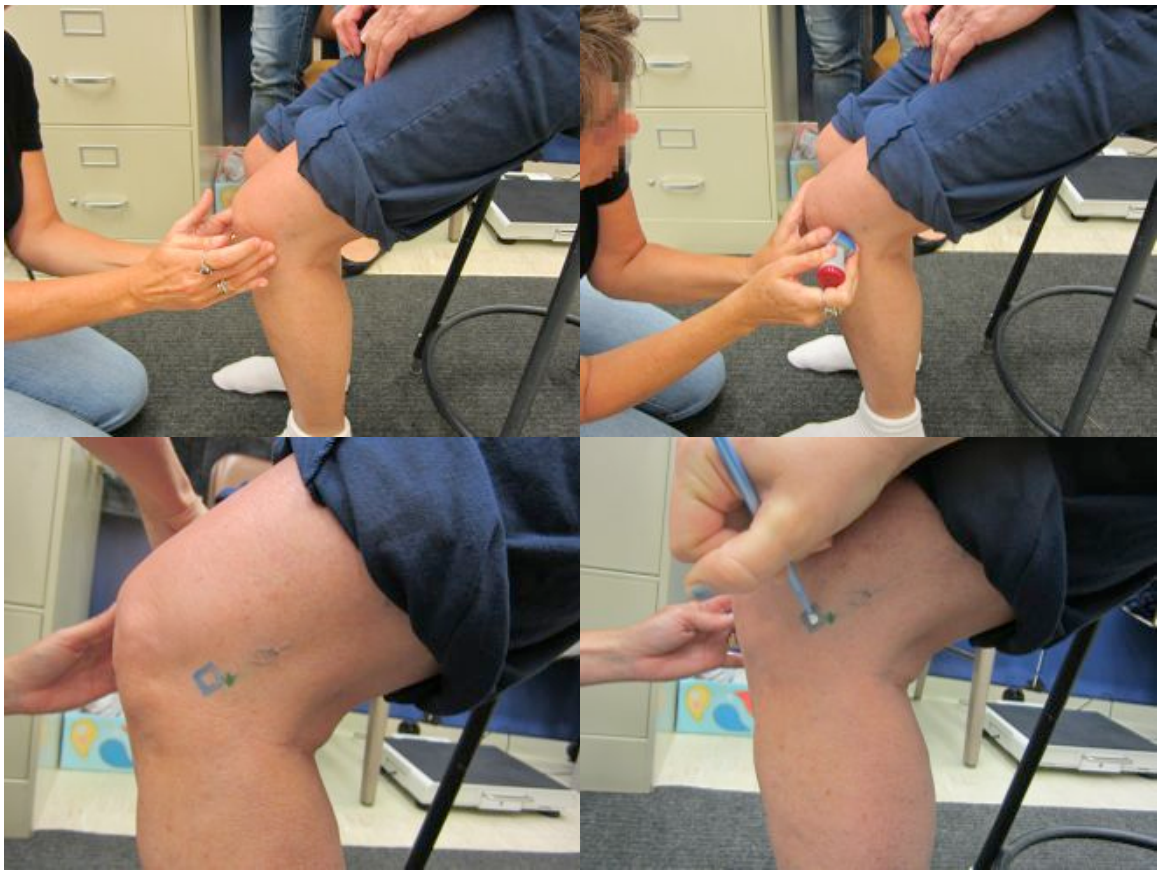


Figure 11. Illustrations of the process of palpating a landmark (upper left), stamping (upper right), marking the corner to digitized (lower left), and marking the contrasting center (lower right).

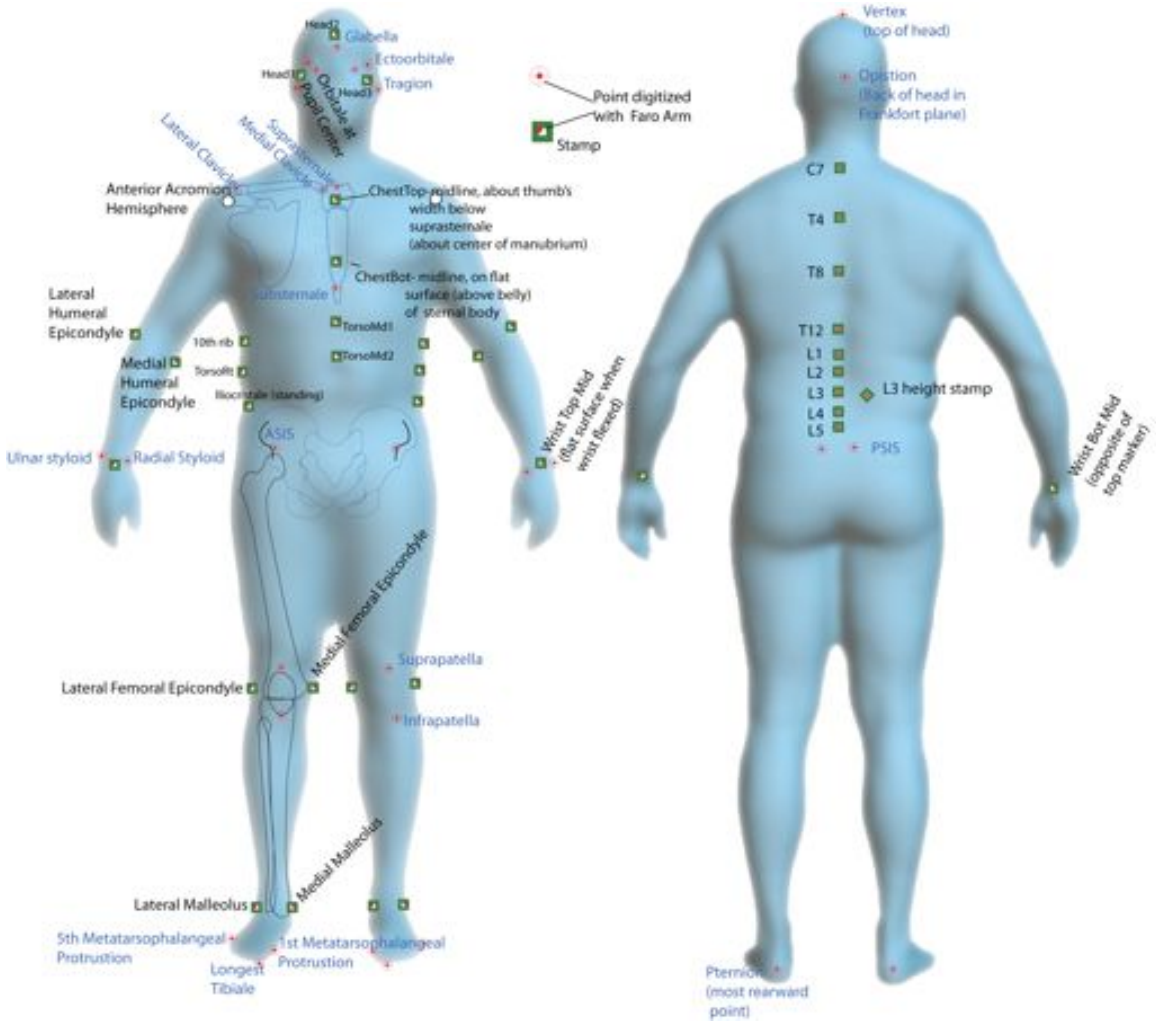


Figure 12. Scanning markers

Table 7
Marker Descriptions

Point Name	Body Part	Additional Description	Point to Digitize
Head3_M	Head	About 1" above glabella, on skin that doesn't move when raising eye brows, not covered by swim cap	Superior, Subject's Left
Head2_M	Head	On or above left cheek bone about 1" anterior to tragion	Superior-Posterior
Head1_M	Head	On or above right cheek bone about 1" anterior to tragion	Superior-Posterior
AcromionLt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere
AcromionRt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere
ElbowMedLt_M	Arm	Medial epicondyle (mark with elbow bent 45°)	Proximal, extensor surface
ElbowMedRt_M	Arm	Medial humeral epicondyle (mark with elbow bent 45°)	Proximal, extensor surface
ElbowLatLt_M	Arm	Lateral epicondyle (mark with elbow bent 45°)	Proximal, extensor surface
ElbowLatRt_M	Arm	Lateral humeral epicondyle (mark with elbow bent 45°)	Proximal, extensor surface
WristMidTopLt_M	Arm	On the back of the wrist slightly proximal to the cross section plane of the ulnar styloid.	Proximal, nearest Ulnar Styloid
WristMidTopRt_M	Arm	On the back of the wrist slightly proximal to the cross section plane of the ulnar styloid.	Proximal, nearest Ulnar Styloid
WristBotTopLt_M	Arm	On the palm side of the wrist opposite the wrist mid marker	Proximal, nearest Ulnar Styloid
WristBotTopRt_M	Arm	On the palm side of the wrist opposite the wrist mid marker	Proximal, nearest Ulnar Styloid
SpineC07_M	Torso	Spinous process of the 7th cervical vertebra (cervicale)	Center
SpineT04_M	Torso	Spinous process of 4th thoracic vertebra	Center
SpineT08_M	Torso	Spinous process of 8th thoracic vertebra	Center
SpineT12_M	Torso	Spinous process of 12th thoracic vertebra	Center
SpineL01_M	Torso	Spinous process of 1st lumbar vertebra	Center
SpineL02_M	Torso	Spinous process of 2nd lumbar vertebra	Center
SpineL03_M	Torso	Spinous process of 3rd lumbar vertebra	Center
SpineL04_M	Torso	Spinous process of 4^{d} lumbar vertebra	Center
SpineL05_M	Torso	Spinous process of 5th lumbar vertebra	Center
10RibLt_M	Torso	Most lateral point on the 10th rib	Superior-Posterior
10RibRt_M	Torso	Most lateral point on the 10th rib	Superior-Posterior
L3Position_M	Torso		
IlioRt_M	Torso	Iliocristale (most superior lateral point on pelvis when standing	Superior-Posterior
IlioLt_M	Torso	Iliocristale (most superior lateral point on pelvis when standing	Superior-Posterior
ChestUpper_M	Torso	Body midline, about one thumb's width down from suprasternale, (or about mid-manubrium)	Superior, Subject's Left
ChestLower_M	Torso	Body midline, first flat, boney surface on sternum body above belly	Superior, Subject's Left
TorsoLt_M	Torso	Midpoint between 10th rib and iliocristale point	Superior-Posterior
TorsoRt_M	Torso	Midpoint between 10th rib and iliocristale point	Superior-Posterior
TorsoMid1_M	Torso	Between TorsoMid2 and substernale	Superior, Subject's Left
TorsoMid2_M	Torso	Above umbilicus	Superior, Subject's Left

KneeFemMedLt_M	Leg	Femoral epicondyle, medial	Proximal, flexor surface
KneeFemMedRt_M	Leg	Femoral epicondyle, medial	Proximal, flexor surface
KneeFemLatLt_M	Leg	Femoral epicondyle, lateral	Proximal, flexor surface
KneeFemLatRt_M	Leg	Femoral epicondyle, lateral	Proximal, flexor surface
AnkleMedLt_M	Leg	Malleolus, medial	Proximal, plantar flexion surface side
AnkleMedRt_M	Leg	Malleolus, medial	Proximal, plantar flexion surface side
AnkleLatLt_M	Leg	Malleolus, lateral	Proximal, plantar flexion surface side
AnkleLatRt_M	Leg	Malleolus, lateral	Proximal, plantar flexion surface side

Participants were scanned in the 22 postures listed in Tables 8 and 9. The postures were chosen from among many considered to capture the range of body shapes expected in automotive seating situations as well as to characterize the overall body shape in ways that could be compared to other datasets. Four standing postures (Figure 13) were included to provide a linkage to previous studies, to facilitate the construction of ergonomic manikins, and for application to pedestrian modeling. Figures 14 through 18 illustrate the seated postures. The most important scans are four sagittally symmetric, supported seated postures (R1, R2, R3, and automotive). R1, R2, and R3 are obtained with a range of recline angles. The automotive posture also includes elevated thighs and extended knees. Due to limitations of the scanning volume, the automotive posture was recorded in multiple segments. After the first scan was completed, the participant was moved rearward to enable the lower legs and feet to be captured with a second scan. Finally, a hand-held laser scanner on a FARO Arm was used to record the surface in the lap area, which was shadowed from the primary scanner in this posture. Two unsupported sitting postures (L1 and L2) were included for reference to other studies and to provide an unobstructed back contour. Six postures with unsupported torso (V1 through V6) demonstrate how torso shape changes with spine flexion and axial rotation. Five postures (A1 through A5) with a range of shoulder flexion and abduction were used to capture the effects of upper-extremity posture. Further details and illustrations of the scan postures are found in Appendix C.

Table 8
Scanning Postures

Posture	Code	Seat Pan	Seat Back	Hips	Lower Limbs	Spine	Shoulders	Hand Scan
Standing Natural	T1	NA			15 cm	Natural	Natural	
Standing Abduction	T2	NA				Natural	Abduction 40°	
Standing Erect	T3	NA				Erect	Abduction 40°	
Standing T-pose	T4	NA			45 cm	Natural	Abduction 90˚	
Automotive	C1	Wedges (14.5˚)	pads		Driving	Natural	Abduction 90˚	Yes
Recline U (Upright)	RU	Wedges (14.5˚)	L1	Nat-ural	Knees 90˚	Erect	Handles*	
Recline 1 (min)	R1		L2			Slump1		Yes
Recline 2 (mid)	R2		L3			Slump2		Yes
Recline 3 (max)	R3		L4			Slump3		Yes
Sitting Lap	L1	0˚	bar	75°	Legs and feet symmetrical with **thighs parallel**, ankles under the knees, and feet parallel	Erect	Handle	
Spine Flexion Min/Nat	V1	0˚	bar	75°		Natural	Handle	
Spine Flexion Max	V2	0˚	bar	75°		Max Flexion	Handle, lower	
Spine Flexion Mid	V3	0˚	bar	75°		Mid Flexion	Handle, lower	
Spine Extension Max	V4	0˚	bar	75°		Ext max	Handle	
Spine Rotation Right	V5	0˚	bar	75°		Rotated	Arms Up	
Spine Rotation Left	V6	0˚	bar	75°		Rotated	Arms Up	
Arm Flexion 90˚	A1	0˚	bar	75°		Erect	Flexion 90°	
Arm Flexion Max	A2	0˚	bar	75°		Erect	Max Flexion	
Arm Abduction 90˚	A3	0˚	bar	75°		Erect	Abduction 90°	
Arm Abduction Max	A4	0˚	bar	75°		Erect	Max Abduct	
Arm Extension Max	A5	0˚	bar	75°		Erect	Max Extension	
Sitting ISO	L2	0˚	bar	90°		Erect	Elbow 90˚	Yes

*Handles = Palm at height of suprasternale, shoulders as if arms were hanging at sides with elbows 45˚ out from body in coronal view and the shoulder-elbow-wrist angle at 120˚

Table 9
Scanning Postures Overview

Posture	Purpose and Description
Standing Natural	Natural, yet symmetrical, standing posture to get a good scan of arms hanging at sides
Standing Abduction	Similar to StandingNatrl but with arms abducted 30˚ to get a good scan of torso
Standing Erect	Similar to StandingArmAb but with spine erect
Standing T-pose	T-pose and legs wide used to get under arm and between leg surfaces
Automotive	Posture in vehicle with back angle =23˚, cushion angle =14.5˚, H30=270 mm
Recline U (Upright) Recline 1 (min) Recline 2 (mid) Recline 3 (max)	A series of postures in which the subject goes from a very erect posture to a very slumped posture, while keeping the knee angle constant. The seat is set with a 23˚ back angle and 14.5˚ cushion angle. The seatback moves rearward to increase the slump of the spine. The hips stay forward on the seat so that the bottoms of the thighs and backs of the calves are scanned well. Seat surface should not cut into the back of the thighs. The arms are forward so that the sides of the torso scan well – but the shoulders are still in a resting position (as if arms were hanging by the side of the subject). Elbows and shoulders are relaxed with the subject's hands on the handles supporting the weight of their arms.
Sitting Lap	An erect posture on a level seat in which the tops of the thighs are visible in the full body scanner
Spine Flexion Min/Nat Spine Flexion Max Spine Flexion Mid	A series of postures in which the entire spine goes from natural sitting to maximum flexion. In SpineMx the chin is on the chest.
Spine Extension Max	Maximum extension of the entire spine (as can be safely done)
Spine Rotation Rt. Max	Rotation of cervical, thoracic and lumbar spine to the right
Spine Rotation Lt. Max	Rotation of cervical, thoracic and lumbar spine to the left
Arm Flexion 90˚ Arm Flexion Max Arm Abduction 90˚ Arm Abduction Max Arm Extension Max	A series of arm positions used to create surfaces of the shoulder, neck and torso
Sitting ISO	A posture from the ISO standard for scanning

Figure 13. Participant in four standing postures.

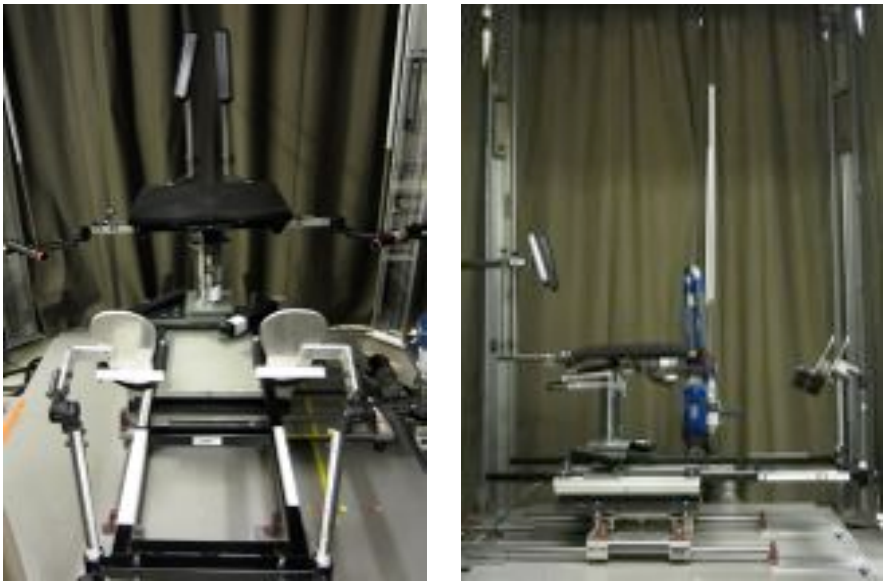


Figure 14. Fixtures in scanner for driver posture

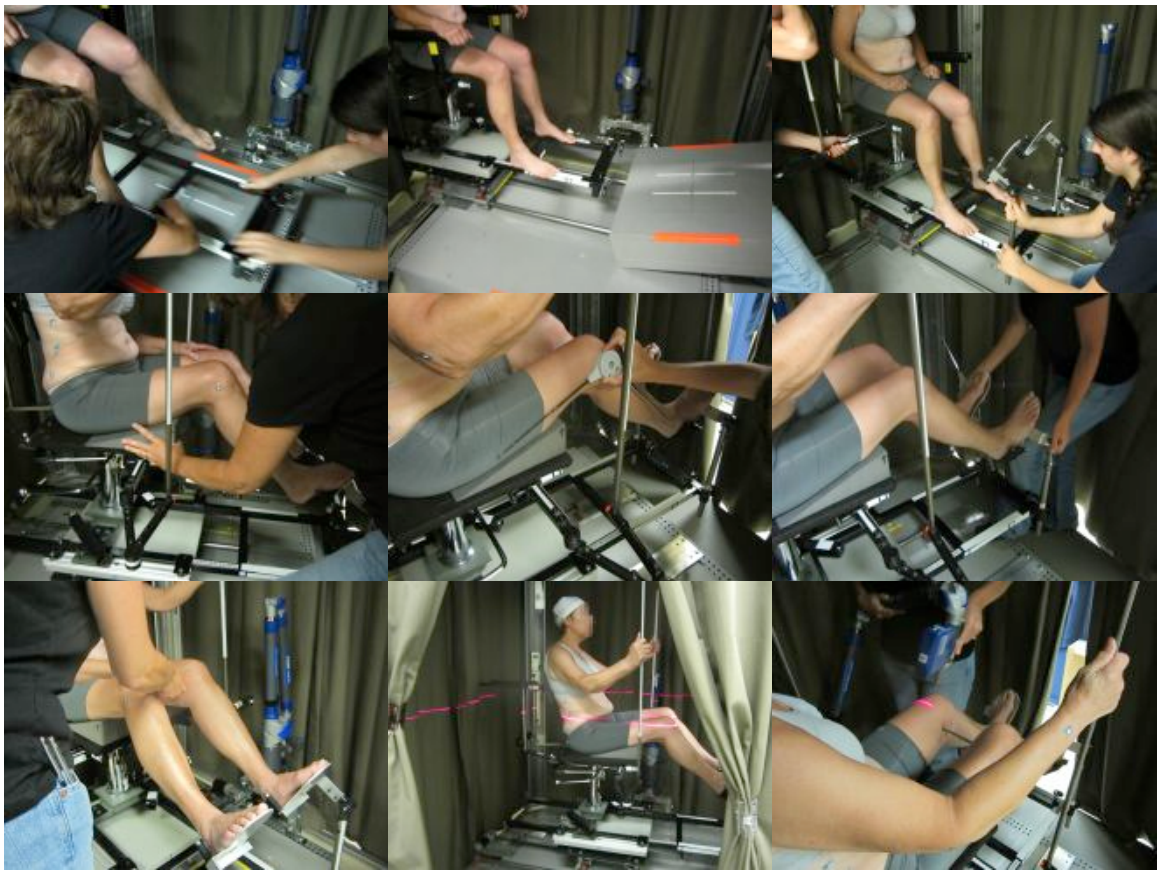


Figure 15. Steps in setting up and scanning the automotive posture (from upper left to lower right).

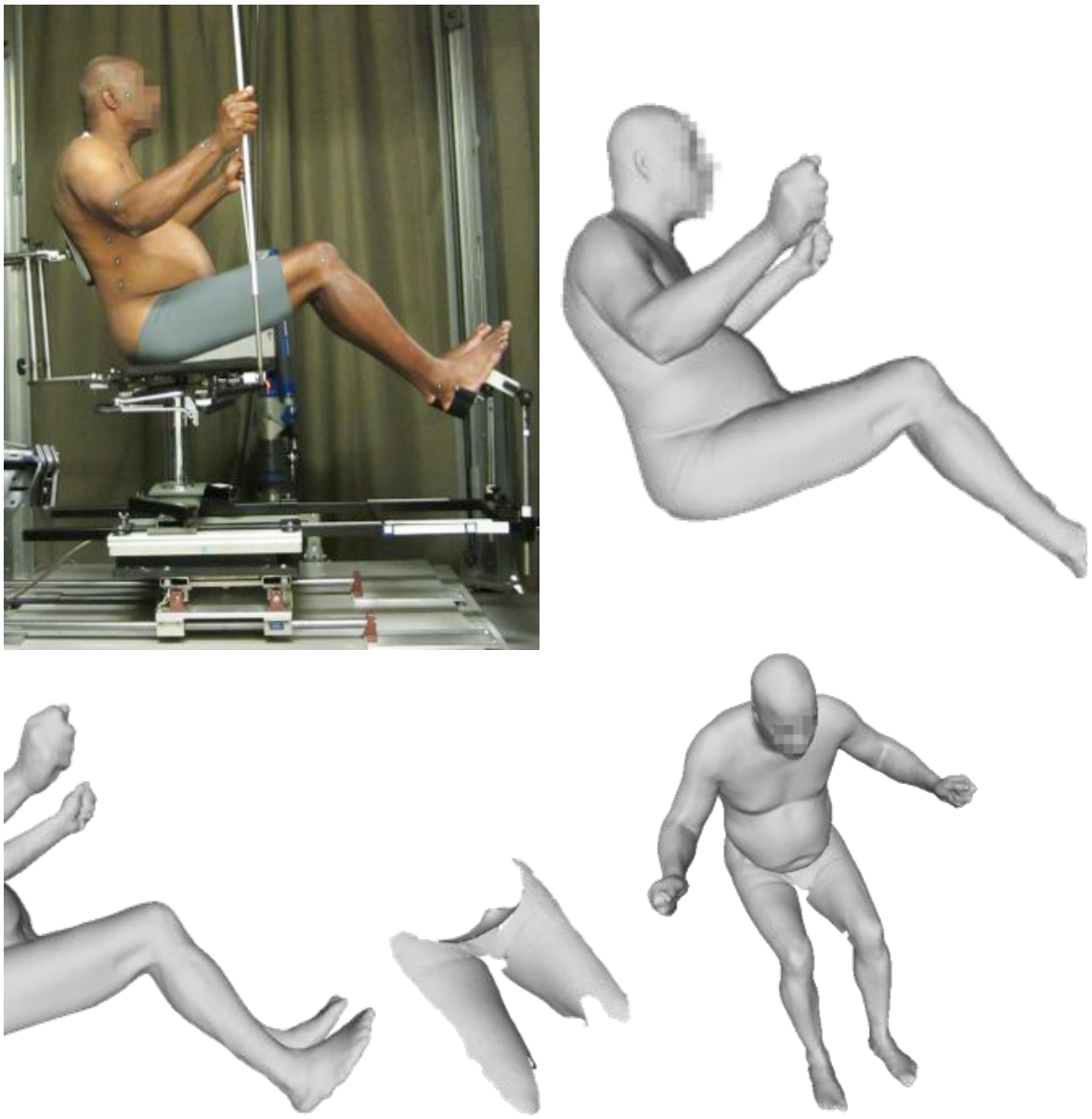


Figure 16. Illustration of the components of the automotive posture brought together into a single surface model.

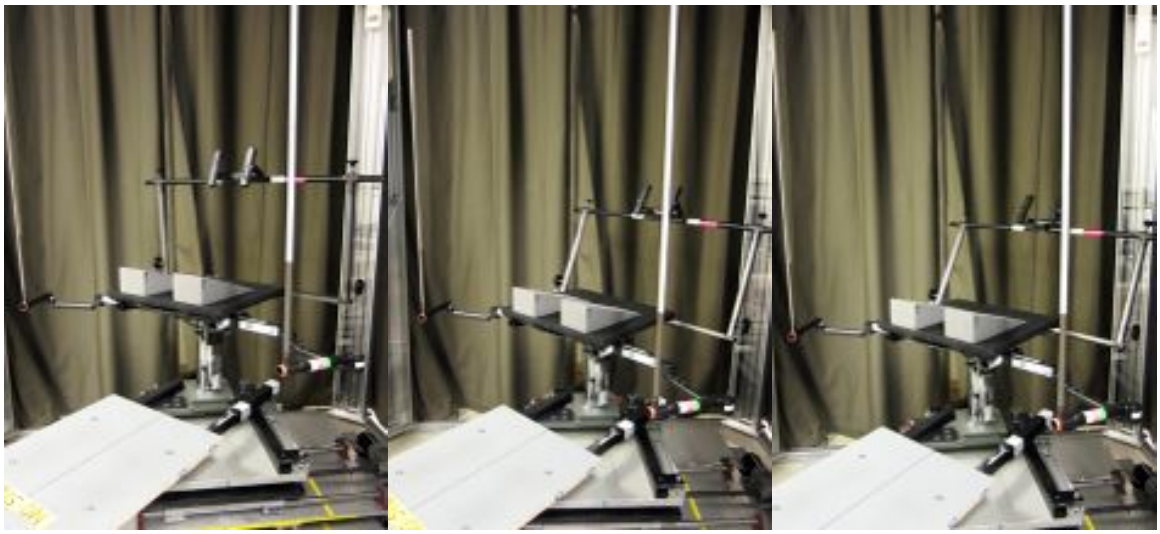


Figure 17. Scanner fixtures for supported sitting postures (R1, R2, R3).

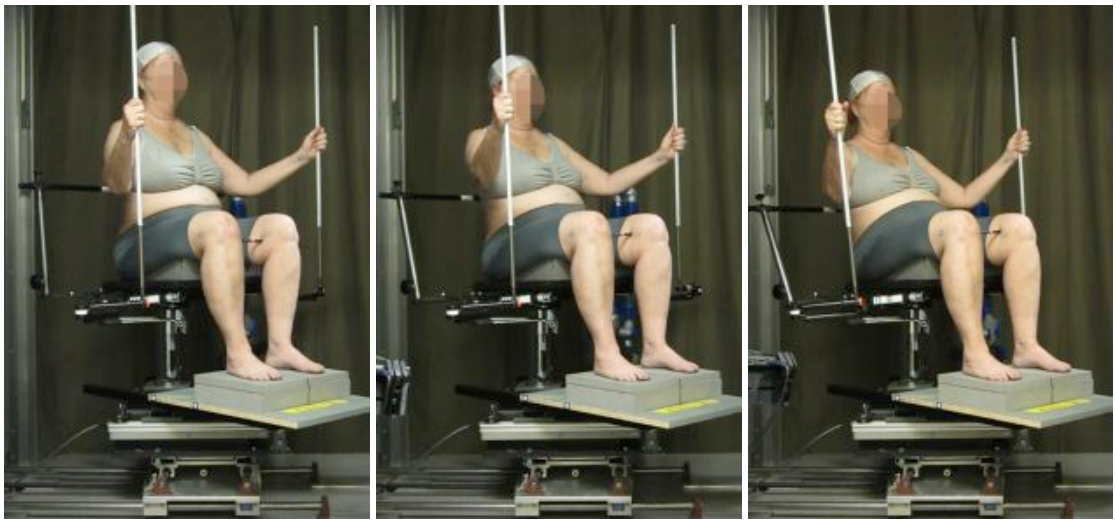


Figure 18. Photos of a participant in supported sitting postures (R1, R2, R3).

Following data collection, an extensive processing and data collection effort was necessary to obtain high-quality scan and landmark data for further analysis. In brief, the scans were manually cleaned in ScanWorX to remove light artifacts and to delete the props and fixtures. Multiple scans from the same posture were merged in Geomagic Studio software. Research assistants used Meshlab software to extract landmark locations. Figure 19 shows screenshots of the landmarks extracted in Meshlab for a representative standing scan. The complete list of landmarks is found in Appendix D.

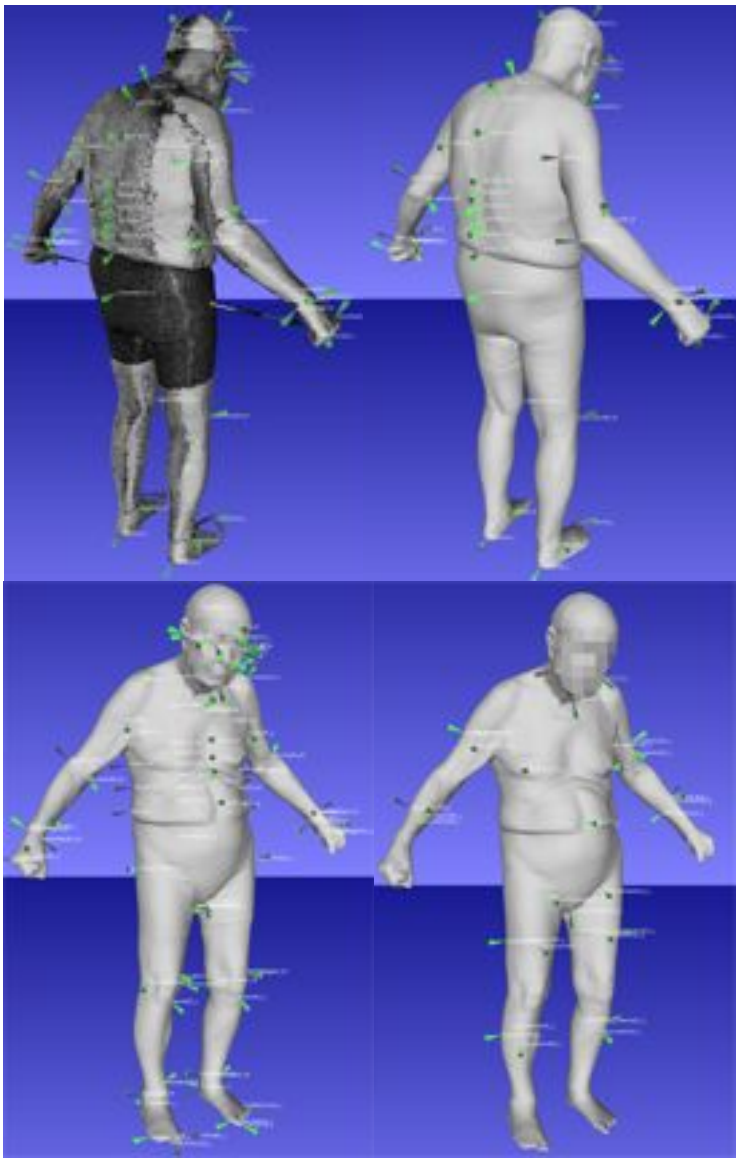


Figure 19. Screenshots from Meshlab showing landmarks extracted from a standing scan in grayscale and surface modes.

Dependent Measures: Posture

The posture analysis followed the methods described in Reed et al. (2002) to develop a Cascade prediction model (CPM). The CPM prioritizes the dependent measures that are most important for vehicle layout and seat design, while other posture variables are "cascaded", i.e., predicted from the first set or via inverse kinematics. Hip location (HipX, HipZ), the mean of the right and left hip joint centers, is predicted with respect to seat H-point. For driver conditions, the reference is the translated (i.e., driver-selected) H-point location. Eye locations (EyeX, EyeZ) are also predicted with respect to H-point locations. Driver-selected H-point location (i.e., seat position) is predicted with respect

to accelerator heel point (AHP). Torso posture is characterized by the angles of kinematic segments with respect to vertical. Head angle is calculated as the orientation of the Frankfurt plane with respect to horizontal, with positive values associated with rearward head rotation (eyes higher than ears).

Table 10
Posture Dependent Measures (mm, deg)

HipX	Side-view fore-aft location of mean hip joint center with respect to seat H-point	
HipZ	Side-view vertical location of mean hip joint center with respect to seat H-point	
EyeX	Side-view fore-aft location of the eye center* with respect to seat H-point	
EyeZ	Side-view vertical location of the eye center* with respect to seat H-point	
HPtX (driver only)	Fore-aft location of driver-selected H-point (seat position) with respect to accelerator heel point (AHP)	
HPtZ (driver only)	Vertical location of driver-selected H-point (seat position) with respect to accelerator heel point (AHP)	
PelvisSegmentAngle	Angle in side view with respect to vertical of vector from mean hip joint center to L5/S1 joint, positive rearward of vertical.	
LumbarSegmentAngle	Angle in side view with respect to vertical of vector from L5/S1 joint to T12/L1 joint, positive rearward of vertical	
ThoraxSegmentAngle	Angle in side view with respect to vertical of vector from T12/L1 to C7/T1 joint, positive rearward of vertical	
NeckSegmentAngle	Angle in side view with respect to vertical of vector from C7/T1 to AO joint, positive rearward of vertical	
HeadAngle	Angle in side view with respect to horizontal of vector from mean tragion to mean infraorbitale, positive with infraorbitale above tragion; equivalent to Frankfurt plane angle with respect to horizontal	

* Eye center is estimated at the vertical location of the corner-eye landmark (ectocanthus) and fore-aft location of infraorbitale.

Dependent Measures: Belt Fit

Following methods used in a previous belt fit study (Reed et al. 2012), lap belt fit was quantified by the fore-aft and vertical location of the upper/rearward margin of the lap

portion of the belt at the lateral location of the anterior-superior iliac spine (ASIS) landmarks on the left and right sides of the pelvis (Figure 5). Shoulder belt fit was quantified by the lateral location of the inboard edge of the shoulder portion of the belt relative to the body midline at the height of the suprasternale landmarks (Figure 6). A fourth-order Bézier curve was fit to the lap and shoulder belt stream points to smooth measurement error and the length of the resulting curves were calculated.

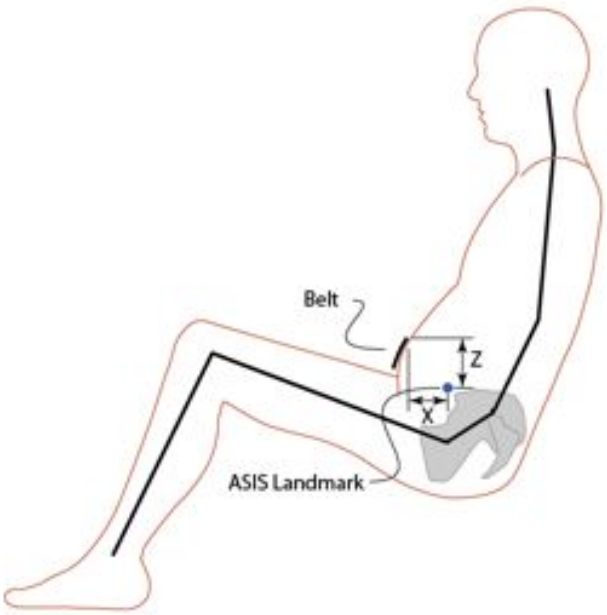


Figure 20. Dependent measures for lap belt fit. The upper/rearward edge of the lap portion of the belt is measured at the lateral position of the right and left anterior-superior iliac spine (ASIS) landmark. The fore-aft (X) coordinate is positive rearward of the ASIS and the vertical coordinate is positive above the ASIS landmark.

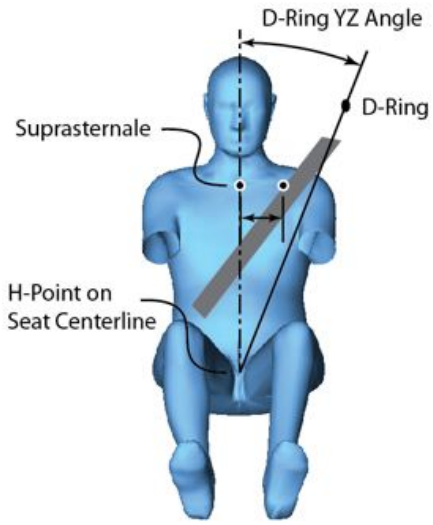


Figure 21. Torso (shoulder) belt fit measurement. Larger positive values indicate more-outboard belt placement. The definition of D-ring YZ Angle is also shown.

RESULTS — STANDARD ANTHROPOMETRY

Tables 11 and 12 list summary statistics for standard anthropometric dimensions for the overall subject pool of 200 adults.

Table 11
Standard Anthropometry for Women (N=100)

	Percentiles						
Measurements*	5th	25th	50th	75th	95th	Mean	SD
Stature with shoes	1507	1582	1624	1683	1745	1629	71
Stature without shoes	1485	1557	1603	1658	1727	1607	71
Weight (kg)	49	60	66	80	102	70	16
BMI (kg/m^2)	19	24	26	30	37	27	6
Erect Sitting Height	779	817	844	879	906	846	41
Eye Height	666	715	737	771	812	736	78
Acromial Height	513	541	562	583	617	562	32
Knee Height	455	478	498	518	548	499	29
Tragion to Top of Head	100	108	114	119	130	114	9
Head Length	175	181	186	193	200	187	11
Head Breadth	141	145	148	152	161	158	98
Shoulder-Elbow Length	309	325	339	349	376	339	20
Elbow-Hand Length	395	412	427	447	476	431	27
Hip Breadth	336	369	395	423	465	398	43
Buttock-Knee Length	526	557	578	607	643	582	37
Buttock-Popliteal Length	440	467	492	524	560	499	61
Biacromial Breadth	302	333	355	367	390	350	28
Shoulder Breadth	383	405	423	453	500	432	37
Chest Depth (Scapula)	216	248	270	301	338	274	37
Chest Depth (Spine)	160	193	216	240	268	217	32
BiASIS Breadth	189	215	239	256	297	239	34
Chest Circumference	829	932	1001	1091	1235	1005	143
Waist Circumference	693	822	929	1063	1202	940	167
Hip Circumference	897	978	1062	1133	1282	1063	155
Upper Thigh Circumference	504	540	587	632	698	594	64

* measured mm unless noted

Table 12
Standard Anthropometry for Men (N=100)

	Percentiles						
Measurements*	5th	25th	50th	75th	95th	Mean	SD
Stature with shoes	1636	1716	1775	1843	1888	1776	82
Stature without shoes	1609	1690	1755	1819	1866	1750	84
Weight (kg)	59	74	86	96	113	85	17
BMI (kg/m^2)	20	25	28	31	35	28	5
Erect Sitting Height	834	875	914	940	974	906	46
Eye Height	712	753	800	828	866	784	87
Acromial Height	549	575	604	635	665	604	38
Knee Height	495	525	552	577	595	546	51
Tragion to Top of Head	110	119	124	130	138	125	12
Head Length	183	192	198	204	210	197	10
Head Breadth	146	152	155	160	166	158	24
Shoulder-Elbow Length	325	357	374	389	417	374	66
Elbow-Hand Length	433	465	478	495	514	478	26
Hip Breadth	330	356	376	402	442	381	40
Buttock-Knee Length	549	589	615	637	675	614	38
Buttock-Popliteal Length	456	495	516	537	581	517	36
Biacromial Breadth	338	369	388	406	428	387	31
Shoulder Breadth	427	451	476	497	522	475	39
Chest Depth (Scapula)	205	243	264	290	313	264	34
Chest Depth (Spine)	183	220	240	261	287	238	33
BiASIS Breadth	202	220	238	252	271	237	23
Chest Circumference	870	995	1060	1150	1228	1056	145
Waist Circumference	757	925	1036	1112	1252	1024	146
Hip Circumference	907	985	1046	1103	1177	1046	92
Upper Thigh Circumference	468	526	565	599	668	570	122

* measured mm unless noted

RESULTS — DRIVER POSTURES

Data analysis is ongoing. Figure 22 illustrates a range of postures observed in the driver mockup.

Figure 22. Illustrative driver postures.

RESULTS — PASSENGER POSTURES

Data analysis is ongoing. Figure 23 illustrates a range of postures observed in the passenger mockup.

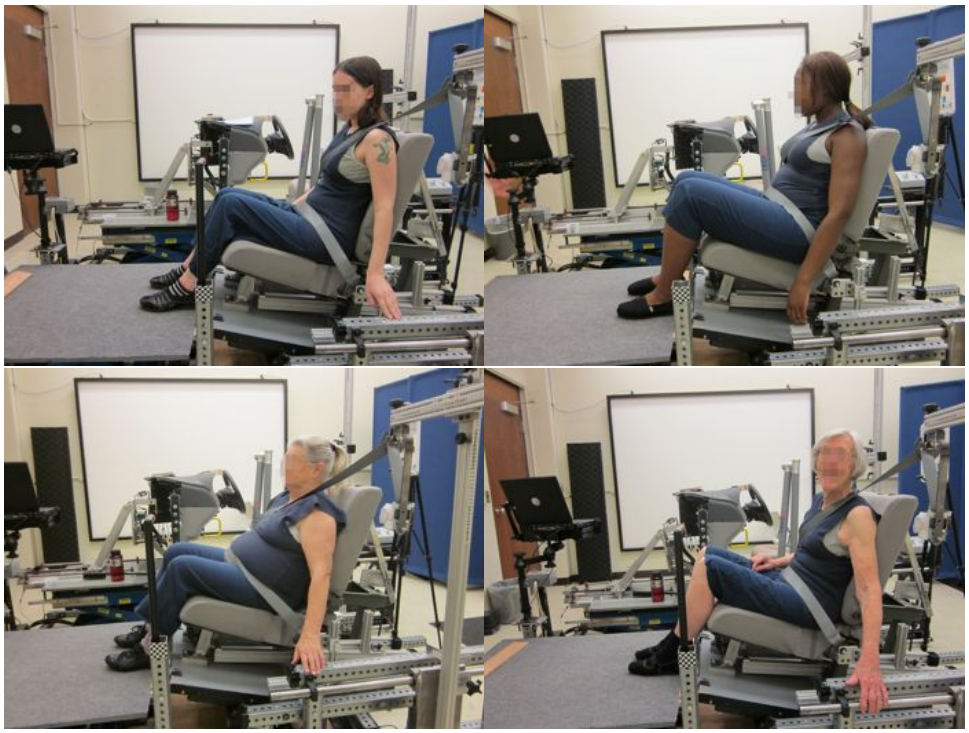


Figure 23. Illustrative passenger postures.

RESULTS — BODY SHAPE

Data analysis is ongoing. Figure 24 shows a range of body shapes captured in the study.

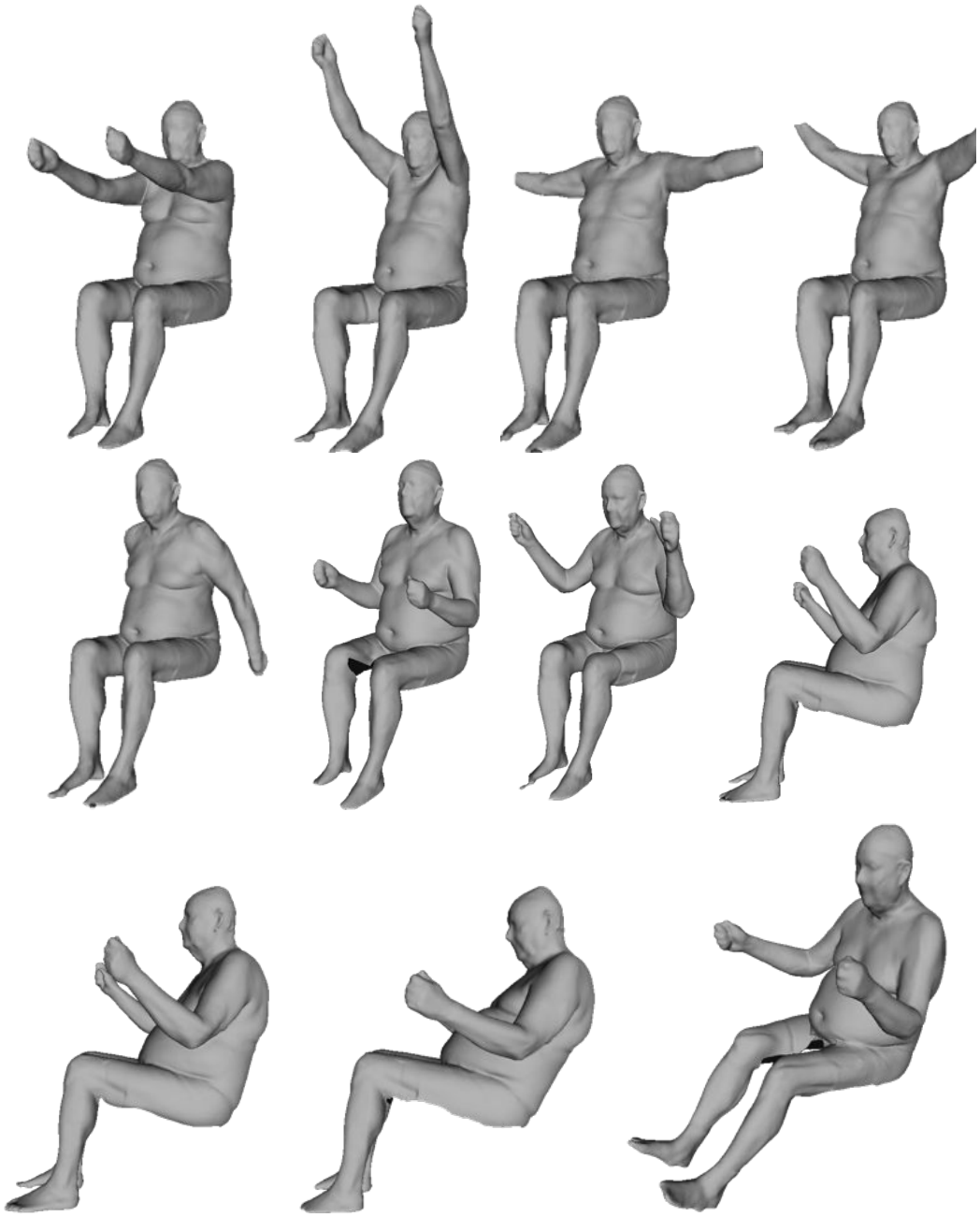


Figure 24a. Example body shapes from one participant.

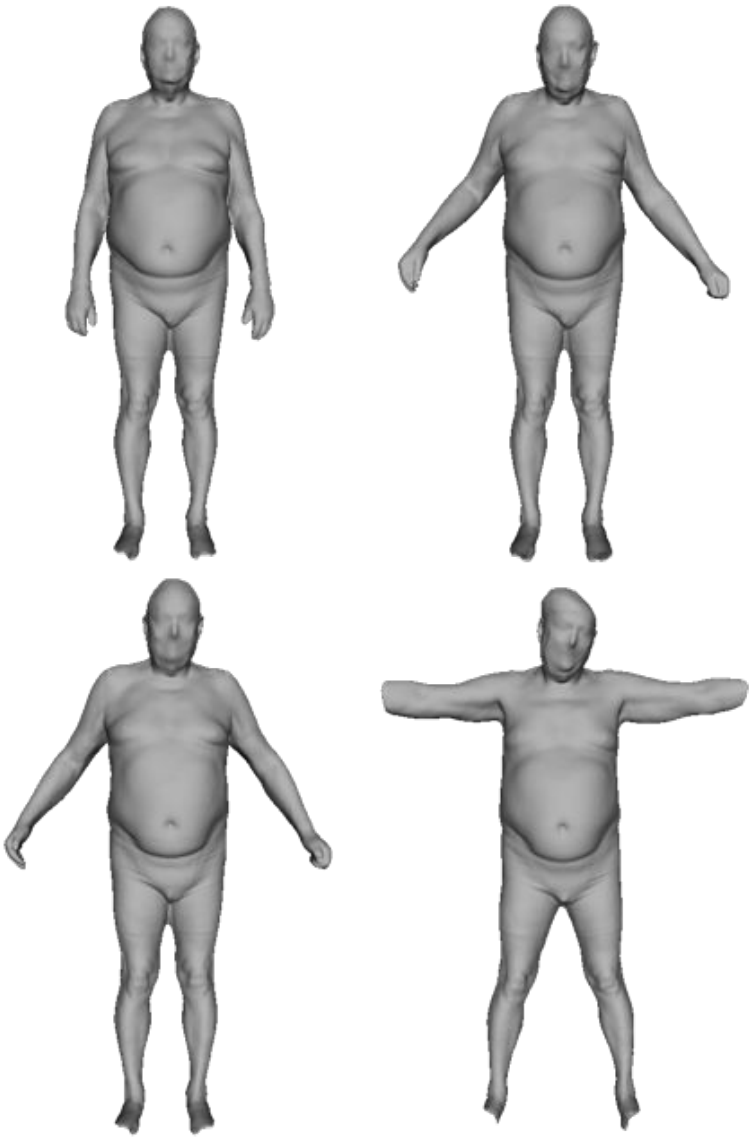


Figure 24b. Example body shapes from one participant.

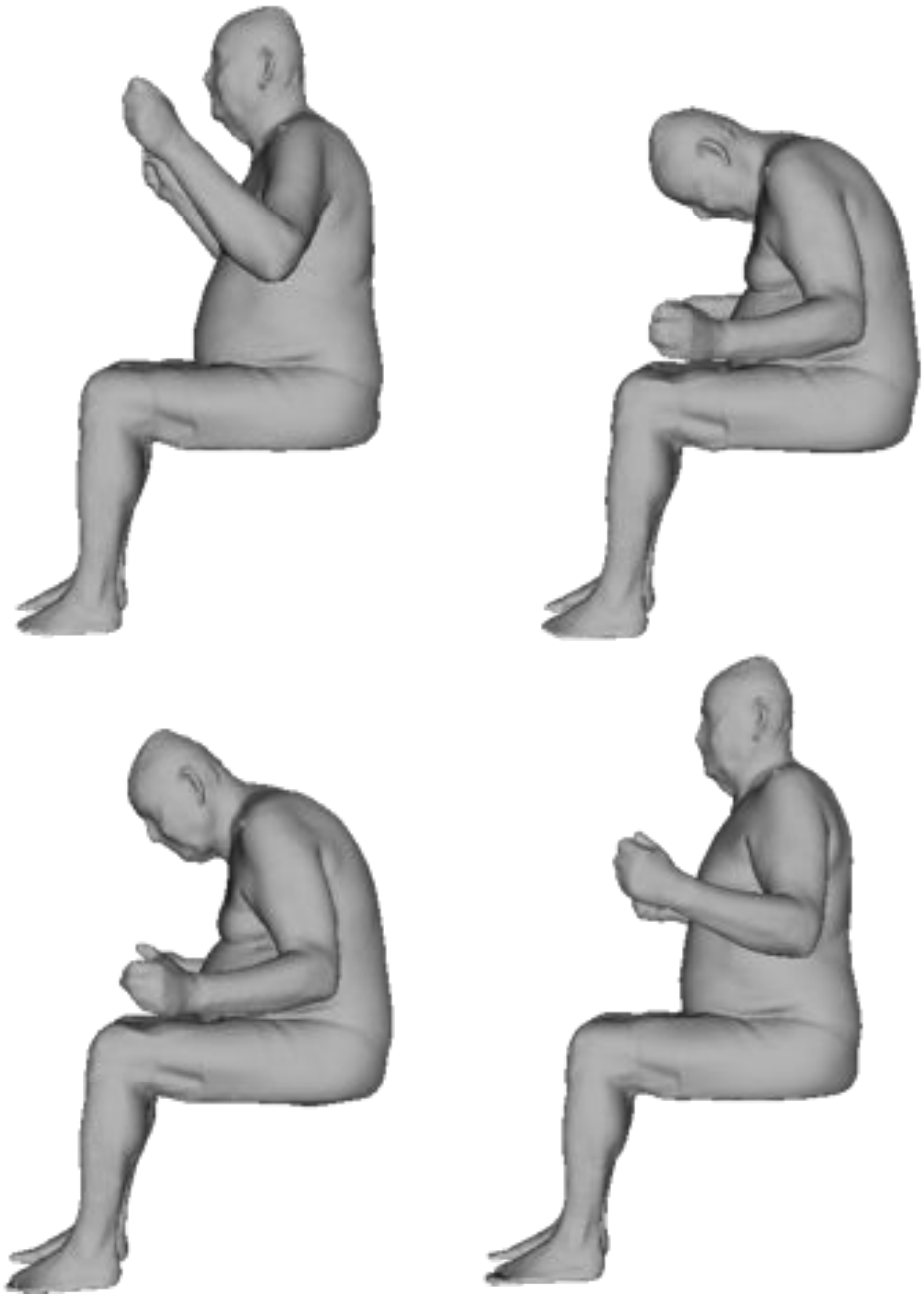


Figure 24a. Example body shapes from one participant.

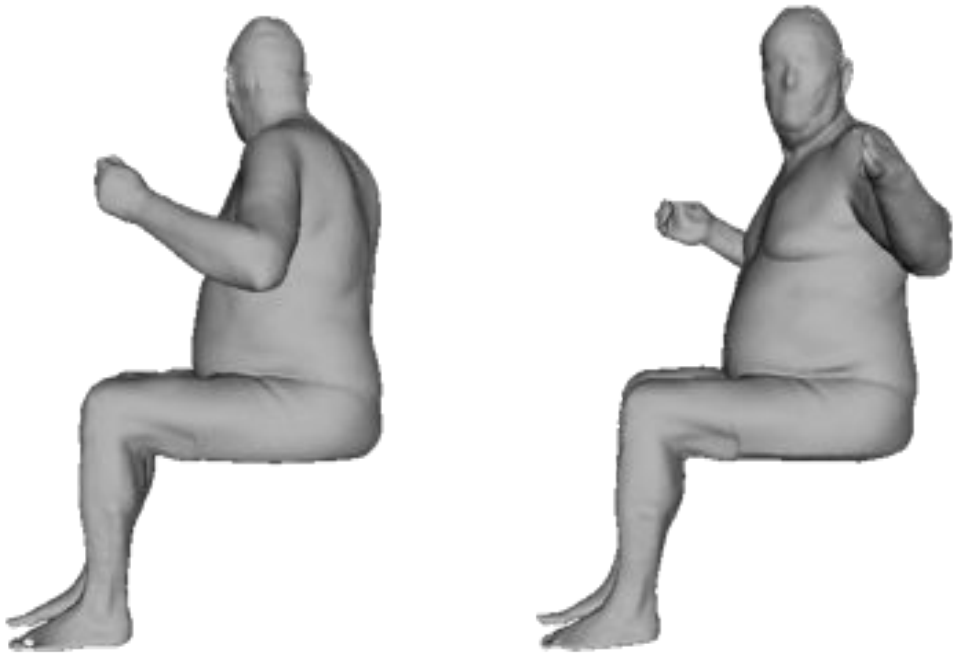


Figure 24c. Illustrative body scans.

RESULTS — FUTURE ANALYSES

This version of the report contains a complete description of the methods and data gathered. However, some important analyses remain. In particular, the final version of this report will include:

- Statistical models predicting driver-selected seat position, seat back angle, and a range of posture variables as a function of vehicle and driver characteristics.

- Statistical models predicting passenger posture as a function of seat and passenger characteristics.

- Statistical models that generate whole-body shape, posture, and major joint locations defining the skeletal linkage for both men and women as a function of overall anthropometry and external body landmark locations.

These models will have wide-ranging applications, including vehicle interior layout, seat design, the development of new ATDs, and the creation of parametric human body finite-element models that can represent the posture and body shape of the wide diversity of vehicle occupants.

DISCUSSION

This study is the first to consider the effects of age along with gender, stature, body weight and other occupant factors on driver and passenger posture and belt fit. Moreover, this is the first study to obtain body shape data from a large, diverse sample of adults in supported seated postures, and the first U.S. study to record body shapes for large numbers of elderly adults. The outcomes of this study will have broad applicability in vehicle design to improve occupant comfort and safety.

REFERENCES

Flegal, K.M, Carroll, M.D. Ogden, C.L., and Curtin, L.R. (2010). Prevalence and Trends in Obesity Among US Adults, 1999-2008. JAMA 303(3):235-241.

Frampton, R., Lenard, J. and Compigne, S. (2012). An In-depth Study of Abdominal Injuries Sustained by Car Occupants in Frontal Crashes. *Annals of the Association of the Advancement of Automotive Medicine* 2012:137-149.

Fryar, CD, Gu, Q, and Ogden, CL. (2012). Anthropometric reference data for children and adults: United States, 2007–2010. National Center for Health Statistics. *Vital Health Statistics*. 11(252).

Glassbrenner, D. and Starnes, M. (2009). *Lives Saved Calculations for Seat Belts and Frontal Air Bags.* Report DOT HS 811 206. National Highway Traffic Safety Administration. Washington, D.C.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., & Walker, R. A. (1989). 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics. Final Report NATICK/TR-89/027. U.S. Army Natick Research, Development and Engineering Center, Natick, MA.

Kent, R.W, Lee, S-H, Darvish, K. Wang, S. Poster, C.S., Lange, A.W. et al. (2005). Structural and Material Changes in the Aging Thorax and Their Role in Crash Protection for Older Occupants. *Stapp Car Crash Journal*, 49:231-249.

Kent, R.W., Forman, J.L., and Bostrom, O. (2010). Is there really a "cushion effect"?: a biomechanical investigation of crash injury mechanisms in the obese. *Obesity* 18(4):749-753.

Reed, M.P., Manary, M.A., and Schneider, L.W. (1999). Methods for measuring and representing automobile occupant posture. Technical Paper 990959. *Proceedings of the SAE International Congress and Exposition,* Society of Automotive Engineers, Warrendale, PA.

Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. (2000). The effects of vehicle interior geometry and anthropometric variables on automobile driving posture. *Human Factors,* 42 (4): 541-552.

Reed, M.P., Manary, M.A., Flannagan, C.A.C., Schneider, L.W., and Arbalaez, R.A. (2001). Improved ATD positioning procedures. *SAE Transactions: Journal of Passenger Cars — Mechanical Systems*, 110: 497-504.

Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. (2002). A statistical method for predicting automobile driving posture. *Human Factors*, 44 (4): 557-568.

Reed, M.P., Ebert-Hamilton, S.M., and Rupp, J.D. (2012). Effects of obesity on seat belt fit. *Traffic Injury Prevention*, 13(4):364-372. 10.1080/15389588.2012.659363

Reed, M.P., and Rupp, J.D. (2013). An anthropometric comparison of current ATDs with the U.S. adult population. *Traffic Injury Prevention*. 14(7):703-705. 10.1080/15389588.2012.752819.

Ridella, S.A., Rupp, J.D., and Poland, K. (2012). Age-related difference in AIS 3+ crash injury risk, types, causation, and mechanisms. *Proceeding of the 2012 IRCOBI Conference*.

Rupp, J.D., Flannagan, C.A.C, Leslie, A.J., Hoff, C.N., Reed. M.P., and Cunningham, R.M. (2013). Effects of BMI on the risk and frequency of serious injury in motor-vehicle crashes. *Obesity*. 21(1):88-97.

Schneider LW, Robbins DH, Pflüg MA, and Snyder RG. (1983). Anthropometry of Motor Vehicle Occupants: Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, Volume 1. Final report DOT-HS-806-715. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

APPENDIX A
Written Consent

The purpose of this study is to obtain data on human body dimensions, postures, body shapes, and safety belt fit in automobile seats. You agree to allow measurements to be taken that will describe your body proportions and size.

Your seating posture and position will be recorded using a digital coordinate measurement device as you sit in a range of vehicle seat conditions. The investigator will touch points on your body to record their locations with a measurement probe. Measurement points include landmarks on the head, chest, pelvis, and extremities. You have observed a demonstration of the measurement point locations and agree that it is acceptable for the experimenter to touch those locations.

Your body surface shape will be recorded using a laser scanner. The laser light is similar to the light used in supermarket checkout machines. The laser light causes no discomfort and is not harmful to the skin or eyes. You will need to remain still in a seated or standing position for about 15 seconds during the measurement.

Your participation in this study is voluntary and conditional on review of your physical qualifications relative to experimental design criteria. You will be paid for your participation at a rate of $12/hour. You may discontinue your involvement at any time with payment for participation up to that time.

The Transportation Research Institute is a research organization and, as such, your records and personal information may be reviewed by research staff. The data gathered in this study will be used in scientific publications and presentations only in coded form not identifying you. The data obtained will be retained indefinitely for analysis.

Photographs will be taken of you to document your body size, shape, and posture. Your identity will be obscured in any photographs used in publications or presentations.

The researchers have taken steps to minimize the risks of this study. Even so, you may still experience some risks related to your participation, even when the researchers are careful to avoid them. These risks include injury due to exertion when performing the requested tasks. Minor skin irritation may occur due to the paint used to identify body landmarks. Please tell the researchers about any concerns or problems you have during the study. By signing this form, you do not give up your right to seek payment if you are harmed as a result of being in this study.

If significant new knowledge is obtained during the course of this research, which may relate to your willingness to continue participation, you will be informed of this knowledge. The person listed below may be contacted for more information about any aspect of this study. If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board, 540 E Liberty St., Ste 202, Ann Arbor, MI 48104-2210, (734) 936- 0933 [or toll free, (866) 936-0933], irbhsbs@umich.edu.

Study ID: HUM00054993 IRB: Health Sciences and Behavioral Sciences Date Approved: 10/4/2011

One copy of this document will be kept together with research records on this study. A second copy will be given to you.

By signing below, you agree to the conditions set forth above and agree that you have had an opportunity to discuss your concerns regarding your participation in the proposed study.

By signing this document, you agree to your participation in a research study.

_____ _____ Signature Date

_____ _____ Witness Name Witness Signature

Principal Investigator: Matthew P. Reed, Ph.D. 734-936-1111 (work) 734-327-0237 (home)

APPENDIX B
PARTICIPANT INTERACTION SCRIPTS

Thank you for your interest in our research study about adult posture, body shape and seat belt fit in cars. The data and knowledge that we will obtain from this study will be valuable for vehicle safety, and for improvement of seatbelt design.

This study takes place in our office located on the northeast side of Ann Arbor. It takes 2 – 3 hours and we pay $12.00 per hour cash at the end of the session.

We will be taking measurements on your body while you are seated in different vehicle seats with a seatbelt on. We will need to touch your hips, arms, legs, back, and chest area to take these measurements. The seats are in simple vehicle mock-ups that you will need to get in and out of several times.

We will also use a scanner that is designed for measuring the exterior surfaces of people and clothing. It cannot see through clothing and is not an X-ray. It uses a light beam to record shapes, and it makes a 3D model on the computer. This scanner is safe for people, similar to a grocery store price scanner.

In order to take these measurements we will need to apply washable stamps on your skin.

Also, we need everyone who is measured to wear the same style of clothes, which we supply. When you are seated in the vehicle seats you will be wearing loose fitting cotton pants and a thermal top with the arms cut off.

When you are seated in the scanning area we need to record the shape of your body, therefore the clothing is form-fitting. Men wear bicycle shorts and no shirt. Women wear bicycle shorts and a sports bra over their own bras. The bicycle shorts are worn directly against the skin like a swimsuit. The scanning is done in a private space in which only two investigators will be present.

Do you have a driver's license?
Are you still interested in coming in to help us? If yes:
Name:
Phone Number:
Email:
Age/Gender:
Height/Weight:

Dates and time you prefer/other information:

Scheduled: Date: Time:

Our address: 2901 Baxter Road. South of Plymouth Road and East off of Huron Parkway. Park in visitor's lot in front of building. We will have an envelope on the front door with a parking pass for you to put on your rear-view mirror. Then come on up to the 4th floor.

Can I email you a map? You have our phone number: (734) 763-3463

We will call you a day or so before your appointment to remind you. Thank you so much for helping in this study!

Introduction Script and Consent

Thank you for volunteering. Today we are going to ask you to do some different things so that we can take measurements on your body. We are going to take measurements using several different types of tools.

We will start by measuring different parts of your body with a device called a Faro Arm. We will take the rounded tip and touch it to different points on your body while you sit in different seats. This arm works like the mouse on a computer. The computer records the location of the tip. We will be touching your head, arms, chest, hips, legs and feet. You will need to sit very still when we take these measurements.

Another way we are going to measure your body is by using a special set of rulers called anthropometers. We will measure the size of your arms, legs, hips, head, and chest.

Another tool we are going to use to take measurements is a scanning machine. There are four columns, and each one produces a laser line. Cameras record the shape of the line as it passes over your body. This takes about 12 seconds, during which time we ask that you stay very still. With the information from the lasers we can make a 3D computer model of the outside surface of your body. We will also use a measurement arm with a small laser to record the shapes that the scanning machine cannot reach, mostly on the tops of your thighs. We will also put markers on your skin. These markers help us take measurements on the computer. We need the markers to stay on until the end of testing, so please let us know if one has rubbed off.

We need to see your arms and legs to do all of these things. Therefore, you will change into special scanning clothes. You will wear a dome cap because the laser doesn't scan hair very well.

Driver Mockup Instruction Script

Overview: At this station we will ask you to sit in this driver seat, and then we will record your posture using this measurement arm.
Please sit very still while we take the measurements otherwise we will have to start the measurements over. We will ask you to stand up at times so that we can make adjustments to the setup.

In the First Condition:

Please have a seat.
This is a simple seat but I am required to show you how the controls work.
When you push this lever the seat back recline changes. Please try it out.
This button controls the up-down, forward-backward and tilt of the seat cushion.
I will demonstrate. Please try it out.

Please place your right foot on the accelerator and your left foot on the floor. Then adjust the seat to a comfortable position for driving, as though you were going to be driving for a long time.

Please put on the seat belt.

Please sit as though you were driving with your hands on the steering wheel and your right foot on the accelerator and your left foot on the floor with the heel on or forward of the yellow tape.

If they naturally sit centered left-right, in a symmetrical posture with the left foot flat on the floor and hands near the 2 and 10 position proceed to next instruction. Otherwise -

- *If they are not centered left-right ask them to do so being sure to use the terms left and right, otherwise they might change their hip position forward-backward. For example say-* Please move your rear-end left (or right) so that you are lined up with the seat.
- *If their hands are in a different position or their feet are in some odd position, ask them to move their hands to 10 and 2, or place the left foot flat on the floor.*
- *If they say that this is how they usually or prefer to sit, say -* I understand, but for this study we ask that everyone sit in a more standard driving position
- *Further explanation if needed -* We are not measuring your personal preference in this study, but rather how people's bodies fit in vehicles.

Relax your shoulders and look forward as though you are looking down the road.
This is the position that I will need you to "freeze" in while I take measurements. Please stay frozen until I tell you to "unfreeze". I may move your hands so that I can reach points on your body, but please keep the rest of your body frozen.

After finishing measurements:
Now please be very careful as you step out to the right. Please stand or sit facing away from the seat while I set up the next condition.

Please return to the seat. I have moved the seat, so you'll need to adjust it again to get to your preferred position. Be sure to adjust the seat back angle, and adjust it forward and backward and up and down and the seat cushion tilt until you reach a comfortable posture.

Passenger Mockup Instruction Script

Overview: At this station we will ask you to sit in this passenger seat, and then we will record the position of your body using this measurement arm.

I will feel for the location of a bone, then touch that location with this tip and press a button. The amount of rotation at each of these joints tells the computer where in space this tip is. It is similar to a mouse on a computer. I will record points on your head, neck, chest, hips, arms and legs.

Please sit very still while we take the measurements otherwise we will have to start the measurements over. We will ask you to stand up at times so that we can make adjustments to the seat.

For Each Condition:
Please have a seat, then put on the seat belt.

If they have not tightened the belt, remind them to do so.
If they say that they do not use the seat belt normally, say – I understand, but for this study we ask that you please wear it anyway.

If they naturally sit centered left-right, in a symmetrical posture with legs uncrossed, proceed to next instruction. Otherwise -

- *If they are not centered left-right ask them to do so being sure to use the terms left and right, otherwise they might change their hip position forward-backward. For example say-* Please move your rear-end left (or right) so that you are lined up with the seat.
- *If their legs or ankles are crossed ask them to uncross them. If they say that this is how they usually or prefer to sit say* - I understand, but for this study we ask that everyone sit with their legs and ankles uncrossed.
- *Further explanation if needed* - We are not measuring your personal preference in this study, but rather how people's bodies fit in vehicles.

Please rest your palms on your thighs with your elbows at your sides.
Relax your shoulders and look straight ahead.
This is the position that I will need you to "freeze" in while I take measurements. Please stay frozen until I tell you to "unfreeze". I may move your hands to reach your hips, but please keep the rest of your body frozen.

APPENDIX C
SCANNNING POSTURES

Table C1
Scanning Postures

Posture	Code	Seat Pan	Seat Back	Hips	Lower Limbs	Spine	Shoulders	Hand Scan
Standing Natural	T1	NA			15 cm	Natural	Natural	
Standing Abduction	T2	NA				Natural	Abduction 40°	
Standing Erect	T3	NA				Erect	Abduction 40°	
Standing T-pose	T4	NA			45 cm	Natural	Abduction 90°	
Automotive	C1	Wedges (14.5°)	pads		Driving	Natural	Abduction 90°	Yes
Recline U (Upright)	RU	Wedges (14.5°)	L1	Nat-ural	Knees 90°	Erect	Handles*	
Recline 1 (min)	R1		L2			Slump1		Yes
Recline 2 (mid)	R2		L3			Slump2		Yes
Recline 3 (max)	R3		L4			Slump3		Yes
Sitting Lap	L1	0°	bar	75°	Legs and feet symmetrical with **thighs parallel**, ankles under the knees, and feet parallel	Erect	Handle	
Spine Flexion Min/Nat	V1	0°	bar	75°		Natural	Handle	
Spine Flexion Max	V2	0°	bar	75°		Max Flexion	Handle, lower	
Spine Flexion Mid	V3	0°	bar	75°		Mid Flexion	Handle, lower	
Spine Extension Max	V4	0°	bar	75°		Ext max	Handle	
Spine Rotation Right	V5	0°	bar	75°		Rotated	Arms Up	
Spine Rotation Left	V6	0°	bar	75°		Rotated	Arms Up	
Arm Flexion 90°	A1	0°	bar	75°		Erect	Flexion 90°	
Arm Flexion Max	A2	0°	bar	75°		Erect	Max Flexion	
Arm Abduction 90°	A3	0°	bar	75°		Erect	Abduction 90°	
Arm Abduction Max	A4	0°	bar	75°		Erect	Max Abduct	
Arm Extension Max	A5	0°	bar	75°		Erect	Max Extension	
Sitting ISO	L2	0°	bar	90°		Erect	Elbow 90°	Yes

*Handles= Palm at height of suprasternale, shoulders as if arms were hanging at sides with elbows 45° out from body in coronal view and the shoulder-elbow-wrist angle at 120°

Table C2
Scanning Postures Overview

Posture	Purpose and Description
Standing Natural	Natural, yet symmetrical, standing posture to get a good scan of arms hanging at sides
Standing Abduction	Similar to StandingNatrl but with arms abducted 30˚ to get a good scan of torso
Standing Erect	Similar to StandingArmAb but with spine erect
Standing T-pose	T-pose and legs wide used to get under arm and between leg surfaces
Automotive	Posture in vehicle with back angle =23˚, cushion angle =14.5˚, H30=270 mm
Recline U (Upright) Recline 1 (min) Recline 2 (mid) Recline 3 (max)	A series of postures in which the subject goes from a very erect posture to a very slumped posture, while keeping the knee angle constant. The seat is set with a 23˚ back angle and 14.5˚ cushion angle. The seatback moves rearward to increase the slump of the spine. The hips stay forward on the seat so that the bottoms of the thighs and backs of the calves are scanned well. Seat surface should not cut into the back of the thighs. The arms are forward so that the sides of the torso scan well – but the shoulders are still in a resting position (as if arms were hanging by the side of the subject). Elbows and shoulders are relaxed with the subject's hands on the handles supporting the weight of their arms.
Sitting Lap	An erect posture on a level seat in which the tops of the thighs are visible in the full body scanner
Spine Flexion Min/Nat Spine Flexion Max Spine Flexion Mid	A series of postures in which the entire spine goes from natural sitting to maximum flexion. In SpineMx the chin is on the chest.
Spine Extension Max	Maximum extension of the entire spine (as can be safely done)
Spine Rotation Rt. Max	Rotation of cervical, thoracic and lumbar spine to the right
Spine Rotation Lt. Max	Rotation of cervical, thoracic and lumbar spine to the left
Arm Flexion 90˚ Arm Flexion Max Arm Abduction 90˚ Arm Abduction Max Arm Extension Max	A series of arm positions used to create surfaces of the shoulder, neck and torso
Sitting ISO	A posture from the ISO standard for scanning

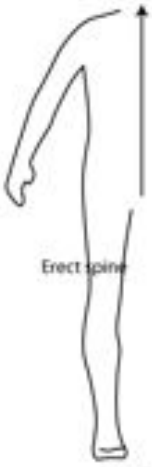
STANDING POSTURES

Natural

Feet: parallel, insole at narrow spaced lines
Arms: hanging, relaxed
Head: looking forward
Spine: natural, but symetrical

Arms Away

Feet: parallel, insole at narrow spaced lines
Arms: shoulders abducted 40°
Head: looking forward
Spine: natural, but symetrical



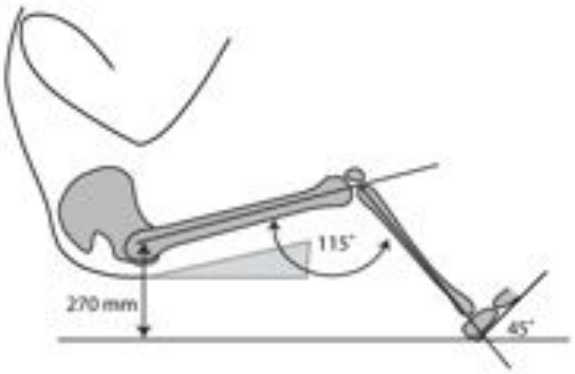
Erect

Feet: parallel, insole at narrow spaced lines
Arms: shoulders abducted 40°
Head: looking forward
Spine: erect

T-Pose

Feet: parallel, insole at WIDE spaced lines, or enough to separate thighs
Arms: shoulders abducted about 90°
Head: looking forward
Spine: natural

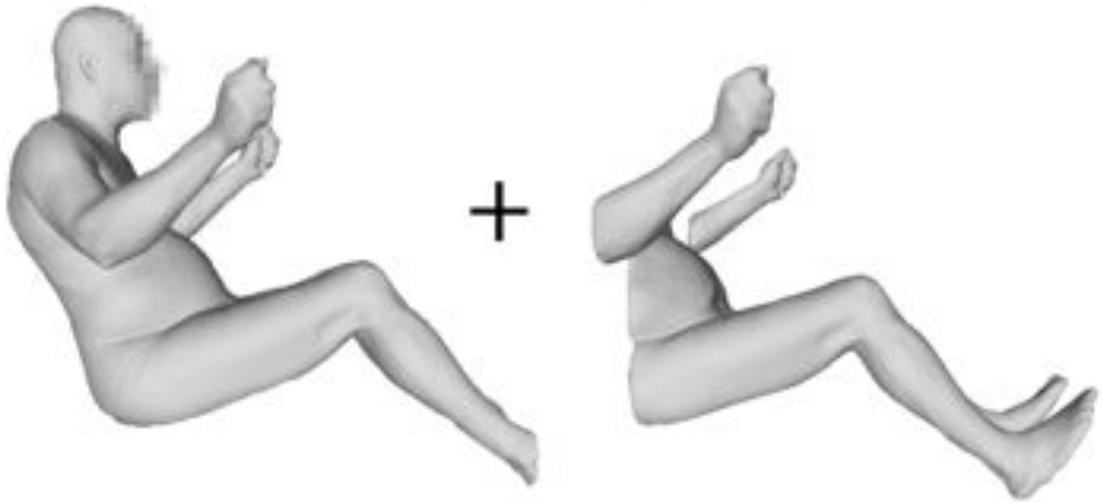
AUTOMOTIVE POSTURE



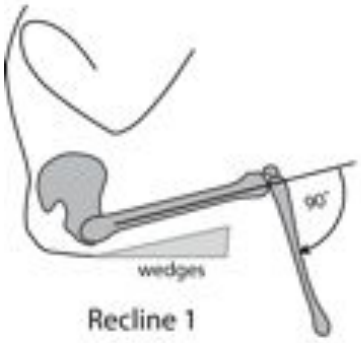
Seat:	stirrups set to H30 = 270 mm
Legs:	parallel (use peg)
Feet:	parallel, stirrup to mid position
Hands:	on poles at suprasternale height
Shoulders:	relaxed, as if arms were hanging at side
Head:	looking forward
Back:	centered on backrest, relaxed spine, more slouched than Recline 1
Buttocks:	at edge of seat but not hanging over

Steps:

Participant sits on stool with buttocks at edge but not hanging over
Investigator ensures participant is centered left-right and then helps participant to backrest
Place a wedge under the center of each thigh with the narrow end at the hip
Participant relaxes spine
Investigator positions arms
    Upper arm 45° relative to body as viewed from above
    120° angle at elbow
Investigator positions heels to 270 mm below hip with knee at 115°
Investigator checks posture symmetry and puts pegs between participant's knees



RECLINE POSTURES



Recline 1

Seat: recline position 1
Legs: parallel (use peg)
Feet: parallel
Hands: on poles at suprasternale height
Shoulders: relaxed, as if arms where hanging at side
Head: looking forward
Back: centered on backrest, relaxed spine

Buttocks: at edge of seat but not hanging over

Recline 2

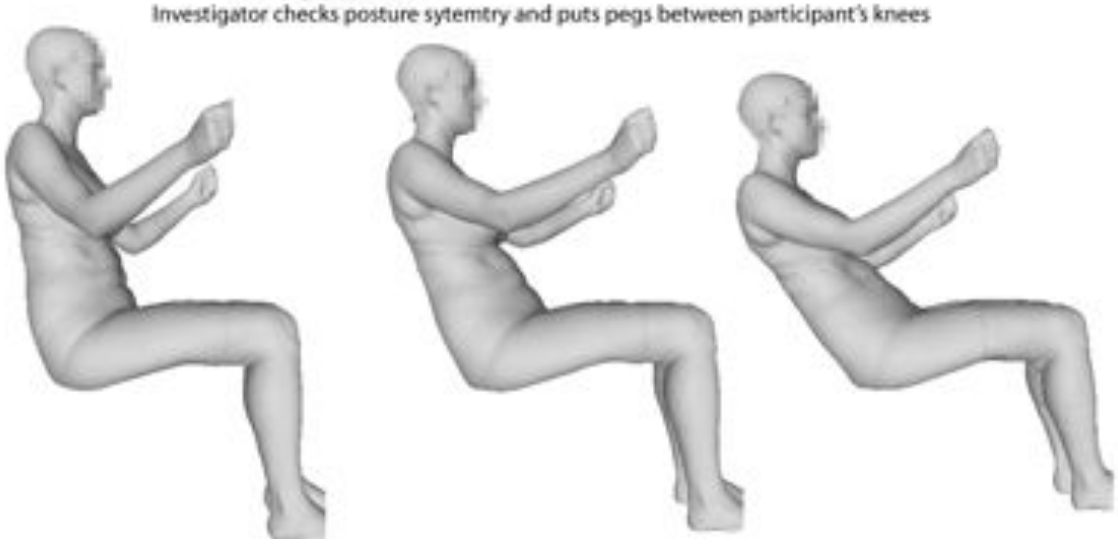
Seat: recline position 2
Legs: parallel (use peg)
Feet: parallel
Hands: on poles at suprasternale height
Shoulders: relaxed, as if arms where hanging at side
Head: looking forward
Back: centered on backrest, relaxed spine, more slouched than Recline 1
Buttocks: at edge of seat but not hanging over

Recline 3

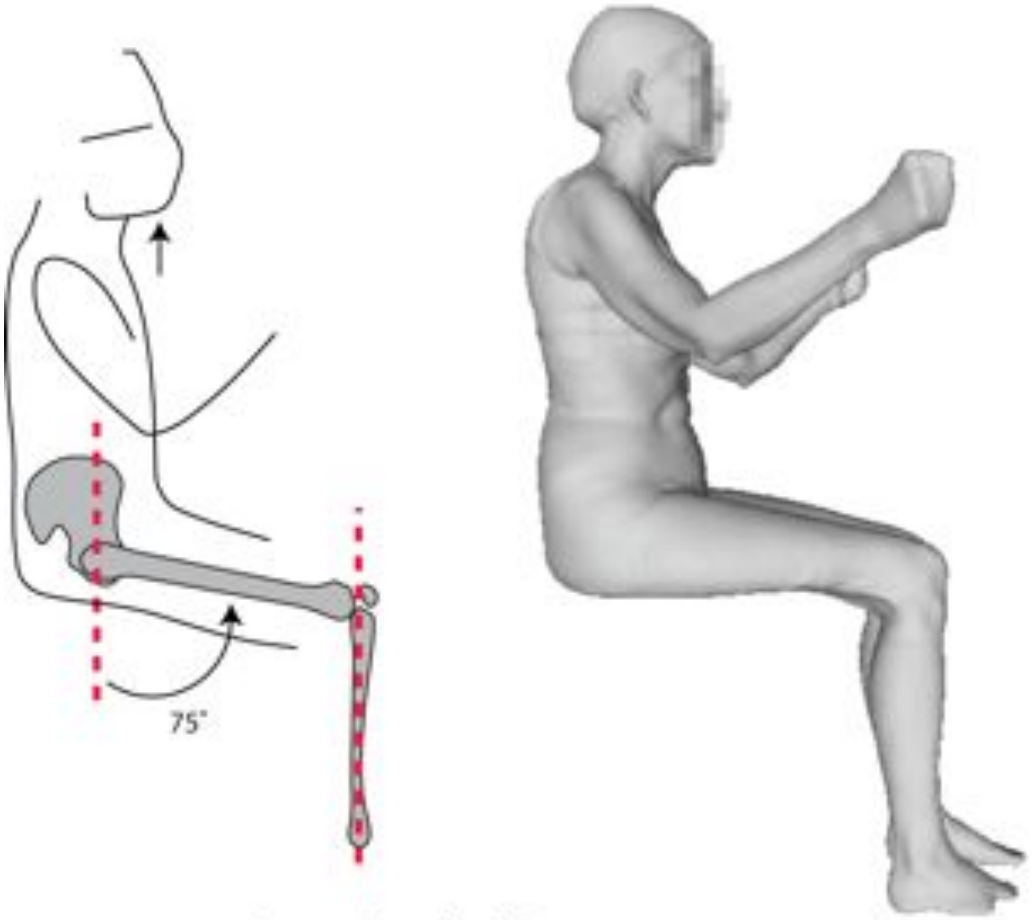
Seat: recline position 3
Legs: parallel (use peg)
Feet: parallel
Hands: on poles at suprasternale height
Shoulders: relaxed, as if arms where hanging at side
Head: looking forward
Back: centered on backrest, relaxed spine, more slouched than Recline 2
Buttocks: at edge of seat but not hanging over

Steps:

Participant sits on stool with buttocks at edge but not hanging over
Investigator ensures participant is centered left-right and then helps participant to backrest
Participant relaxes spine
Investigator positions arms
Upper arm 45° relative to body as viewed from above
120° angle at elbow
Investigator checks posture sytemtry and puts pegs between participant's knees



SITTING POSTURE



Lap Angled Down

Backrest: none (bar)
Hips: 75° (comp 105°)
Legs: parallel (use peg)
Ankles: under knees
Feet: parallel
Hands: on poles at
suprasternale height
Shoulders: relaxed, as if arms
where hanging at side
Head: looking forward,
Frankfort about 5° up from level
Spine: erect
Buttocks: at edge of seat but
not hanging over

SPINE FLEXION

Natural Slouch
"Min"

Posture: sitting
Hips: 75° (comp 105°)
Legs: close to parallel
Ankles: under knees
Feet: close to parallel
Head: looking forward
Spine: natural slouch
Hands: on poles
Shoulders: relaxed

Maxiumum
"Max"

Posture: sitting
Hips: 75° (comp 105°)
Legs: close to parallel
Ankles: under knees
Feet: close to parallel
SPINE flexion order:
1. Slouch lumbar spine
2. Slouch thoracic spine
3. Bring chin to chest
C7 ends up being over hips
(No bending forward at waist)
Hands: slid down 15 cm on poles
Shoulders: relaxed, hanging

Investigator: coaches to get maximum flexion of entire spine and keep C7 over hips

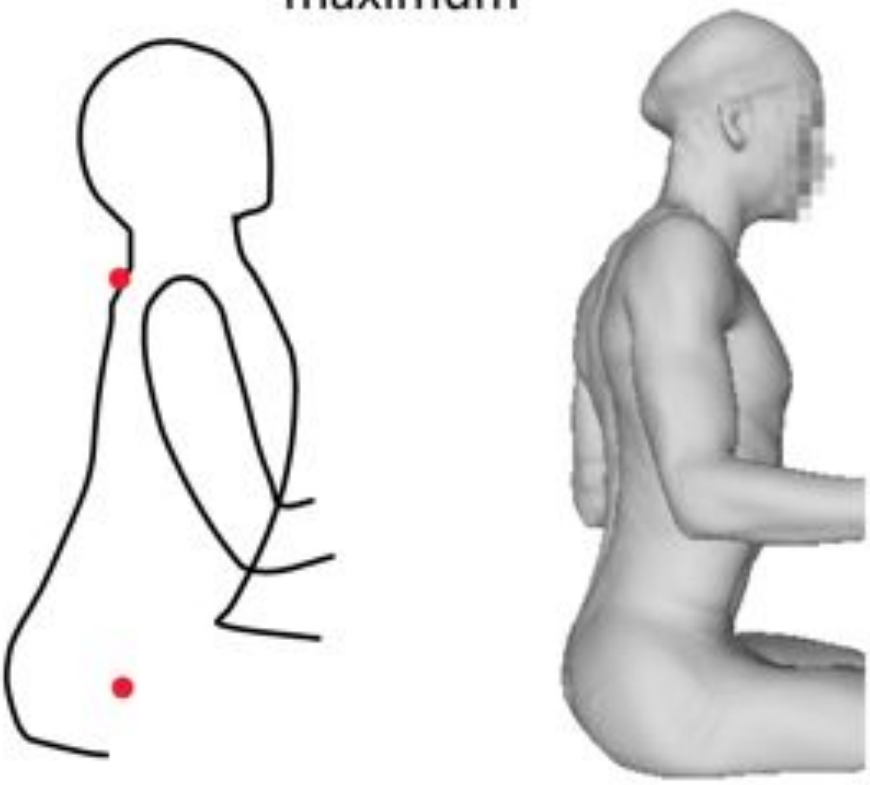
Midway
"Mid"

Posture: sitting
Hips: 75° (comp 105°)
Legs: close to parallel
Ankles: under knees
Feet: close to parallel
SPINE flexion order:
1. Slouch lumbar spine
2. Slouch thoracic spine
3. Bring chin to chest
C7 ends up being over hips
(No bending forward at waist)
Hands: slid down 15 cm on poles
Shoulders: relaxed, hanging

Investigator: coaches to get a flexion midway between natural slouch and maximum flexion and keep C7 over hips

The purpose of these 3 postures is to get a range of flexion in the cervical, thoracic and lumbar spine.
If the participant bends at the waist, the top of the spine does not scan well.

SPINE EXTENSION
maximum



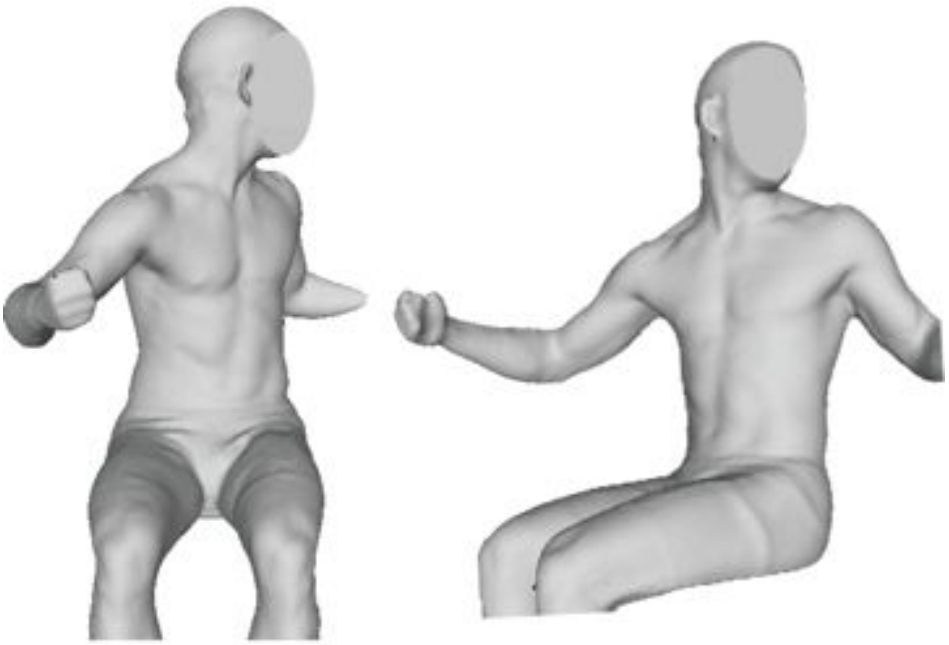
Posture: sitting
Hips: 75˚ (comp 105˚)
Legs: close to parallel
Ankles: under knees
Feet: close to parallel
Hands: on poles

SPINE extension order:
1. Stick out stomach
2. Bring shoulders back and chest forward
3. Head looking forward

C7 ends up being over hips

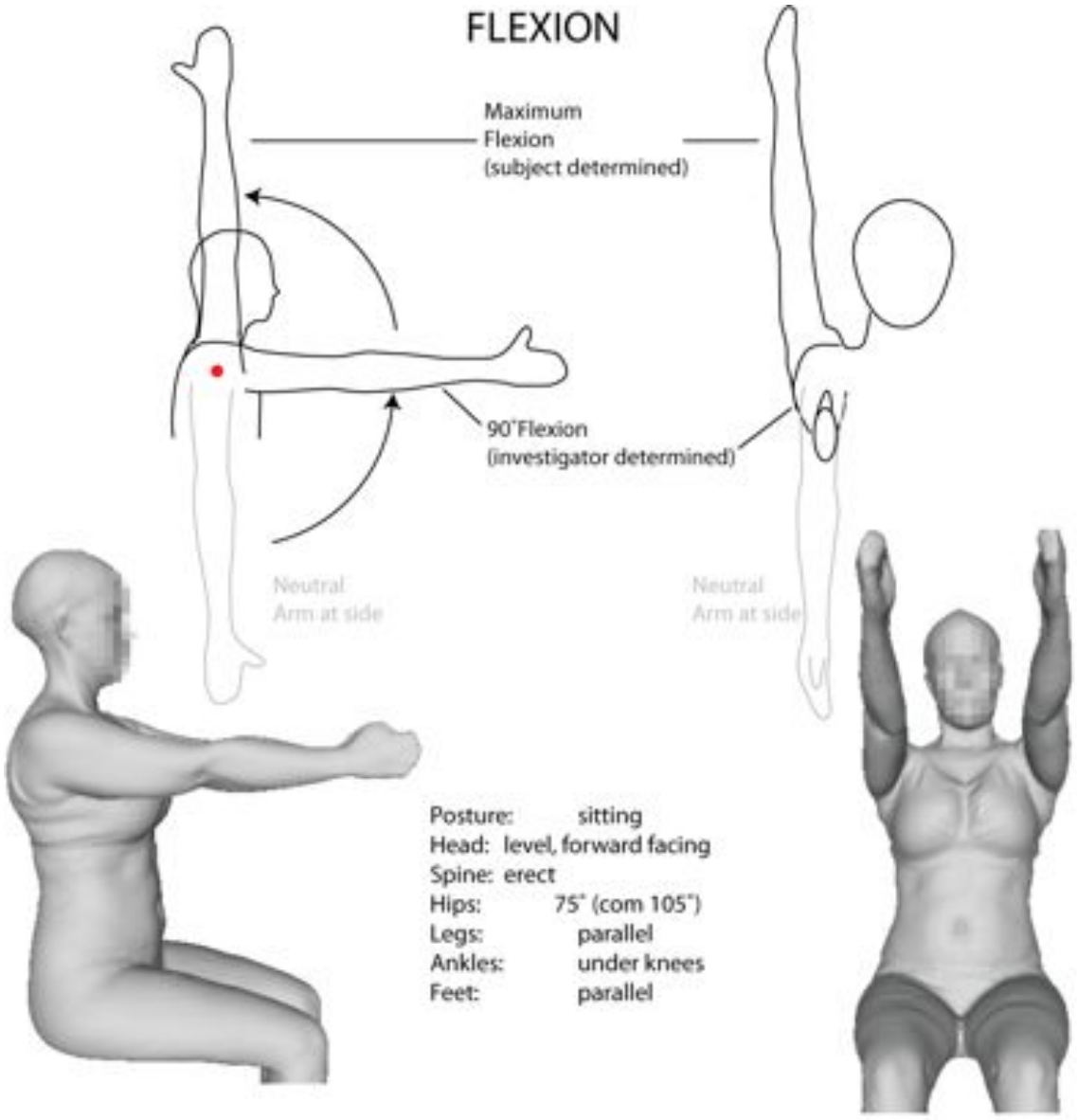
Investigator: coaches to get maximum extension of entire spine and to keep torso forward over thighs so that the participant does NOT lean backand lose balance

SPINE ROTATION



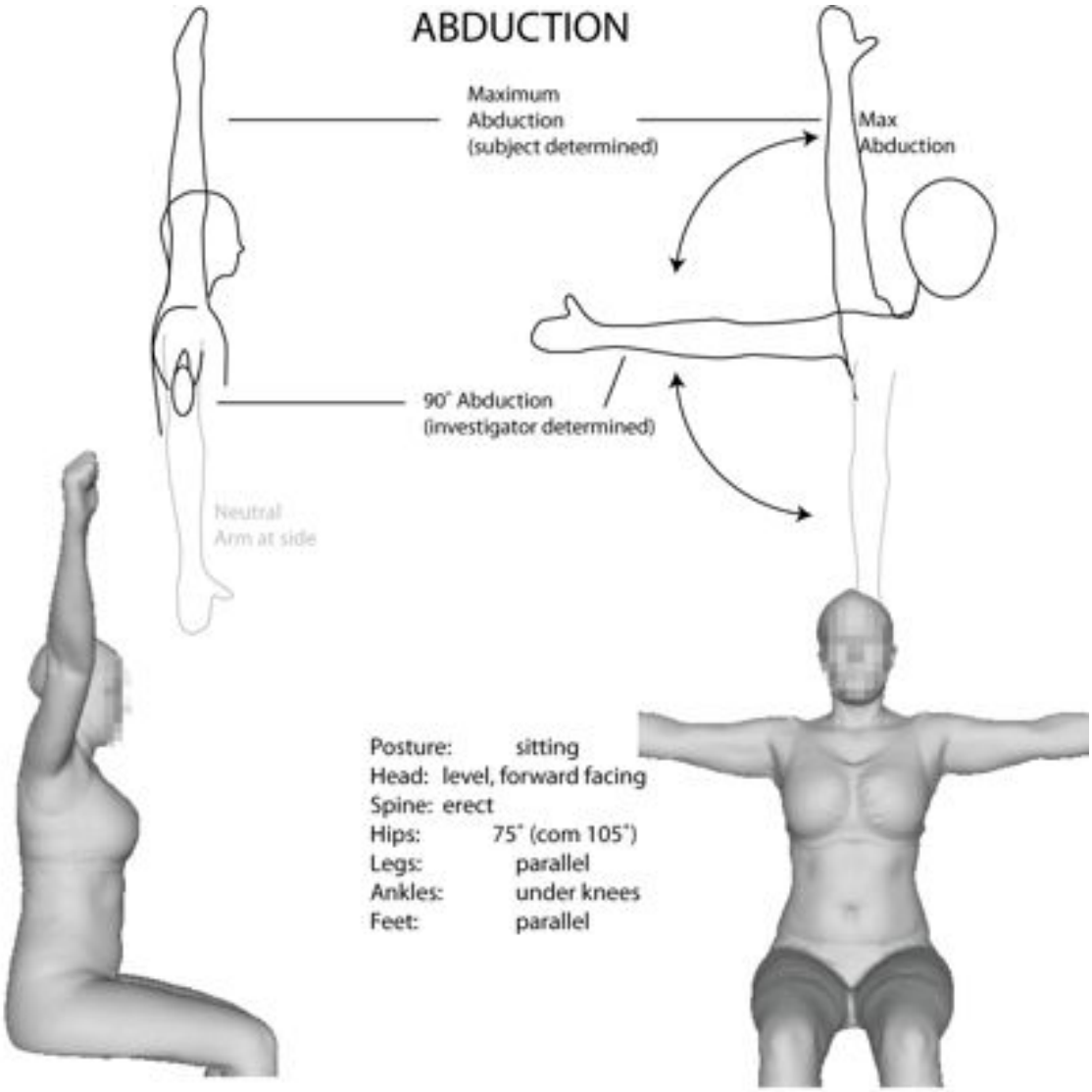
Posture: sitting
Hips: 75° (comp 105°)
Legs: close to parallel
Ankles: under knees
Feet: close to parallel
SPINE entire spine rotated
(No bending forward at waist)
Hands: 1) st pole height settomg
2) both rotate with body
3) arm that crosses chest brought back to front
Shoulders: relaxed, hanging

Investigator: coaches to get maximum maximum rotation without leaning



Starting in neutral posture- arms hanging at sides, thumbs forward
Rotate both arms up until humerus is at 90˚ or maximum relative to thorax

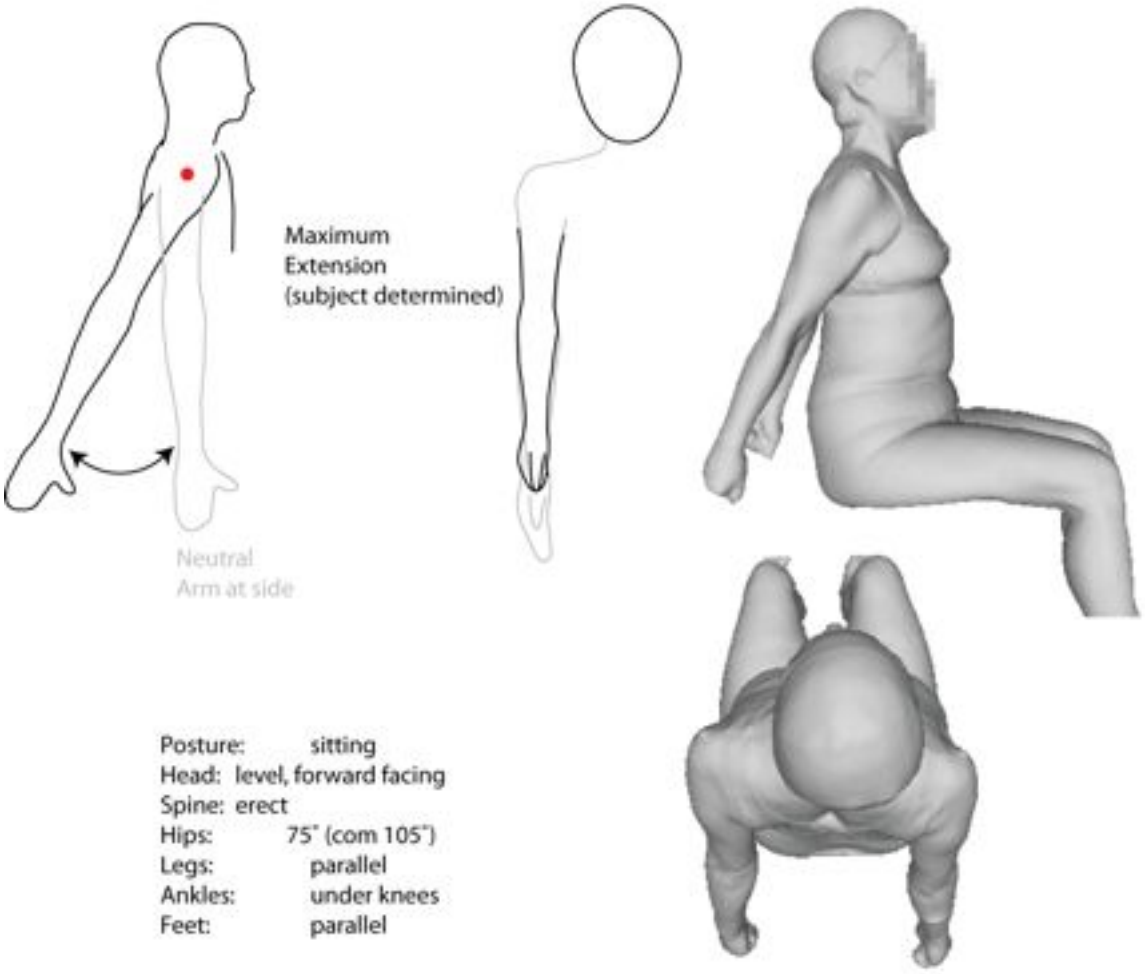
Rotate as though ther is a pin in shoulder - do not move shoulder forward or upward
Keep rest of body still - no leaning or twisting of the torso
Keep the elbows straight but not locked
Keep the arms as parallel as possible to the center line of the body - minimal abduction
Help participant hold arms in place until scan starts



Starting in neutral posture- arms hanging at sides, thumbs forward
Rotate hands so thumbs are pointing away from body
Raise both arms until humerus is at 90˚ or maximum relative to thorax

Keep rest of body still - no leaning or twisting of the torso, no head tilting
Keep the elbows straight but not locked
Keep the arms in line with the plane of the body - in line with ear
Help participant hold arms in place until scan starts

EXTENSION



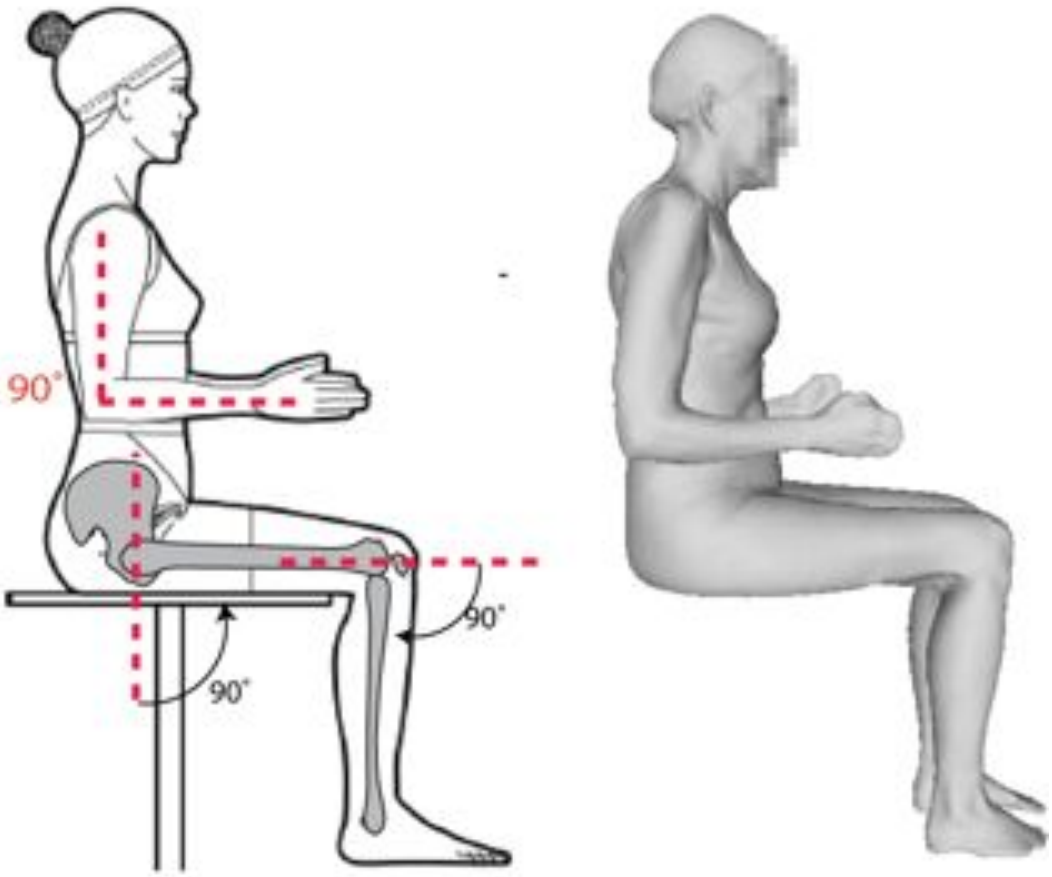
Posture: sitting
Head: level, forward facing
Spine: erect
Hips: 75° (com 105°)
Legs: parallel
Ankles: under knees
Feet: parallel

Starting in neutral posture- arms hanging at sides, thumbs forward
Rotate both arms rearward

Rotate as though pin in shoulder, do not move shoulder forward or upward
Keep rest of body still - no leaning or twisting of the torso, no chin jutting
Keep the elbows straight but not locked
Keep the arms as parallel as possible to the center line of the body

Help participant hold arm in place until scan starts

ISO Posture



ISO Standard

Backrest: none (bar)
Hips: 90°
Legs: parallel (use peg)
Knees: 90°
Feet: parallel (use foam block)
Hands: Neutral, unsupported
Elbows: 90°
Shoulders: at sides
Head: Frankfort plane level
Spine: erect
Buttocks: at edge of seat but not hanging over

APPENDIX D
Points Digitized on Scans

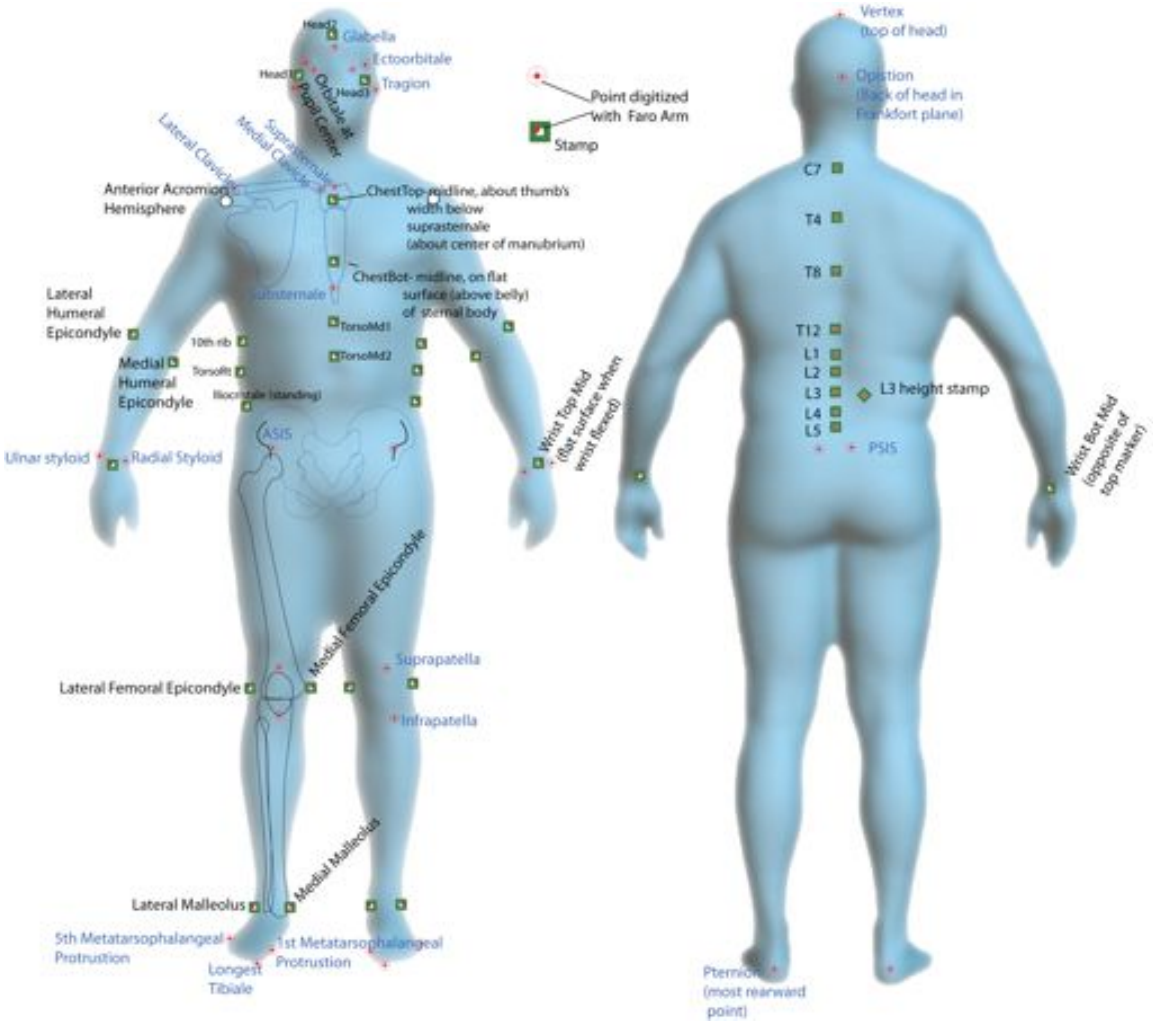


Figure D1. Markers illustrated on standing scan.

Marker Descriptions

Point Name	Body Part	Additional Description	Point to Digitize
Head3_M	Head	About 1" above glabella, on skin that doesn't move when raising eye brows, not covered by swim cap	Superior, Subject's Left
Head2_M	Head	On or above left cheek bone about 1" anterior to tragion	Superior-Posterior
Head1_M	Head	On or above right cheek bone about 1" anterior to tragion	Superior-Posterior
AcromionLt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere
AcromionRt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere
ElbowMedLt_M	Arm	Medial epicondyle (mark with elbow bent 90°)	Proximal, extensor surface

ElbowMedRt_M	Arm	Medial humeral epicondyle (mark with elbow bent 90˚)	Proximal, extensor surface
ElbowLatLt_M	Arm	Lateral epicondyle (mark with elbow bent 90˚)	Proximal, extensor surface
ElbowLatRt_M	Arm	Lateral humeral epicondyle (mark with elbow bent 90˚)	Proximal, extensor surface
WristMidTopLt_M	Arm	On the back of the wrist slightly proximal to the cross section plane of the ulnar styloid.	Proximal, nearest Ulnar Styloid
WristMidTopRt_M	Arm	On the back of the wrist slightly proximal to the cross section plane of the ulnar styloid.	Proximal, nearest Ulnar Styloid
WristMidBotLt_M	Arm	On the palm side of the wrist opposite the wrist mid marker	Proximal, nearest Ulnar Styloid
WristMidBotRt_M	Arm	On the palm side of the wrist opposite the wrist mid marker	Proximal, nearest Ulnar Styloid
SpineC07_M	Torso	Spinous process of the 7th cervical vertebra (cervicale)	Center
SpineT04_M	Torso	Spinous process of 4th thoracic vertebra	Center
SpineT08_M	Torso	Spinous process of 8th thoracic vertebra	Center
SpineT12_M	Torso	Spinous process of 12th thoracic vertebra	Center
SpineL01_M	Torso	Spinous process of 1st lumbar vertebra	Center
SpineL02_M	Torso	Spinous process of 2nd lumbar vertebra	Center
SpineL03_M	Torso	Spinous process of 3rd lumbar vertebra	Center
SpineL04_M	Torso	Spinous process of 4d lumbar vertebra	Center
SpineL05_M	Torso	Spinous process of 5th lumbar vertebra	Center
10RibLt_M	Torso	Most lateral point on the 10th rib	Superior-Posterior
10RibRt_M	Torso	Most lateral point on the 10th rib	Superior-Posterior
L3Position_M	Torso		
IlioRt_M	Torso	Iliocristale (most superior lateral point on pelvis when standing	Superior-Posterior
IlioLt_M	Torso	Iliocristale (most superior lateral point on pelvis when standing	Superior-Posterior
ChestUpper_M	Torso	Body midline, about one thumb's width down from suprasternale, (or about mid-manubrium)	Superior, Subject's Left
ChestLower_M	Torso	Body midline, first flat, boney surface on sternum body above belly	Superior, Subject's Left
TorsoLt_M	Torso	Midpoint between 10th rib and iliocristale point	Superior-Posterior
TorsoRt_M	Torso	Midpoint between 10th rib and iliocristale point	Superior-Posterior
TorsoMid1_M	Torso	Between TorsoMid2 and substernale	Superior, Subject's Left
TorsoMid2_M	Torso	Above umbilicus	Superior, Subject's Left
KneeFemMedLt_M	Leg	Femoral epicondyle, medial	Proximal, flexor surface
KneeFemMedRt_M	Leg	Femoral epicondyle, medial	Proximal, flexor surface
KneeFemLatLt_M	Leg	Femoral epicondyle, lateral	Proximal, flexor surface
KneeFemLatRt_M	Leg	Femoral epicondyle, lateral	Proximal, flexor surface
AnkleMedLt_M	Leg	Malleolus, medial	Proximal, plantar flexion surface side
AnkleMedRt_M	Leg	Malleolus, medial	Proximal, plantar flexion surface side
AnkleLatLt_M	Leg	Malleolus, lateral	Proximal, plantar flexion surface side
AnkleLatRt_M	Leg	Malleolus, lateral	Proximal, plantar flexion surface side

AcromionLt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere

AcromionRt_H	Torso	Center of hemisphere on most anterior point on the acromion	Center of hemisphere

Landmarks (no stamps)

Point Name	Body Part	Additional Description
HeadTopCt_L	Head	Most superior point on head or helmet
HeadBackCt_L	Head	Most posterior point on head or helmet
HeadTragLt_L	Head	Notch just above the tragus of the ear
EyeCorLt_L	Head	Point on orbit nearest the corner of eye
EyeCenLt_L	Head	Point on orbit below the eye at the same lateral position as the pupil when looking straight forward
HeadGlabCt_L	Head	Smooth elevation of the frontal bone just above the bridge of the nose, between eyebrows
EyeCenRt_L	Head	Point on orbit below the eye at the same lateral position as the pupil when looking straight forward
EyeCorRt_L	Head	Point on orbit nearest the corner of eye
HeadTragRt_L	Head	Notch just above the tragus of the ear
WristLatRt_L	Arm	Styloid process on ulna (pinky side) lateral point on wrist “bump”
Mcar5LatRt_L	Arm	Knuckle – grip axis, pinky side
Mcar2MedRt_L	Arm	Knuckle – grip axis, index side
WristMedRt_L	Arm	Styloid process on radius (thumb side) – opposite of wrist “bump”
WristMedLt_L	Arm	Styloid process on ulna (thumb side) lateral point on wrist “bump”
Mcar2MedLt_L	Arm	Knuckle – grip axis, pinky side
Mcar5LatLt_L	Arm	Knuckle – grip axis, index side
WristLatLt_L	Arm	Styloid process on radius (pinky side) – opposite of wrist “bump”
InnerThighCt_E	Torso	Most inferior midline point on torso – mid crotch point
ThighJnctRtLat_L	Torso	Thigh – abdominal junction, lateral point (defining a line)
ThighJnctRtMed_L	Torso	Thigh – abdominal junction, medial point (defining a line)
ThighJnctLtMed_L	Torso	Thigh – abdominal junction, medial point (defining a line)
ThighJnctLtLat_L	Torso	Thigh – abdominal junction, lateral point (defining a line)
AxillaLtFt_L	Torso	Armpit Front
AxillaRtFt_L	Torso	Armpit Front
AxillaRtRr_L	Torso	Armpit Rear
AxillaLtRr_L	Torso	Armpit Rear
CenterButtocks_E	Torso	Most posterior midline point on the buttocks
SternSupCt_L	Torso	Anterior surface of jugular notch
SternSubCt_L	Torso	Substernale
FootMtar5LatLt_L	Leg	Ball of foot, lateral side
FootToe1Lt_L	Leg	Tip of big toe
FootMtar1MedLt_L	Leg	Fall of foot, medial side
FootMtar1MedRt_L	Leg	Ball of foot, lateral side
FootToe1Rt_L	Leg	Tip of big toe
FootMtar5LatRt_L	Leg	Fall of foot, medial side
KneeSupLt_L	Leg	Most proximal point on left patella
KneeInfLt_L	Leg	Most distal point on left patella
KneeSupRt_L	Leg	Most proximal point on right patella
KneeInfRt_L	Leg	Most distal point on right patella
FootHeelRt_L	Leg	Most posterior point on right heel
FootHeelLt_L	Leg	Most posterior point on left heel

Landmarks

Point Name	Body Part	Additional Description
Gonion_Lt_L	Head	Corner of jaw
Infrathyroid_Ct_L	Head	Adam's apple
Gonion_Rt_L	Head	Corner of jaw
BustPoint_Rt_L	Torso	Most anterior point on pectoral muscle or bust
BustPoint_Lt_L	Torso	Most anterior point on pectoral muscle or bust
Omphalion_Ct_L	Torso	Belly button (or center of belly button crease)
ArmUpper_Ant_Rt_L	Arm	Three points on each limb segment These points ring-around the middle of each semen on the anterior, posterior and lateral surfaces a determined in a neutral standing position. Nothing on the medial surface, as the inner thighs and inner arms usually do not scan well. Note: the anterior arm points will be pointing posterior when the shoulder is flexed (A1)- but still digitized the point on the biceps…etc.
ArmUpper_Lat_Rt_L	Arm	
ArmUpper_Pos_Rt_L	Arm	
ArmLower_Ant_Rt_L	Arm	
ArmLower_Lat_Rt_L	Arm	
ArmLower_Pos_Rt_L	Arm	
ArmLower_Pos_Lt_L	Arm	
ArmLower_Ant_Lt_L	Arm	
ArmUpper_Ant_Lt_L	Arm	
ArmUpper_Pos_Lt_L	Arm	
LegUpper_Ant_Lt_L	Leg	
LegUpper_Lat_Lt_L	Leg	
LegUpper_Pos_Lt_L	Leg	
LegLower_Ant_Lt_L	Leg	
LegLower_Lat_Lt_L	Leg	
LegLower_Pos_Lt_L	Leg	
LegLower_Pos_Rt_L	Leg	
LegLower_Lat_Rt_L	Leg	
LegLower_Ant_Rt_L	Leg	
LegUpper_Ant_Rt_L	Leg	
LegUpper_Lat_Rt_L	Leg	
LegUpper_Pos_Rt_L	Leg	
ThighJn_CtMidline_Rt_L	Leg/Torso	On the top (anterior) midline of the thigh where it contacts the abdomen.
ThighJn_CtMidline_Lt_L	Leg/Torso	On the top (anterior) midline of the thigh where it contacts the abdomen.
CrotchMidThighHt_Ct_L	Leg/Torso	Center of crotch at the mid-thigh height

Points on Scanning Equipment

Point Name	Equip. Part	Additional Description	Point to Digitize
ForcePlateTop_Rt_S	Force plate	The top right corner of the force plate (Relative to all scans except CB/CF which would be rear right corner)	Top edge at corner
ForcePlateTop_Lt_S	Force plate	The top left corner of the force plate (Relative to all scans except CB/CF which would be the front left corner)	Top edge at corner
ForcePlateTop_Ct_S	Force plate	The top center corner of the force plate (Relative to all scans except CB/CF which would be front right corner)	Top edge at corner
ForcePlate_Fore_M	Force	Top rear (relative to subject in CB) of more forward tape marker on force plate	Top rear corner
ForcePlate_Aft_M	Force	Top rear (relative to subject in CB) of more frearward tape marker on force plate	Top rear corner

SeatTop_Ft_Lt_S	*Seat surface*	*The front, left (relative to subject) top corner of the seat*	*Top edge at corner*
SeatTop_Ft_Rt_S	*Seat surface*	*The front, right (relative to subject) top corner of the seat*	*Top edge at corner*
SeatTop_Rr_Lt_S	Seat surface	The rear, left (relative to subject) top corner of the seat	Top edge at corner
SeatTop_Rr_Rt_S	Seat surface	The rear, right (relative to subject) top corner of the seat	Top edge at corner
Seat_Lt_M	Seat	Top-rear (relative to subject) corner of the tape marker on the left side of the seat	Top rear corner
Seat_Rt_M	Seat	Top-rear (relative to subject) corner of the tape marker on the right side of the seat	Top rear corner

SeatBackBar_Lt_M	Seat back for R, L, A, V	Top, outside corner of the left tape marker	Top outer corner
SeatBackBar_Rt_M	Seat back for R, L, A, V	Top, outside corner of the right tape marker	Top outer corner
CBSeatBack_Rt_S	Seat back CB	Center of the right "T" of the upright and cross piece on the seat back, outboard	Outboard center
CBSeatBack_Lt_S	Seat back CB	Center of the left "T" of the upright and cross piece on the seat back, outboard	Outboard center
SeatBackHorz_NrPivot_V	Seat back support	Two points along the bottom surface of the lower horizontal brace to define a vector. Fore-aft when used in CB, lateral when used in other postures	Nearest the pivot
SeatBackHorz_FrPivot_V	Seat back support		Furthest from the pivot

Handle_Top_Lt_S	Upright handle	Top of hand left hand positioner rod	Top outboard
Handle_Bot_Lt_S	Upright handle	Bottom of hand left hand positioner rod	Bottom outboard
Handle_Top_Rt_S	Upright handle	Top of hand right hand positioner rod	Top outboard
Handle_Bot_Rt_S	Upright handle	Bottom of hand right hand positioner rod	Bottom outboard
Handle_Pivot_Rt_S	Upright handle	Point on outboard edge of locking hub (pivot) nearest the handle on the right side	Most outboard point
Handle_Pivot_Lt_S	Upright handle	Point on outboard edge of locking hub (pivot) nearest the handle on the left side	Most outboard point

DiagPlatform_Rr_M	Diagonal foot platform	Top rear corner (re sub) of rear tape marker on the side of the diagonal foot platform	Top rear corner
DiagPlatform_Ft_M	Diagonal foot platform	Top rear corner (re sub) of front tape marker on the side of the diagonal foot platform	Top rear corner
DiagPlatform_Rr_Rt_S	Diagonal foot platform	Right rear corner (re sub) along surface of diagonal foot platform	Top edge at visible corner

CBFootPos_Rr_M	Frame for CB foot positioner	Top rear corner of rear tape marker on the side of the frame	Top rear corner
CBFootPos_Ft_M	Frame for CB foot positioner	Top rear corner of front tape marker on the side of the diagonal foot platform	Top rear corner

APPENDIX E
Methods for Standard Anthropometry

Table E1
Standard Anthropometry

1	Weight	12	Maximum Hip Breadth
2	Stature (with shoes)	13	Buttock Knee Length
2.5	Stature (without shoes)	14	Buttock-Popliteal Length
3	Erect Sitting Height	15	Biacromial Breadth
4	Eye Height (Sitting)	16	Shoulder Breadth
5	Acromial Height (Sitting)	17	Chest Depth (on a scapula)
6	Knee Height	18	Chest Depth (on spine)
7	Tragion to Top of Head	19	Bispinous (BiASIS) Breadth
8	Head Length	20	Chest Circumference at Axilla
9	Head Breadth	21	Waist Circumference
10	Shoulder Elbow Length	22	Hip Circumference at Buttocks
11	Elbow-Hand Length	23	Upper Thigh Circumference

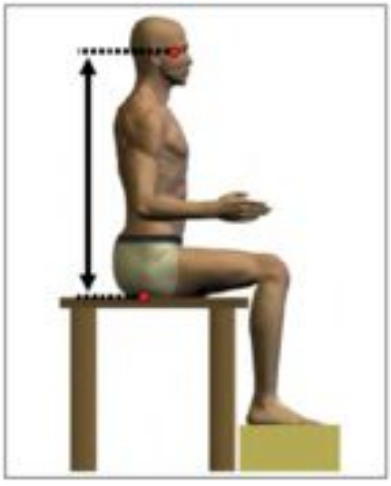
1. Weight -- measured using a scale to the nearest 0.1 kg.

2. Stature

DESCRIPTION: The vertical distance from a standing surface to the top of the head.
UNDRAWN LANDMARK: Top of head (vertex).
PROCEDURE: Participant is in the anthropometric standing position with the head in the Frankfurt plane. Stand at one side of the participant, and use an anthropometer to measure the vertical distance between the standing surface and the top of the head. Move the blade of the anthropometer across the top of the head to ensure measurement of the maximum distance. Use firm pressure to compress the participant's hair. The measurement is taken at the maximum point of quiet respiration.
INSTRUMENT: Anthropometer.
CAUTION: Be sure that the head is in the Frankfurt plane.

3. Erect Sitting Height
DESCRIPTION: The vertical distance between a sitting surface and the top of the head.
UNDRAWN LANDMARK: Top of head (vertex).
PROCEDURE: Participant is in the anthropometric sitting position with the head in the Frankfurt plane. Stand at the right rear of the participant, and use an anthropometer to measure the vertical distance between the sitting surface and the top of the head. Use sufficient pressure to compress the hair. The measurement is made at the maximum point of quiet respiration.
INSTRUMENT: Anthropometer.
CAUTION: Be sure the head is in the Frankfurt plane.


4. Eye Height (Sitting)
DESCRIPTION: The vertical distance between a sitting surface and the top of the head.
UNDRAWN LANDMARK: Top of head (vertex).
PROCEDURE: Participant is in the anthropometric sitting position with the head in the Frankfurt plane. Stand at the right rear of the participant, and use an anthropometer to measure the vertical distance between the sitting surface and the top of the head. Use sufficient pressure to compress the hair. The measurement is made at the maximum point of quiet respiration.
INSTRUMENT: Anthropometer.
CAUTION: Be sure the head is in the Frankfurt plane.

5. Acromial Height (Sitting) – ANSUR I
The vertical distance between a sitting surface and the acromion landmark on the tip of the right shoulder is measured with an anthropometer. The subject sits erect looking straight ahead. The shoulders and upper arms are relaxed and the forearms and hands are extended forward horizontally with the palms facing each other. The measurement is made at the maximum point of quietest respiration.

6. Knee Height
DESCRIPTION: The vertical distance between a footrest surface and the suprapatella landmark.
DRAWN LANDMARK: Suprapatella, right. ***<< marked standing***
PROCEDURE: Participant sits with the thighs parallel, the knees flexed 90°, and the feet in line with the thighs. The arms are relaxed at the sides. Stand at the right of the participant, and use an anthropometer to measure the vertical distance between the footrest and the drawn suprapatella landmark at the top of the knee.
INSTRUMENT: Anthropometer.

7. Tragion to Top of Head

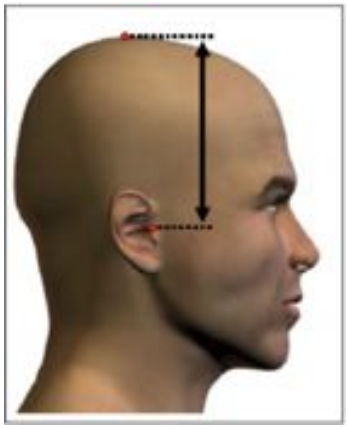
DESCRIPTION: The vertical distance between the right tragion landmark on the cartilaginous flap in front of the earhole and the horizontal plane tangent to the top of the head.

DRAWN LANDMARK: Tragion, right.

UNDRAWN LANDMARK: Top of head (vertex).

PROCEDURE: Participant sits with the head in the Frankfurt plane. Stand to the right of the participant, and use a beam caliper with paddle blade to measure the vertical distance between the right tragion landmark and the top of the head. The fixed blade is on tragion. Be sure the beam is parallel to the long axis of the head. Exert sufficient pressure to obtain contact between the paddle blade and the skin.

INSTRUMENT: Beam caliper with paddle blade.



8. Head Length

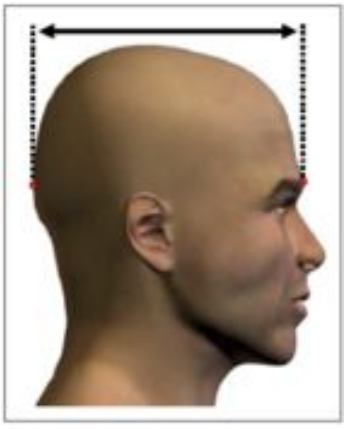
DESCRIPTION: The distance from the glabella landmark between the brow ridges to opisthocranion.

DRAWN LANDMARK: Glabella.

UNDRAWN LANDMARK: Opisthocranion.

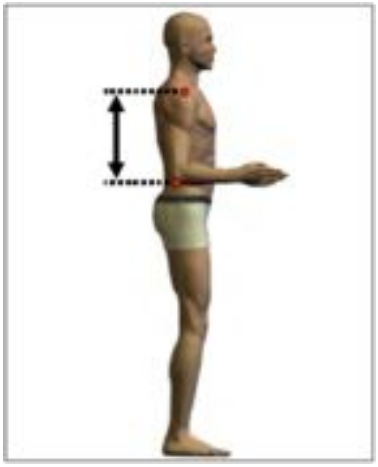
PROCEDURE: Participant sits. Stand at the right of the participant. Use a spreading caliper to measure in the midsagittal plane, the distance between the glabella landmark and opisthocranion. Place one tip of the caliper on glabella, and move the other tip up and down on the back of the head in the midsagittal plane until the maximum measurement is obtained. Use light pressure on glabella and enough pressure on opisthocranion to compress the hair.

INSTRUMENT: Spreading caliper.



9. Head Breadth
DESCRIPTION: The maximum horizontal breadth of the head above the ears.
UNDRAWN LANDMARKS: Euryon, right and left.
PROCEDURE: Participant sits. Stand behind the participant, and use a spreading caliper to measure the maximum horizontal breadth of the head above the ears (euryon, right and left). Exert sufficient pressure to obtain contact between the caliper and the skin.
INSTRUMENT: Spreading caliper.


10. Shoulder-Elbow Length
DESCRIPTION: The distance between the right acromion landmark and the olecranon landmark on the bottom of the right elbow.
DRAWN LANDMARK: Acromion, right
UNDRAWN LANDMARK: Olecranon, bottom.
PROCEDURE: Participant stands erect with the upper arm hanging at the side and the elbow flexed 90°. The hand is straight, and the palm faces inward (medially). Stand at the right of the participant, and use a beam caliper to measure the distance between the drawn acromion landmark on the tip of the shoulder and the bottom of the elbow (olecranon, bottom). The measurement is made parallel to the long axis of the upper arm. Place the fixed blade of the caliper on acromion. Exert only enough pressure to attain contact between the caliper and the skin.
INSTRUMENT: Beam caliper.
CAUTION: Be sure that the zero edge of the blade of the caliper is on acromion when the measurement is made and that the skin is not distorted.

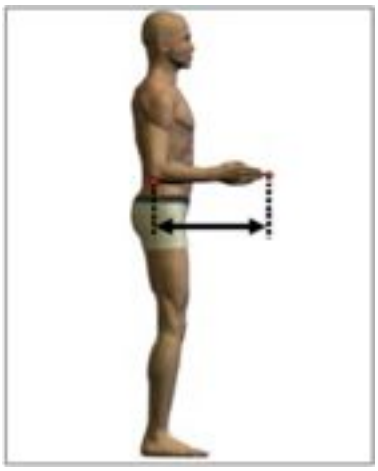



11. Elbow- Hand Length

DESCRIPTION: The horizontal distance between the back of the tip of the right elbow to the tip of the right middle finger.

UNDRAWN LANDMARKS: Olecranon, rear; Dactylion III, right.

PROCEDURE: Participant stands erect with the upper arms hanging at the side and the right elbow flexed 90°. The hand is held out straight with the palm facing inward. Stand to the right of the participant, and use a beam caliper to measure the horizontal distance between the back of the tip of the elbow (olecranon, rear) to the tip of the middle finger (dactylion III). Place the fixed blade on olecranon,



12. Maximum Hip Breadth

DESCRIPTION: Maximum hip (or thigh) breadth of a seated participant.

PROCEDURE: Participant sits erect with the feet and knees together and the arms relaxed at the sides. Stand in front of the participant, and use a beam caliper to measure the most lateral points on the hips or thighs (whichever are broader). The blades of the caliper are kept at approximately a 45° angle to the horizontal and moved up and down to locate the maximum breadth. Exert only enough pressure to ensure that the caliper blades are on the body.

INSTRUMENT: Beam caliper.

CAUTION: The recorder should help the participant hold the knees together. Make sure the participant's torso is still erect immediately prior to taking the measurement.

13. Buttock-Knee Length – Snyder
DESCRIPTION: The horizontal distance between a buttock plate placed at the most posterior point of either buttock and the anterior point of the right knee.
UNDRAWN LANDMARK: Knee point, anterior.
PROCEDURE: Participant is in the anthropometric sitting position, but with arms relaxed on the lap. Stand at the right of the participant, and slide the buttock plate toward the participant until it makes light contact with the most posterior point on either buttock. When the plate is in position lock it in place. Use an anthropometer to measure the horizontal distance between the buttock plate and the front of the knee (knee point, anterior). The base of the anthropometer is anchored on the buttock plate. Exert only enough pressure on the instrument to attain contact between the anthropometer blade and the knee.
INSTRUMENTS: Anthropometer, Buttock plate.
CAUTION: To ensure that the anthropometer is horizontal, be sure that the base of the anthropometer is fully against the buttock plate.

14. Buttock-Popliteal Length

DESCRIPTION: The horizontal distance between a buttock plate placed at the most posterior point of either buttock and the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh).

UNDRAWN LANDMARK: Popliteal fossa at the dorsal juncture of the calf and thigh.

PROCEDURE: Participant is in the anthropometric sitting position with the arms relaxed on the lap. Stand at the right of the participant, and slide the buttock plate toward the participant until it makes light contact with the most posterior point on either buttock. When the plate is in position, lock it in place. Use an anthropometer to measure the horizontal distance from the buttock plate to the back of the knee. This is done in such a way that the blade of the anthropometer is placed as high and as far forward as possible in the popliteal fossa behind the knee (dorsal juncture of the calf and thigh) without compressing tissue. Exert only enough pressure on the instrument to attain contact between the anthropometer blade and the skin.

INSTRUMENTS: Anthropometer, Buttock plate.

CAUTION: To ensure that the anthropometer is horizontal, be sure that the base of the anthropometer is fully against the buttock plate. The computer will add 1 cm to the recorded dimension to account for the width of the anthropometer blade.

15. Biacromial Breadth

DESCRIPTION: The distance between the right and left acromion landmarks on the tips of the shoulder.

DRAWN LANDMARKS: Acromion, right and left.

PROCEDURE: Participant is in the anthropometric sitting position. Stand behind the participant, and use a beam caliper to measure the distance between the drawn right and left acromion landmarks at the tips of the shoulders. The beam should be parallel to the coronal plane. If the acromial landmarks cannot be seen from behind, stand in front of the participant. The measurement is taken at the maximum point of quiet respiration. Use sufficient pressure to maintain firm contact with the skin.

INSTRUMENT: Beam caliper.

CAUTION: The participant must not be allowed to change the position of the shoulders.

16. Shoulder Breadth

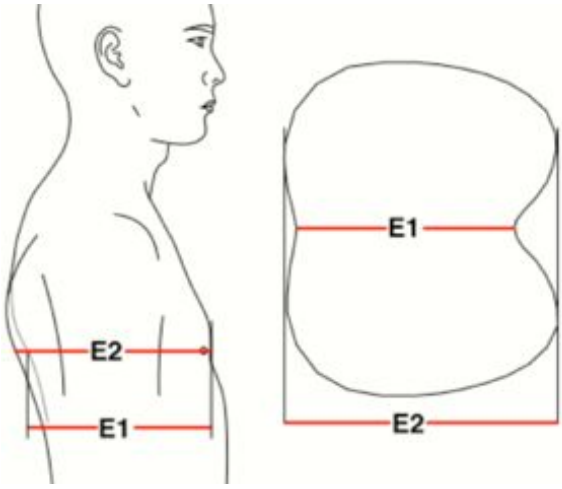
DESCRIPTION: The maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles.

PROCEDURE: Participant is in the anthropometric sitting position. Stand behind the participant, and use a beam caliper to locate the greatest horizontal distance between the outside edges of the deltoid muscles on the upper arms. This is done by brushing the caliper blades up and down the upper arms. When the blades lightly touch the skin on both sides, withdraw the instrument to read off the measurement. The measurement is made at the maximum point of quiet respiration. Note that the deltoid landmarks are NOT used for this dimension.

INSTRUMENT: Beam caliper.

17. Chest Depth (on scapula) – (E2 in illustration)
DESCRIPTION: The horizontal distance between the right chest point anterior landmark and the back at the same level.
DRAWN LANDMARK: Chest point, anterior, right.
PROCEDURE: Participant is in the anthropometric standing position. Stand at the right of the participant, and use a beam caliper to measure the horizontal distance between the chest at the level of the right chest point anterior landmark and the back at the same level. Place the fixed blade of the caliper on the back. On women, the landmark will be an adhesive dot on the bra. Before taking the measurement verify that this landmark has not shifted. This measurement is taken at the maximum point of quiet respiration. Exert only enough pressure to maintain contact between the caliper and the skin (or bra).
INSTRUMENT: Beam caliper.
CAUTION: Participant must not be allowed to change the position of the shoulders.

18. Chest Depth (on spine) – (E1 in illustration)
The horizontal distance between the sternum, at the level of the right bust point on women or the nipple on men (*and children*), and the spine at the same level is measured with a curved caliper. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



19. Bispinous Breadth – ANSUR I

The straight-line distance between the right and left anterior superior iliac spine landmarks is measured with a bema caliper. The subject stands looking straight ahead with the heels together and the weight distribute equally on both feet.

20. Chest Circumference at Axilla

DESCRIPTION: The maximum circumference of the chest at the fullest part of the breast. *DRAWN LANDMARK: Chest point, anterior, right.*

PROCEDURE: Participant is in the anthropometric standing position in front of a mirror. Stand in front of the participant, and use a tape to measure the horizontal circumference of the chest at the level of the right chest point anterior landmark. On women, the landmark will be an adhesive dot on the bra. Before taking the measurement verify that this landmark has not shifted. Use the mirror to check the position of the tape as it crosses the participant's back. This dimension will cross very soft tissue at the armpit and bust, and some compression of the tissue will inevitably occur. Be sure, however, to keep this to a minimum. Exert only enough tension on the tape to maintain contact between the tape and the skin. The tape will span body hollows in this measurement. The measurement is taken at the maximum point of quiet respiration.

INSTRUMENT: Steel tape.

21. Waist Circumference

DESCRIPTION: The horizontal circumference of the waist at the level of omphalion encompassing the waist (omphalion) landmarks.

DRAWN LANDMARKS: Waist (omphalion), right, left, anterior and posterior.

PROCEDURE: Participant is in the anthropometric standing position in front of a mirror. Stand in front of the participant, and use a tape to measure the horizontal distance around the torso at the level of the center of the navel. The tape will pass over the drawn waist (omphalion) landmarks at the front, DESCRIPTION: The horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock.

DRAWN LANDMARKS: Buttock point, right lateral and left lateral.

UNDRAWN LANDMARK: Buttock point, posterior.

PROCEDURE: Participant stands erect on a table with heels together. Ask the participant to hold up the right leg of the shorts to expose the landmark. Stand at the participant's right, and use a tape to measure the horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock. The tape should pass over the posterior buttock point (not drawn) and the buttock point landmarks drawn on the right and left hips. If necessary, ask male participants to adjust the genitalia so as to interfere as little as possible with the tape. Exert only enough tension on the tape to maintain contact between the tape and the skin.

INSTRUMENT: Steel tape.

CAUTION: The participant must not tense the abdominal muscles.

22. Hip Circumference at Buttocks
DESCRIPTION: The horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock.
DRAWN LANDMARKS: Buttock point, right lateral and left lateral.
UNDRAWN LANDMARK: Buttock point, posterior.
PROCEDURE: Participant stands erect on a table with heels together. Ask the participant to hold up the right leg of the shorts to expose the landmark. Stand at the participant's right, and use a tape to measure the horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock. The tape should pass over the posterior buttock point (not drawn) and the buttock point landmarks drawn on the right and left hips. If necessary, ask male participants to adjust the genitalia so as to interfere as little as possible with the tape. Exert only enough tension on the tape to maintain contact between the tape and the skin.
INSTRUMENT: Steel tape.
CAUTION: The tape must be maintained in a horizontal plane.


23. Upper Thigh Circumference
DESCRIPTION: The circumference of the thigh at its juncture with the buttock.
DRAWN LANDMARK: Gluteal furrow point, right.
PROCEDURE: Participant stands erect on a table with the weight distributed equally on both feet. The legs are spread apart just enough so that the thighs do not touch, and the right hand is on the chest. Stand at the right of the participant, and use a tape to measure the circumference of the thigh at its juncture with the buttock (gluteal furrow point). The measurement is made perpendicular to the long axis of the thigh. Exert only enough tension on the tape to maintain contact between the tape and the skin.
INSTRUMENT: Steel tape.
CAUTION: The participant must not tense the thigh muscles. The tape must not be placed in a furrow.


Definitions

Acromion: The most lateral bony point on the acromion process of the scapula (shoulder blade). It is near the shoulder joint center of rotation.

Axilla: the armpit

Bust point: The anterior point of the bra cup

Chest point: The most anterior right point on the chest.

Buttock Point: Point at the level of the maximum protrusion of the right buttock.

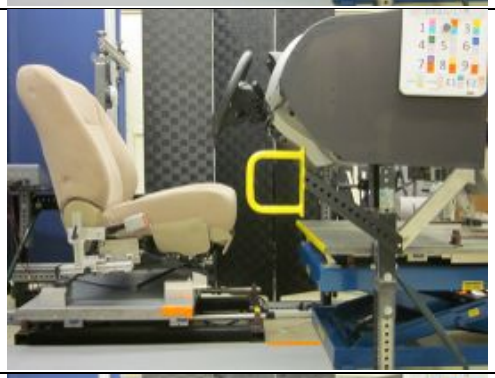
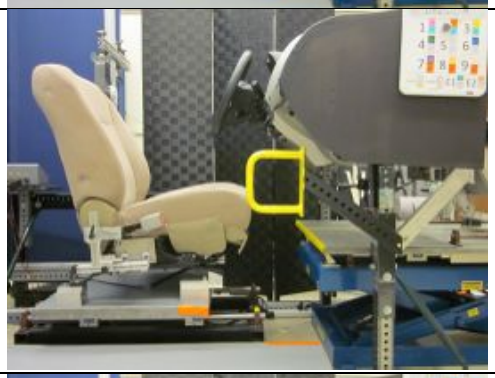
Glabella: The most prominent point palpable on the forehead between the eyebrows (Supra-orbital ridges) and above the junction of the nose (nasofrontal suture) with the forehead.

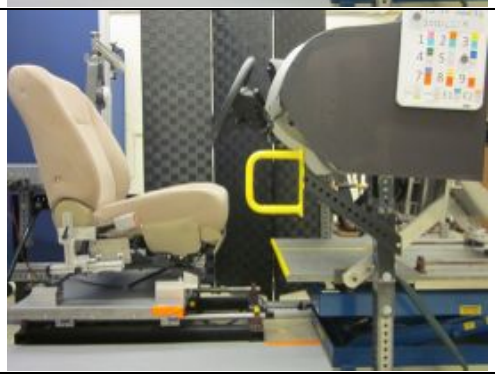
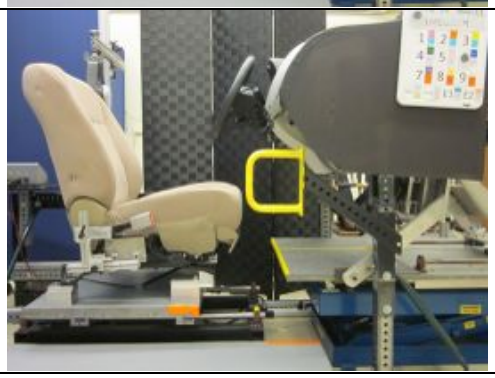
Iliocristale: The highest palpable point of the right and left iliac crests of the pelvis, one half the distance between the anterior superior iliac and posterior superior iliac spines.

Procedure- Participant stands in the anthropometric standing position. Stand in front of the participant. Use both hands to locate the anterior and posterior points of the iliac crests and note one half the distance between them. At this midpoint, use the tip of the finger to move upwards on the right side to locate the highest palpable point, and draw a short horizontal line through the landmark. Draw two dots anterior to the line. Repeat the process on the left side.

Gluteal furrow point: the lowest point of the lowest furrow or crease at the juncture of the right buttock and the thigh.

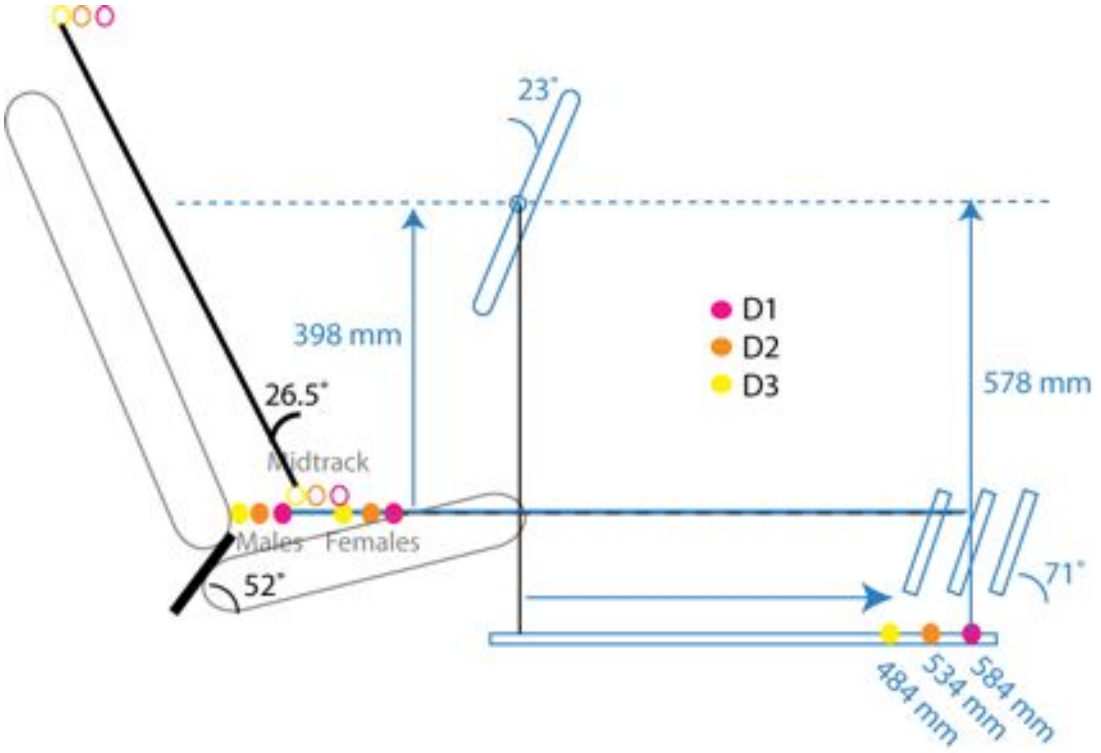
APPENDIX F
Photos of Driver Test Conditions

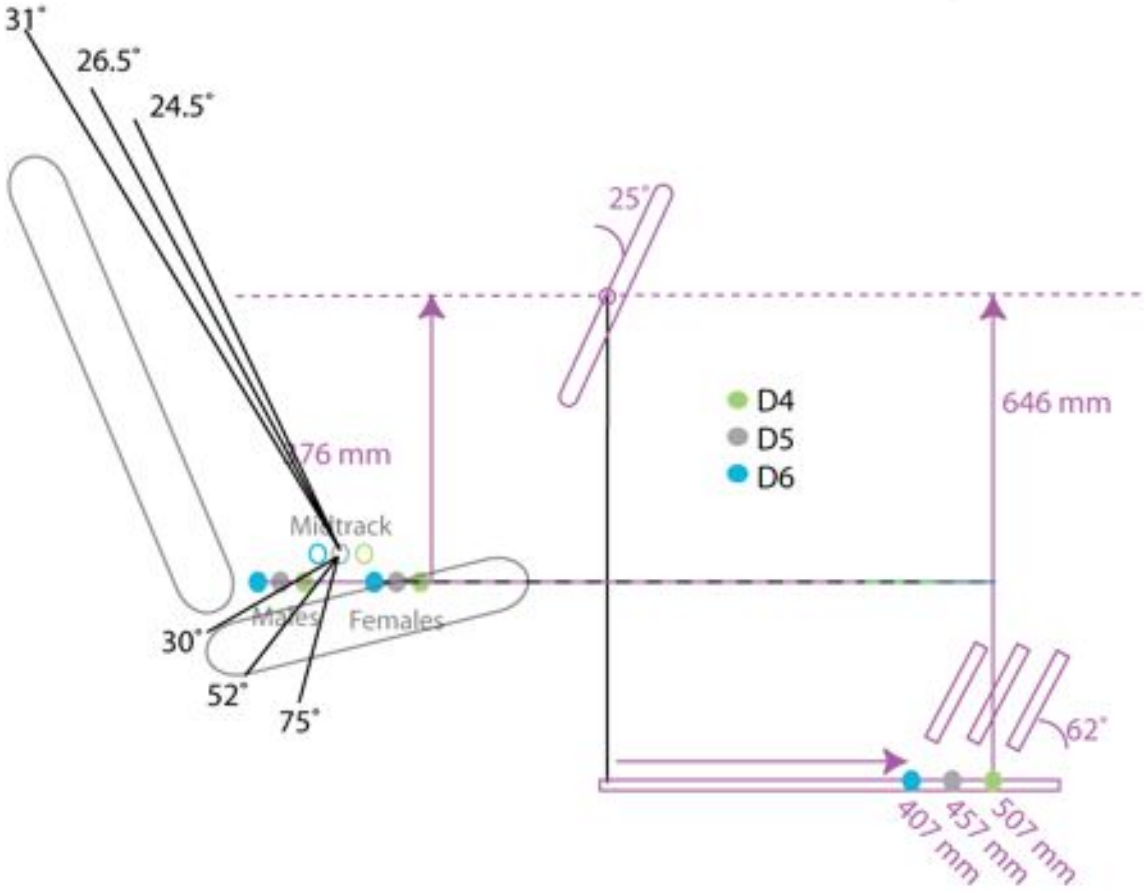
Package	Belt	Male	Female
D1	mid		
D2*	mid		
D3	mid		

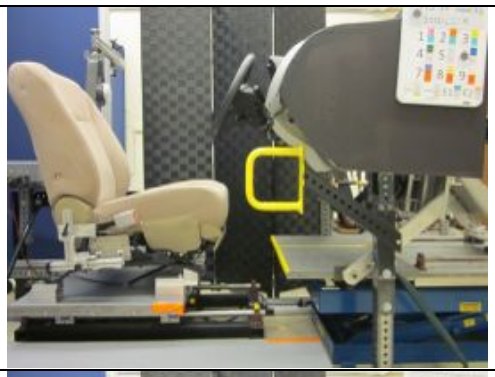
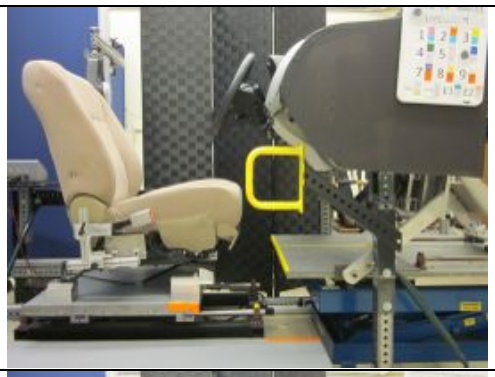
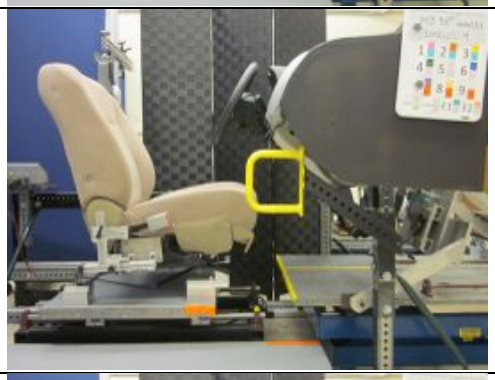
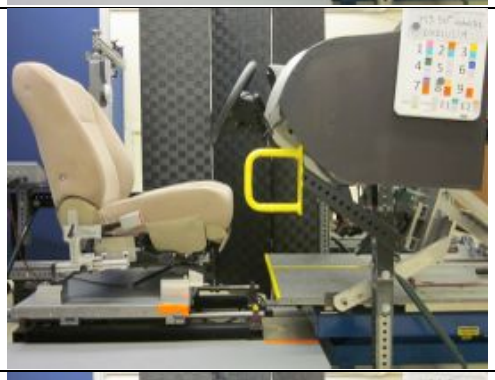
D4*	mid		
D5	mid		
D6*	mid		

D5	**mid**		
D5	**30˚**		
D5	**75˚**		
D5	**EXT 1**		

D5	**EXT 2**		


23°
398 mm
D1
D2
D3
578 mm
26.5°
Midtrack
Males
Females
52°
71°
584 mm
534 mm
484 mm


31°
26.5°
24.5°
25°
D4
D5
D6
646 mm
76 mm
Midtrack
Males
Females
30°
52°
75°
62°
507 mm
457 mm
407 mm

D6*	mid		
D7	mid		
D8*	mid		
D9	mid		

APPENDIX G
Photos of Passenger Test Conditions

P1	19°	270	mid	mid	
P2*	19°	360	mid	mid	

P3	23˚	180	mid	mid	
P4	23˚	270	mid	mid	
P4	23˚	270	**30˚**	**30˚**	

P4	23˚	270	**75˚**	**75˚**	
P4	23˚	270	**EXT 1**	**EXT 1**	
P4	23˚	270	**EXT 2**	**EXT 2**	

P5	23°	360	mid	mid	
P6	27°	270	mid	mid	
P7*	27°	180	mid	mid