This is to certify that the

thesis entitled

Influence of Automotive Seat Factors on Posture and

Applicability to Design Models

presented by

Phaedra Elizabeth Gutowski

has been accepted towards fulfillment
of the requirements for

Master's degree in Engineering Mechanics

[signature]
Major professor

Date Nov. 21, 2000

INFLUENC

INFLUENCE OF AUTOMOTIVE SEAT FACTORS ON POSTURE AND APPLICABILITY TO DESIGN MODELS

By

Phaedra Elizabeth Gutowski

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Materials Science and Mechanics

2000

INFLUENC

Through th

effects of seat an

for four automot

packages with res

seats were adjust

allowed to choos

were not instruct

locations of the s

its relation to the

occupants did n

slid forward in th

erect postures w

from the driver s

differences rea

factors to deter

ABSTRACT

INFLUENCE OF AUTOMOTIVE SEAT FACTORS ON POSTURE AND APPLICABILITY TO DESIGN MODELS

By

Phaedra Elizabeth Gutowski

Through the use of a video-based motion data collection system the effects of seat and package factors on subject selected posture were examined for four automotive seats. Subjects were placed in both sedan and van interior packages with respect to seat height and toebar to steering wheel depth. The seats were adjusted to both the lumbar on and off positions with the test subjects allowed to choose their own fore/aft seat position and backrest recline. Subjects were not instructed on placement of the pelvis in the seat. Several internal joint locations of the spine were estimated to examine the overall spinal position and its relation to the position and contour of the seat. Results indicated that occupants did not use the lumbar supports as they were intended, and instead slid forward in the seats, away from the lumbar supports. Subjects chose more erect postures when the seats were in the higher van setting. Postural changes from the driver to passenger position affected the angle of the knees, with some differences reaching up to the hips. These findings can be combined with seat factors to determine correlations between SAE manikin and human responses.

DEDICATION

In loving memory of
my grandparents

George E. White
1921 –1999

Melvin A. Paul
1914 – 1998

Katherene E. Allman
1912 – 1994

I would like t

this endeavor:

Casey Pruett

and financial support

Heidi Bogard,

their help with test b

My committee

Dr. Thomas Pence fo

Dr. Robert Hubbard f

show how my studies

her friendship and te

necessary to interpre

My family, par

advice and encourag

has played a major ro

My best friend

throughout this endea

achieving personal g

this study.

ACKNOWLEDGEMENTS

I would like to thank the following individuals for their contributions towards this endeavor:

Casey Pruett, Jochen Balzulat and the staff of TecMath for their technical and financial support.

Heidi Bogard, Joanne Ewen, Thomas Fowler, and Walter Macklem for their help with test buck construction, subject testing and data processing.

My committee members for their efforts towards my degree completion - Dr. Thomas Pence for his advice and assistance in starting my graduate career. Dr. Robert Hubbard for his enthusiasm, advice, encouragement, and ability to show how my studies relate to practical applications. Dr. Tamara Reid Bush for her friendship and technical expertise in test protocol definition and the statistics necessary to interpret these data.

My family, particularly my parents, Malcolm and Nancy Paul, for their advice and encouragement in all aspects of my life. Their love and belief in me has played a major role in my success.

My best friend and husband, Mark, for lending an ear during difficult times throughout this endeavor. Thank you for understanding the importance of achieving personal goals and having the “courage” to marry me in the middle of this study.

Section

TABLE OF CONTENTS

LIST OF TABLES

Figure No.

LIST OF FIGURES

KEY TO ABBREVIATIONS

Abbreviation	Term
ACos	Arc cosine
ASIS	Anterior Superior Iliac Spine
ASPECT	Automotive Seat and Package Evaluation and Comparison Tools
BRA	Body Recline Angle
C7	Seventh Cervical Vertebrae
HJC	Hip Joint Center
JCI	Johnson Controls, Inc.
L1	First Lumbar Vertebrae
L3	Third Lumbar Vertebrae
L5	Fifth Lumbar Vertebrae
LLA	Lower Lumbar Angle
LLJ	Lower Lumbar Joint
LNJ	Lower Neck Joint
LSLA	Lumbar Spine Link Angle
LSP	Lumbar Support Prominence
PD	Pelvic Depth
PH	Pelvic Height
PLA	Pelvic Link Angle
PSIS	Posterior Superior Iliac Spine
PW	Pelvic Width
SAE	Society of Automotive Engineers
T8	Eighth Thoracic Vertebrae
T12	Twelfth Thoracic Vertebrae
TLC	Total Lumbar Curvature
TSLA	Thoracic Spine Link Angle
ULA	Upper Lumbar Angle
ULJ	Upper Lumbar Joint
UMTRI	University of Michigan Transportation Research Institute

1. INTRODUCTION

Seats support diverse user groups, ranging from infants in travel seats to people who are elderly or disabled. These diverse user groups therefore require diverse designs to appropriately accommodate and support each occupant. Several authors have cited the need for improved seating to reduce stress in the spine and its resulting low back pain [20, 22, 44, 45, 70], reduce pressure sores in the buttocks [19, 70], and improve comfort [19, 79]. The definition of comfort has even been debated and ranges from the lack of discomfort to actually improving the health of the occupant.

Due to the various implications, seating is a concern in many markets, including medical [19, 70], airline [19], office [43, 47], and automotive [27, 36, 39, 44, 50, 53, 60]. There has been a renewed interest in seating since the time spent in seated positions has increased drastically due to the proliferation of automobiles and computers, and society has shifted towards white-collar work and longer commuting distances. However, the methods of seat design have lagged behind the demands for improved function and comfort. Until recently, designing seats for comfort was often based solely on subjective measures. Occupants, such as fighter pilots, would point out where the seat was uncomfortable and designers would alter the cushion stiffness in that area, in hopes of improvement [19]. Although this method may have helped that individual, no records were kept for how to reproduce a seat or what factors a given size or user group found important.

1.1 Automotive

The auto
maintaining a co
in part by the co
on the controls, a
passenger seats
"rest chair" [79].

The comb
and the vibratio
development of
found that drivi
discs. Althoug
vibration – it w
day were more
A consistent p
lumbar discs a
was attributab
out of shock-a
capable of sup
vibrational loa
the spinal stres

Owing to
measure, impro

1.1 Automotive Seating

The automotive driver has been described as being physically at rest while maintaining a constant state of alertness [32]. The driver's posture is controlled in part by the constraints of this task – the feet must be on the pedals, the hands on the controls, and the eyes sustaining the visual demands. The driver and passenger seats have accordingly been referred to as the "work chair" and the "rest chair" [79].

The combination of maintaining a constant position for extended periods and the vibrational environment of an automobile has been implicated in the development of spinal disc degeneration. Epidemiological studies [44, 45] have found that driving increases the likelihood of developing acute herniated lumbar discs. Although there is still some debate over the culprit – poor posture versus vibration – it was apparent that persons that drove cars at some point during the day were more likely to develop this problem than those who did not drive at all. A consistent pattern was also noted between the occurrence of acute prolapsed lumbar discs and the age of the car driven. It was not possible to tell if this trend was attributable to improved biomechanical properties of newer cars or wearing out of shock-absorbing properties in the older cars. In either case, a seat that is capable of supporting a healthy posture may be better suited to handling vibrational loads since improper sitting posture has been implicated in increasing the spinal stress from vibration and road shock [79].

Owing to the fact that posture is highly individualized and difficult to measure, improvements in seating industries, such as automotive, have been

relatively slow to
factors in seat c
has illustrated se
Factors such as
improved vehic'e
contours have a
conforms to pe
different desig
and vibration c
another when
discomfort, th
inducing the
severe, the r
that were th
determinatio

Altho
44, 45, 70].
they play w
design deci
technologie
pressure ma
and their re'a

relatively slow to take form. It is the job of the engineer to account for human factors in seat designs; however, research, such as that by Shen and Vertiz [10], has illustrated several reasons why seat studies may not directly help engineers. Factors such as interface pressure and vibration have been reduced due to improved vehicle dynamics and road conditions over the last several years. Seat contours have also been designed to accommodate a generic body shape that conforms to people more closely than previous models. Therefore, when seats of different designs satisfy the basic requirements of minimizing interface pressure and vibration discomfort, it is difficult for these seats to be distinguished from one another when tested for comfort. In the presence of multiple sources of discomfort, the overall feeling of discomfort is determined by the component inducing the highest discomfort. However, when none of these sources are severe, the role of each source on comfort becomes obscure and seat features that were thought to be unimportant may start playing significant roles in the determination of occupant comfort and subsequent seated position.

Although it is agreed that seated postures need improvement [19, 20, 22, 44, 45, 70], the lack of acceptance of comfort measures and the unknown role they play with return on investments has lowered the priority of comfort criteria in design decision making. Fortunately, significant improvements in measurement technologies, such as video-based biomechanical analyses, force plates, and pressure mapping, have increased the acceptance of these objective measures and their relation to subjective ratings in comfort assessments [19, 21].

To create

ease the imple

interact with sea

geometry, and m

location, controls

the vehicle. Unt

human reaction t

be created that w

Although

lordosis and hav

to accomplish th

have been des

settings and po

is relatively un

It has be

and lumbar sup

cause even gre

designed witho

do not allow co

angle, may cau

achieving that i

spine unsuppor

affected by sea

To create computer models that save time and money for prototyping and ease the implementation of design changes, more information about how people interact with seats is needed. Predicting the location of occupants, their geometry, and motion in a car leads to better determination of safety restraint location, controls reach, and visibility – factors that affect the overall operation of the vehicle. Until further studies of the effects of seat and interior features on the human reaction to seats have been conducted and interpreted, software cannot be created that will appropriately imitate the human response.

Although it is agreed [10, 70] that the ideal seat would promote lumbar lordosis and have sufficient adjustments to be comfortable for many people, how to accomplish this goal is still debatable. Several production and prototype seats have been designed to incorporate the current information on individual seat settings and posture; however, the actual response of individuals to these seats is relatively unknown.

It has been suggested [58] that people may not use the available backrest and lumbar supports in accordance with the designs. This incorrect use may cause even greater discomfort to the occupant than if the seat had been designed without the lumbar support or other key features. Lumbar supports that do not allow comfortable pelvis rotation, given the subject selected backrest angle, may cause the occupant to shift forward in the seat, consequently achieving that individual's desired pelvis orientation but leaving the lower lumbar spine unsupported. The purpose of this study was to measure posture as it is affected by seat and interior package factors for a range of subject sizes. The current stud

in posture d

positions. an

current study uses a video-based data collection system to examine the changes in posture due to lumbar prominence variations, package settings, hand and leg positions, and size of occupants.

2.1 Motion Data

Video-ba

determine the th

to the human bod

covered with nu

around the circu

systems only me

the body segme

orientation with

therefore great

system by Mac

Figure 1: Vide

In some

in these instan

2. BACKGROUND

2.1 Motion Data Acquisition

Video-based motion analysis systems are often used in biomechanics to determine the three-dimensional coordinates of retro-reflective targets attached to the human body. The retro-reflective tape used to make these targets is covered with numerous glass beads that reflect the infrared light emitting from around the circumference of each camera lens, refer to Figure 1. Since these systems only measure the target locations, the assumption must be made that the body segments are rigid and the targets maintain a constant relative orientation with respect to the underlying bones. The choice of bony landmarks therefore greatly impacts the reliability of the resulting data. The Qualisys system by MacReflex [55] was used in this study.

(a) (b)

Figure 1: Video-based motion analysis target (a) and targeted test subject (b).

In some cases, targets are not visible to the cameras. A probe was used in these instances to reach the desired location. Point P, shown in Figure 2, was calculated by t

the probe.

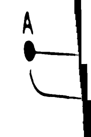


Figure 2: Calcula

2.2 Anatomy

2.2.1 Anatomica

The posi

planes shown in

is the plane tha

plane is any ve

the body into a

located at the f

of the body. Th

portions by the

centerline, of th

relative positio

to the trunk of t

to the trunk, wi

calculated by tracking the locations of targets A and B and knowing the length of the probe.

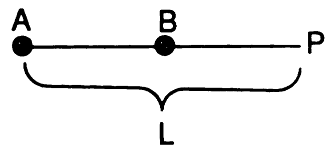


Figure 2: Calculating a probed location.

2.2 Anatomy

2.2.1 Anatomical Positioning

The position and movement of the body are described by the anatomical planes shown in Figure 3. The mid-sagittal plane, or median plane, of the body is the plane that separates the body into the left and right sides [16]. A frontal plane is any vertical plane perpendicular to a sagittal plane. This plane divides the body into anterior and posterior sections, with anterior facing toward or located at the front of the body and posterior facing toward or located at the back of the body. The body is also divided into upper (superior) and lower (inferior) portions by the transverse plane. Medial refers to closer to the median plane, or centerline, of the body and lateral is away from the center of the body. The relative position of the body segments is described by telling which part is closer to the trunk of the body or to a major joint. Proximal refers to a part that is closer to the trunk, with distal being further away.

Latera

Right

Figure 3

2.2.2 Th

T

infraorbi

in Figure

is horizo

Frankfo

Figure 4.

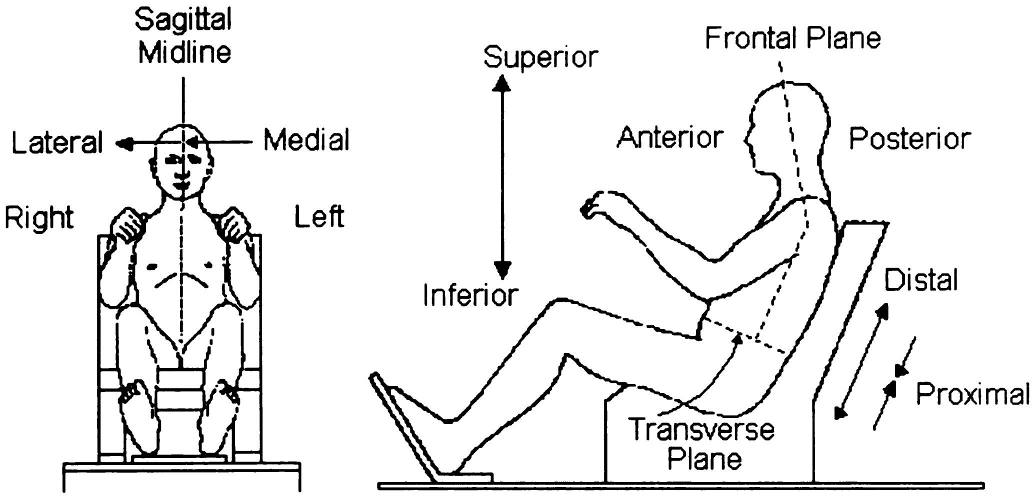


Figure 3: Anatomical planes of the body [67].

2.2.2 The Head

The Frankfort plane of the head is defined as a plane through the infraorbitale landmark of the eye and the tragion landmarks of the ears as shown in Figure 4 below. The head is often considered level when the Frankfort plane is horizontal.

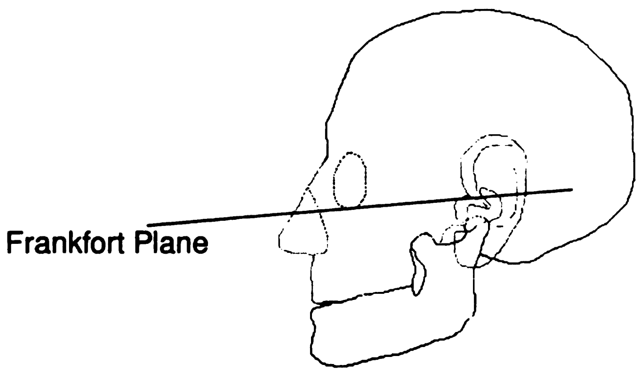


Figure 4: The Frankfort plane of the head.

2.2.3 Th

W

ensure

the sub

used so

the sub

therefor

S

would b

the test

Olecra
Proce
Ulna (
Elbow

Figure 5

2.2.4 Th

I

condyle

landmar

2.2.3 The Upper Extremities

When targeting the body, care must be used in target location selection to ensure visibility to multiple cameras and not affect the motion or positioning of the subject. For example, when targeting the elbow only the lateral surface was used so as to be visible to the cameras and not have the target knocked off when the subject moved his/her arms. The lateral epicondyle of the humerus was therefore used in this study (refer to Figure 5).

Similarly, the wrist was located with the ulnar condyle since this landmark would be visible to the cameras, is easily identified, and of limited interference to the test subject.

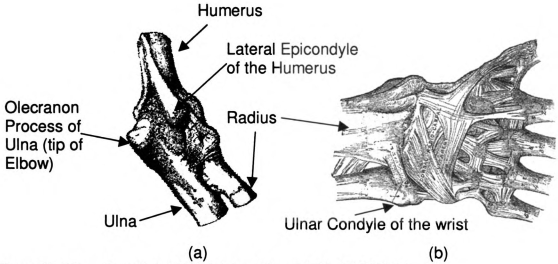


Figure 5: The elbow joint [25] (a) and the wrist joint [76] (b).

2.2.4 The Lower Extremities

In the knee joint, the distal end of the femur has lateral and medial condyles as shown in Figure 6 (a) and (b) below. These condyles are palpable landmarks and can therefore be used as target locations to locate the femur. In cases where th

be needed on e

either femoral c

was chosen for

knocked off whe

Figure 6: Anat

The upp

the acetabulum

detail with the p

The loca

analysis of this

with the ball of f

of foot target wa

visible to the cam

cases where the internal joint motions are to be examined, three targets would be needed on each bony segment; however, for a simplified sagittal analysis either femoral condyle is sufficient to locate the knee joint. The lateral condyle was chosen for this study to maintain visibility and prevent the target from being knocked off when the subject moved around the test space.

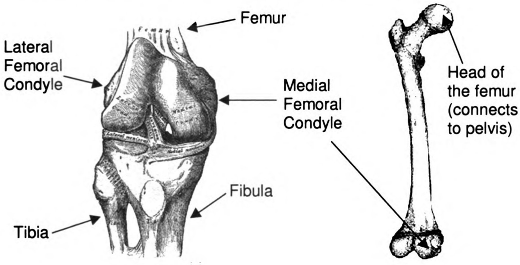


Figure 6: Anatomy of the (a) knee joint [46] and the (b) femur [26].

The upper head of the femur has a smooth spherical surface that fits into the acetabulum of the pelvis to form the hip joint. This will be discussed in further detail with the pelvis, refer to Figure 6 (b) above for a view of this bone structure.

The location of the ankle and foot are also of interest in a biomechanical analysis of this nature. The lateral malleolus is often used to locate the ankle with the ball of foot being used to locate the rest of the foot. For this test the ball of foot target was placed on the lateral side on top of the shoe in order to be visible to the cameras as shown in Figure 7.

Figure 7: Lanc

2.2.5 The Thc

The an

comprised of t

sternum joins

referred to as

become fused

the sternum w

often not visib

camera view d

was also assu

First Thoracic
Vertebrae (T1)

Twelfth
Thoracic
Vertebrae
(T12)

First Lumbar
Vertebrae (L1)

Figure 8: Thora

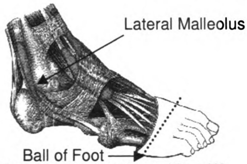


Figure 7: Landmarks of the ankle and foot [3].

2.2.5 The Thorax

The anatomy of the thorax, or ribcage shown below in Figure 8, is comprised of three bony structures: the spine, the ribs, and the sternum. The sternum joins the left and right ribs on the front of the body, with the top portion referred to as the manubrium. The manubrium and the body of the sternum become fused by adulthood [16]. The sternal notch and a point mid-way down the sternum were chosen for this study. The xyphoid was not used since it is often not visible on female subjects. The xyphoid is also typically blocked from camera view during testing, due to the arms in the driver position. The ribcage was also assumed rigid [75].

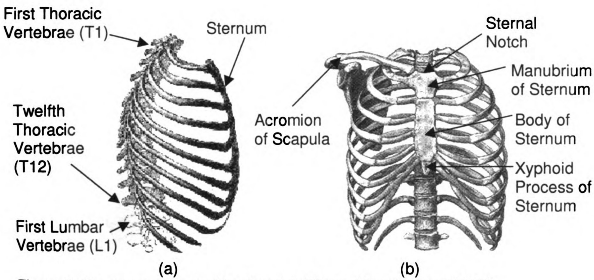


Figure 8: Thorax anatomy; side view (a) [62] and frontal view (b) [8].

2.2.6 The Spine

The spine

(C1 – C7), twelve

vertebrae (S1 – S

between the vert

add to the mob

thoracic region is

limits motion of t

by the connectio

sacrum complex

spine. The cocc

joined to the sa

Each reg

demonstrated in

concave toward

(kyphotic), the l

shown in Figure

(a

Figure 9: The v

2.2.6 The Spine

The spine is typically comprised of seven cervical vertebrae, denoted as (C1 – C7), twelve thoracic (T1 – T12), five lumbar (L1 – L5), and five sacral vertebrae (S1 – S5), as shown in Figure 9 below. In the lumbar region, the discs between the vertebrae are about one-third of the thickness of the vertebrae and add to the mobility of the lumbar spine [16]. The thickness of the discs in the thoracic region is only about one-sixth of the vertebral thickness and significantly limits motion of the thoracic spine. Mobility of the thoracic spine is further limited by the connection of these vertebrae to the ribcage. The fused vertebrae of the sacrum complete the pelvic ring with the two ilia, while the coccyx completes the spine. The coccyx is usually formed from four small bones, fused together and joined to the sacrum.

Each region of the vertebral column has a characteristic curvature, demonstrated in Figure 9. When standing, the cervical region is typically concave toward the back, referred to as lordosis. The thoracic region is convex (kyphotic), the lumbar region is again concave, and the sacrum is convex as shown in Figure 9 (b).

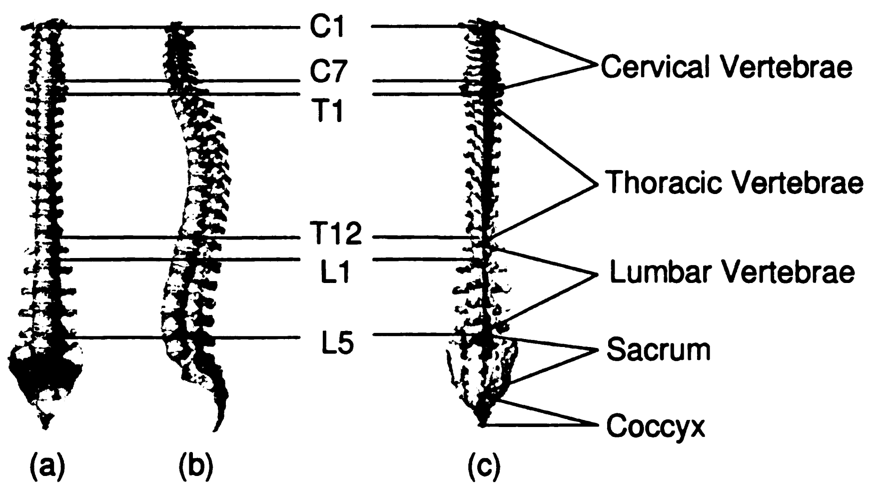


Figure 9: The vertebrae of the spine, (a) anterior, (b) left lateral, (c) posterior view [73].

2.2.7 The Pelv

The pel

of the iliac crest

are often used to

located and targ

in Figure 10 be

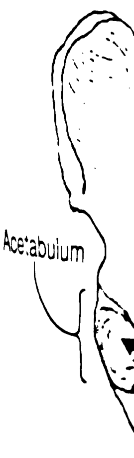


Figure 10: Fro

A third

dimensional sp

the first sacral

center (HJC).

between the le

meet.

2.2.7 The Pelvis

The pelvis has two bony protrusions (one on each side) at the frontal edge of the iliac crests. These protrusions are the anterior superior iliac spines and are often used to locate the pelvis in biomechanical studies since they are easily located and targeted with minimal privacy invasion to the test subject, as shown in Figure 10 below.

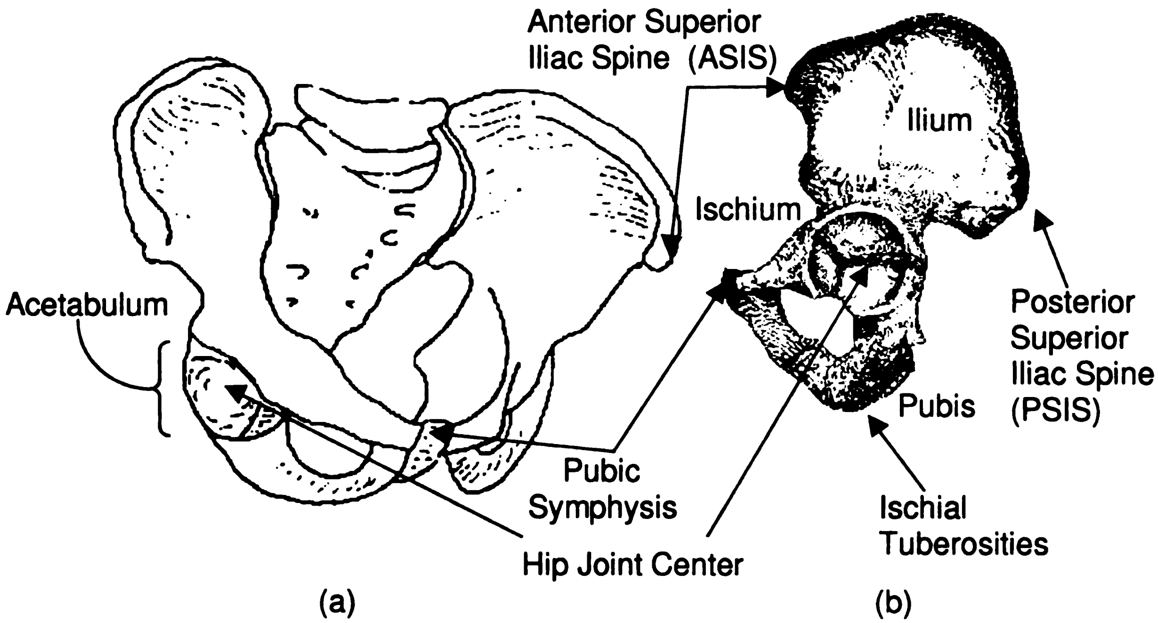


Figure 10: Frontal view of the pelvis (a)[6] and side view (b) [54].

A third point on the pelvis is necessary to determine its position in three-dimensional space. The most commonly used options are the pubic symphysis, the first sacral vertebrae on the back, either ischial tuberosity, or either hip joint center (HJC). As can be seen from Figure 10, the pubic symphysis is the joint between the legs where the front portion of the left and right sides of the pelvis meet.

Since us

test subject to c

between his or

the back of the

excluded from us

require that press

estimated from p

study as it can b

later be discuss

hemisphere w

2.3 The Biome

2.3.1 Seated F

The sha

rotation of the

trunk in stand

Figure 11(a).

rearward and t

when sitting.

(a)

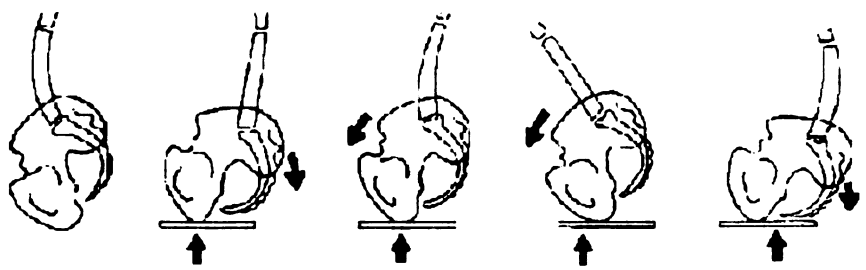
Figure 11: The p
unsupported in t
position; (d) sitt

Since use of the pubic symphysis in a biomechanical study requires the test subject to be comfortable with the privacy invasion of placing a probe between his or her legs, it was excluded. Use of the S1 landmark requires that the back of the test subject be visible during testing so this option was also excluded from use. Methods involving locations of either ischial tuberosity [10] require that pressure mat data also is collected and the ischial tuberosity location estimated from peak pressure values. The right HJC was therefore used in this study as it can be estimated from the ASIS and femoral target motion data as will later be discussed. In these cases the acetabulum is assumed to be a hemisphere with the HJC defined as the center of the acetabulum [49].

2.3 The Biomechanics of Sitting and Seat Design

2.3.1 Seated Posture

The shape of the lumbar spine during sitting depends, in part, on the rotation of the pelvis. Lordosis of the spine is usually required to balance the trunk in standing since the sacral endplate is typically inclined forward, refer to Figure 11(a). Radiographic studies [17] have verified that the pelvis rotates rearward and the lumbar spine flattens, relative to normal standing lordosis, when sitting.



(a) (b) (c) (d) (e)

Figure 11: The pelvis and lumbar spine when (a) standing; (b) sitting relaxed, unsupported in the middle position; (c) sitting erect, unsupported in the middle position; (d) sitting in the anterior posture; (d) sitting in the posterior posture [17].

The lum…

thigh and trunk …

and the backrest…

together if the se…

higher than the …

As the kn…

of the pelvis, ro…

curvature [36] a…

Figure 12: Effe…
[17].

With the…

tuberosity is co…

hips flexed in th…

superolaterally …

covered by skin…

the ischial tuber…

which lies over th…

The lumbar spine is easily forced into flexion if the angle between the thigh and trunk is less than 90 degrees [78]. Even if the angle between the seat and the backrest appears large enough, the thigh and trunk may be too close together if the seat is too soft or too low to the floor so that the knees are much higher than the hips.

As the knee straightens, the hamstring muscle pulls forward on the bottom of the pelvis, rotating the top of the pelvis rearward and reducing lumbar curvature [36] as shown in Figure 12 below.

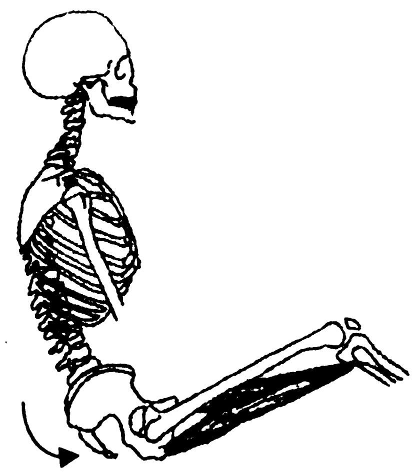


Figure 12: Effect of hamstring tension on pelvis positioning and lumbar curvature [17].

With the hip in the extended position, such as standing, the ischial tuberosity is covered by the gluteus maximus muscle [79]. However, with the hips flexed in the sitting position, the gluteus maximus muscle slides superolaterally off the ischial tuberosity. The ischial tuberosity is therefore only covered by skin and fat tissues when sitting. Prolonged, localized pressure over the ischial tuberosity may cause inflammation of the ischiogluteal bursa [79], which lies over the sciatic and posterior femoral cutaneous nerves. This condition proc

confused with a

gluteal muscula

with thick musc

A princip

prolonged spina

intravertebral dis

forward and the

The head is the

tension. Upper

pelvic tilt, thus i

upper spine an

In gener

individual seat.

not only has to

must also prov

neck, shoulde

and work area

considered wi

tasks.

2.3.2 Muscle L

Althoug

adjustability, ba

condition produces pain over the buttocks and posterior thighs and is easily confused with a herniated disc. Individuals with small ischial tuberosities or thin gluteal musculature or fat will usually develop pain sooner that those individuals with thick musculature, fat, or broad ischial tuberosity surfaces.

A principle cause of low back pain is thought to be slouching as it involves prolonged spinal flexion. This posture leads to increased loading on the intravertebral discs and ligaments of the back [48]. The upper torso also rotates forward and the abdominal contents move up into the chest, impairing breathing. The head is then forward of the base of the neck, leading to neck and back tension. Upper trunk posture results from a combination of spinal flexion and pelvic tilt, thus incorrect posture in the lower back can lead to discomfort in the upper spine and neck if a specific vision task is required.

In general, posture depends not only on chair design, but also on individual seating habits and the tasks to be performed [17]. The driver's seat not only has to provide a position for access to vehicle controls and visibility, but must also provide enough support to operate these controls. The position of the neck, shoulders, and upper and lower extremities depend on the specific task and work area location. Therefore, a seat and its associated posture must be considered within the context of the remainder of the vehicle and the required tasks.

2.3.2 Muscle Loading

Although anthropometry must be accounted for in terms of seat adjustability, basing a seat design solely on these measures ignores the fact that sitting is a dyna

compounded b

are recorded w

elbows at 90 de

loading will occu

[48, 79]. Anders

abdominal press

while loading the

measurements a

Having th

shoulder muscle

muscles in the s

tension in the s

ischial tuberosi

the upper trunk

support can als

2.3.3 Pressure

Pressur

Circulation is n

interferes with

lead to cell cha

tuberosities are

pressure.

sitting is a dynamic activity that influences the comfort of a seat [79]. This error is compounded by the fact that anthropometric measurements (refer to Appendix A) are recorded with the trunk vertical and the angles of the hips, knees, ankles, and elbows at 90 degrees. When the body is not properly supported, static muscle loading will occur as various muscle groups act to maintain or restore stability [48, 79]. Andersson, *et al.*, [2], measured the intradiscal pressure, intra-abdominal pressure, and myoelectric activity of posterior muscles of the back while loading the spine in different fixed postures and found that these measurements all increased when the spinal flexion angle was increased.

Having the arms extended forward in front of the body puts tension on the shoulder muscles and may cause the torso to slump forward while straining the muscles in the shoulder and neck area. Proper arm support not only relieves tension in the shoulders and neck but also decreases body weight passed to the ischial tuberosities and helps prevent slumped postures in the upper trunk so that the upper trunk then shifts weight to the backrest [79]. Adding proper foot support can also improve use of the backrest.

2.3.3 Pressure

Pressure in the body may restrict blood flow and compress nerves. Circulation is necessary for normal cellular metabolism so any condition which interferes with the circulation that provides nutrients and eliminates wastes may lead to cell changes that cause pain or discomfort [48]. Since the ischial tuberosities are closest to the seat surface they often experience the most pressure.

Drummo

subjects compa

balanced seat

distributed ove

uneven pressu

tried to mainta

defined as "co

examined by F

distributed an

comfortable s

distribution. T

overall seat c

pressure of th

2.3.4 Seat Pa

Leg su

backs of the t

lower leg is no

this would inte

Chair h

decrease in kn

the ischial tube

seat too high (c

to the extent tha

Drummond and co-workers [21] measured pressure distributions of normal subjects compared to clinical patients to determine some characteristics of balanced seating. Normal trunk balance was reflected by equal pressure distributed over the right and left sides, with poor balance recognized as either uneven pressure or a posterior shift in the center of pressure while the individual tried to maintain stability. The pressure distribution of two seats that had been defined as “comfortable” and “uncomfortable” by subjective measures were examined by Park and Kim [53]. It was found that the body pressure was well distributed and symmetrically centered on the ischial tuberosities in the comfortable seat. The uncomfortable seat had an asymmetric pressure distribution. These researchers found a statistically significant relation between overall seat comfort and the pressure of hip and lumbar regions relative to the pressure of the entire cushion.

2.3.4 Seat Pan

Leg support is a critical factor in reducing the load on the buttocks and the backs of the thigh [17]. The feet should be supported so that the weight of the lower leg is not sustained by the front part of the thighs resting on the seat, as this would interfere with blood flow in the legs and lead to numbness.

Chair height is also important since having the seat too low causes a decrease in knee and hip flexion angles and transfers the weight of the trunk to the ischial tuberosities and flexes the spine towards kyphosis [79]. Having the seat too high (or the seat pan too long) puts pressure on the backs of the thighs to the extent that the occupant tends to slide forward in the seat. This results in impro

press

the sa

disco

impin

nerve

preve

with f

ASIS

in the

occu

intern

2.3.5

back

Conv

lumba

long a

locat

pelvis

suppo

improper use of the backrest, low back pain due to kyphosis, and excessive pressure localized to the gluteal region posterior of the ischial tuberosities and on the sacrum if the posture is maintained long enough [17, 78]. Ischemia and discomfort from tissue distortion quickly follows [79]. Should the pressure impinge on the back of the knees, the legs may swell and pressure on the sciatic nerve may cause pain. The seat pan should also be inclined slightly rearward to prevent forward sliding in the seat and keep the occupant's back in full contact with the backrest.

The horizontal seat belt strap is designed to be positioned on or below the ASIS of the pelvis [79]. Slouching or a cushion that is too soft can produce slack in the belt and a high probability that the seat belt will end up across the occupant's abdomen. In a crash, this positioning could result in serious or fatal internal injuries.

2.3.5 Lumbar Support and Backrest Inclination

It has been found that an appropriate backrest angle lowers stress on the back, which can be further reduced by the addition of a lumbar support [17]. Conversely, changes in backrest inclination can shift a lumbar support along the lumbar spine so much that it may no longer be in the lumbar region at all. As long as the lumbar support is somewhere within the lumbar region, the precise location was found to be of little importance in this study.

However, in driving, upper sacral support is critical to help stabilize the pelvis and lumbosacral joint [79]. Appropriate backrest recline and lumbar support can reduce spinal stress from road shock and vibration by distributing loads and prev

posture (refer

sacrum and th

support and p

for the sacrum

requirement.

buttocks may

occupant wou

support in a c

A myoe

paraspinal mu

interaction be

experimental

and vertically

angle through

on 12 back m

was found to

backwards fro

in seat pan inc

angles, the EM

from 14 to 19 d

signals with ce

cm and trapeziu

loads and preventing the coccyx from bearing weight, as it would in a kyphotic posture (refer to Figure 11 (e)). It has been suggested [79] that the upper sacrum and the posterior iliac crests must contact the backrest for appropriate support and positioning. An open or recessed space below the lumbar support for the sacrum and buttocks is therefore necessary to meet this contact requirement. Lumbar support designs that do not allow extra space for the buttocks may position the occupant further forward on the seat. As a result, the occupant would be too far forward from the headrest to receive suitable head support in a collision.

A myoelectric analysis performed by Hosea and co-workers [32] on paraspinal musculature associated with automotive driving revealed a complex interaction between the thoracic and lumbar regions of the back. An experimental driver's seat with a lumbar support that adjusted both horizontally and vertically was used while forcing the subject to maintain a constant knee angle throughout all test positions. Electromyography (EMG) data was collected on 12 back muscle groups during the 3.5 hours of driving. Minimum EMG activity was found to occur with the backrest angled between 120 and 130 degrees backwards from a forward horizontal for all regions examined. Although changes in seat pan inclination were not found to have any significant affect on joint angles, the EMG signals showed lower activity when the angle was increased from 14 to 19 degrees. Various levels of lumbar support gave minimum EMG signals with cervical and thoracic regions having minimums at 3 cm, lumbar at 5 cm and trapezius at 7 cm of lumbar support.

It

backres

maintai

S

Althoug

part of t

lower ba

contact

with poo

2.4 Sea

2.4.1 Ea

T

drafting

13(a) an

interiors

due to th

to repres

manner

devices

people –

thus igno

manikins

It has also been recommended [79] that passengers use a slightly greater backrest recline than drivers. Since it is not necessary for passengers to maintain alertness, they should take advantage of a more relaxed posture.

Some seats have been designed with a moveable upper thorax support. Although this may bring the headrest closer, a forward inclination of the upper part of the backrest tends to push on the upper trunk and shoulders, causing the lower back to move away from the backrest and have difficulty maintaining contact with the lumbar support. Kyphosis of the lumbar spine would then result with poor pressure distribution over the seat and backrest.

2.4 Seating Tools Development

2.4.1 Early Seating Tools

The Society of Automotive Engineers (SAE) originally intended the 2-D drafting template and 3-D manikin (SAE J826 H-point machine) shown in Figures 13(a) and 13(b), respectively, to be used for occupant accommodation in vehicle interiors [64] and not as measures or indications of seating comfort. However, due to the lack of more appropriate tools, these SAE devices are often employed to represent human geometry during seat design. Usage of these devices in this manner can result in a failing seat design for two main reasons. First, these devices were built to represent the body dimensions of only one size group of people – medium stature and medium weight males with various leg lengths – thus ignoring the influence on posture of different physiques. Secondly, these manikins do not have a sufficient number of torso articulations to interact with a seat surface a

occupant in th

forward slop

Figure 13

Se

manikin

measure

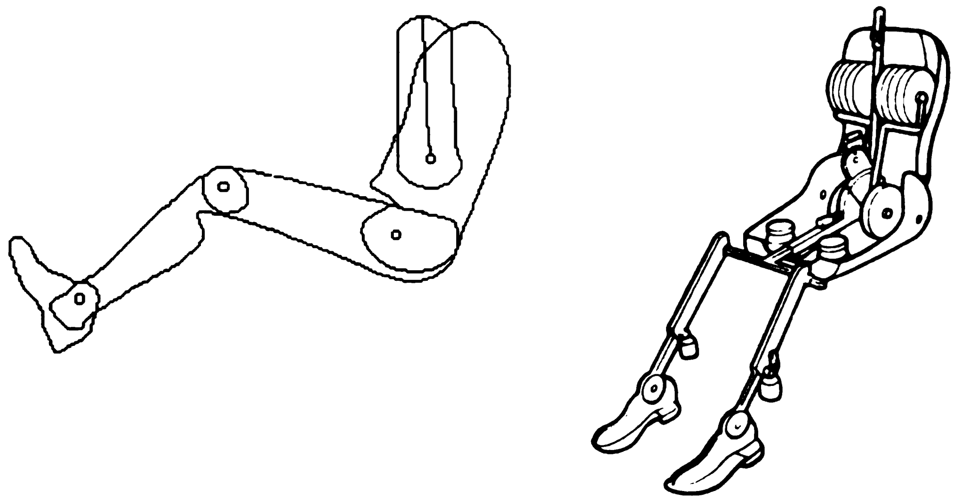
have be

the proc

accoun

inspect

seat surface and therefore they do not represent the positioning of a human occupant in that seat. When used for seat designing, the flat lumbar regions and forward sloping torsos result in seats that promote slumped postures.



(a) (b)

Figure 13: SAE tools. a) 2-D drafting template and b) 3-D manikin [64].

Seats designed with a contoured back or lumbar support rotate the SAE manikin forward, as shown in Figure 14 (a) below, precluding the necessary measurements required to meet industry standards. Therefore a seat that may have been comfortable fails to meet industry specifications and may never reach the production stage. The incompatibility region of Figure 14 (b) must be accounted for if a manikin such as J826 is to be used for seat design and inspection.

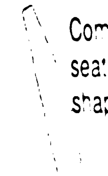


Figure 14: Incon

2.4.2 Time Effe

Seat pos

the University o

66]. Although a

conditions, data

the presence o

Wachsle

Subjects were

sitting and aga

seat. Ratings r

after four hours

on the basis of

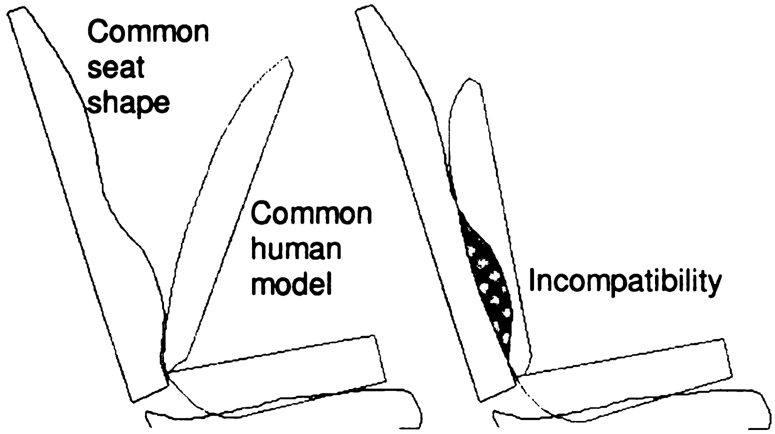


Figure 14: Incompatibility between seats with lumbar supports and the J826 manikin.

2.4.2 Time Effects

Seat positions that were selected pre- and post-driving were examined by the University of Michigan Transportation Research Institute (UMTRI) [59, 60, 66]. Although a small difference was found between pre and post-driving conditions, data suggested that this difference was due to other factors such as the presence of a seat belt and the initial position of the seat.

Wachsler and Learner [74] investigated the ratings of seating comfort. Subjects were asked to rate the comfort of several seats after five minutes of sitting and again after every hour for as long as the subject could tolerate the seat. Ratings made after five minutes were essentially the same as those made after four hours of sitting, allowing prediction of fairly long-term effects of sitting on the basis of a short time sample.

2.4.3 Textile Influences

Affects of seat covering materials on the position of the occupant have been examined by Hur and Park [39], who experimentally surveyed 408 people on their preferences of seat coverings and evaluated these textiles. Of those surveyed, 145 preferred leather, and 135 preferred woven fabrics, with the rest preferring pile knits and other unlisted fabrics. Of those ranking leather the highest, many did so due to the fact that they associated it with luxury, with the second reason being softness. Woven fabrics were chosen mostly for softness. When temperature tests were performed, in which each textile was placed in contact with a copper plate set at body temperature, only slight differences of less than 2 degrees were found. A sweat test was also performed to examine water vapor transmission and air permeability. Woven fabrics had the fastest water vapor diffusion and were a close second to pile knits for airflow. However, it was determined that these factors would only come into play in a hot and humid environment, therefore not a test issue in a laboratory environment of relatively constant temperature.

2.4.4 Seat Factors

Seat factors are those parameters of seats that influence occupant posture by affecting spinal curvature, torso posture, and position of the hip joint center. Experimental conditions for measuring these factors were examined by Michigan State University [35] and used to select a broad range of seats for the current study. The back angle, cushion angle, and H-point location can be found from the existing

important in desc

seat and the ve

identified two o

of lumbar prom

point along the

From th

lumbar promine

prominence tha

to be related to

mechanism ma

prominence bu

support was th

relatively stab

then the back

maintain conta

areas and lack

greater lumba

padding and a

Reed, e

dashboard, ste

influence of lum

simulation test,

from the existing J826 manikin. Additional seat factors determined to be important in describing the seat pan were the H-point deflection relative to the seat and the vertical stiffness under the H-point and knee axes. This study also identified two other factors necessary for describing the seat back – the amount of lumbar prominence and the location of the lumbar prominence above the H-point along the back angle.

From their automotive seating study, Shen and Vertiz [71] found that a lumbar prominence of 20 mm was favored. The preference of less lumbar prominence than expected from Andersson's suggested 50 mm [1] was thought to be related to how the prominence is accomplished since using a rigid mechanism may cause discomfort. They found that the subjects liked the lumbar prominence but found the method used to obtain it objectionable. The lumbar support was thought to carry a large amount of torso load and maintain a relatively stable back posture and pelvis. If the lumbar prominence is too great then the back may be pushed forward so far that the rest of the back cannot maintain contact with the seat, leading to uncomfortable pressure in the lumbar areas and lack of support on the other body regions. The authors noted that greater lumbar prominence might be preferred if it is achieved through soft padding and a flexible lumbar mechanism.

Reed, *et al.*, [59, 60] used a test buck with minivan dimensions, a dashboard, steering wheel, and accelerator and brake pedals to examine the influence of lumbar support on driving posture. Results from a one-hour driver simulation test, using lumbar prominence settings from 0 to 45 mm, revealed that

the initial postures
measured through
trials where the lum
support was vertica
were pooled toget
difference between
tangent to the pos
found that a 45 m
corresponding am
tend to conform to
difficulties in esta
suggested that lu
lumbar support e
was determined t
data suggested t
approach the ave
support. Pressu
inhibit rearward t
resulting hamstri
heights would ca
shift forward an a
when the lumbar

the initial postures chosen by the test subjects were very similar to postures measured throughout the hour. No significant differences were found between trials where the lumbar support was fixed versus those cases where the lumbar support was vertically adjustable, or between subject size groupings, so all data were pooled together. Lumbar prominence was defined as the maximum difference between the curved lumbar region of the seat and a reference line tangent to the posterior curves of the buttocks and thorax. These researchers found that a 45 mm lumbar prominence did not result in a posture with a corresponding amount of lordosis, suggesting that the test subject's back did not tend to conform to the seat. The small change in subject back contours, and difficulties in establishing consistent reference lines for a seated subject, suggested that lumbar lordosis and back contour may not be good measures of lumbar support effectiveness. The relative orientation of the pelvis and thorax was determined to be the more appropriate method. The authors thought their data suggested that the average seated lumbar lordosis for drivers would not approach the average standing lordosis, even with a well designed lumbar support. Pressure mat data suggested that the test seat did not substantially inhibit rearward thorax rotation. Accounting for the effect of knee angle and resulting hamstring tension on pelvis orientation, it was assumed that lower seat heights would cause even less lumbar lordosis. The hip joint center was found to shift forward an average of 11.4 mm and upward an average of 3 mm in the seat when the lumbar prominence was at its peak compared to a flat backed seat.

McNally [5

prominence in au

instructed to sit w

positively correla

relative orientatio

body segments r

correlation. This

of the thorax and

Reed's study pro

produce more d s

body shape mism

flexion. Therefor

should be examin

The idea th

and thorax, instea

Biomechanically A

Hubbard [33]. Th

segments that artic

having a one-to-on

automotive environ

information on this

referred to Bush, et

McNally [50] performed a study on mid-sized males to determine if lumbar prominence in automotive seats affects posture. In this study the subjects were instructed to sit with their pelvis fully into the seat. It was found that posture was positively correlated to lumbar prominence if the parameter considered was the relative orientation of body segments to each other. However, orientations of body segments relative to arbitrary directions, such as vertical, did not exhibit this correlation. This agrees with the findings of Reed [59] that the relative orientation of the thorax and pelvis should be the parameter for measuring spinal posture. Reed's study prompted his statement that a highly prominent, firm support may produce more discomfort as a result of pressure concentration due to seat and body shape mismatch than would be eliminated by reductions in seated spine flexion. Therefore, alternative methods of producing seated lumbar lordosis should be examined.

The idea that spinal curvature can be achieved by positioning the pelvis and thorax, instead of the lumbar region, was demonstrated with the creation of a Biomechanically Articulating Chair (BAC), prototyped for seating research by Hubbard [33]. This seat was equipped with thigh, pelvic, lumbar, and thoracic segments that articulate with the occupant, with the thorax and pelvis supports having a one-to-one counter-rotation. Experimental studies using this seat in the automotive environment will be discussed in the following sections. For further information on this concept applied to the office environment the reader is referred to Bush, *et al.*, [84].

2.4.5 Packag

Packa

previously m

type, will cha

pelvis orienta

and vision ta

interior but n

been used t

armrests ma

25-30 perce

upper back

2.4.6 Huma

The

surface cas

skin contou

created to r

However, th

body shape

2.4.5 Package Factors

Package factors refer to interior components of seat placement [35]. As previously mentioned in Reed's work [59], seat height, which varies by vehicle type, will change the occupant's posture due to the change in knee angle and pelvis orientation from hamstring tension. Package factors also include reach and vision tasks, although these are usually considered when designing the interior but not the seat. Seat height and steering wheel-to-pedal distances have been used to predict driver selected fore-aft positions [27]. Proper usage of armrests may also play a prominent role since they have been found to reduce 25-30 percent of the pressure under the ischial tuberosities [77] and reduce upper back and neck pain [78].

2.4.6 Human Models

The University of Michigan Transportation Research Institute used seat surface casting and photos of anthropometric landmarks to determine exterior skin contour points for crash dummy development [67-69]. Body shapes were created to represent the mid-sized male, large male, and small female. However, the seats used did not have significant lumbar prominences so these body shapes tend to represent slumped postures as shown in Figure 15.

Figure 15: U

While

computer gra

spine was m

anatomical j

69] were us

The model i

center mob

one counte

compared t

contour sur

UMTRI's 50

model: one

to specify th

horizontal ar

noted that a s

contour.

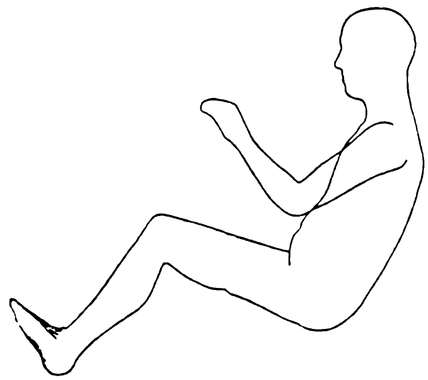


Figure 15: UMTRI mid-male body contour [67].

While at Michigan State University, Haas [31, 36] developed a 2-D computer graphics model (JOHN) and a mid-sagittal spinal motion program. The spine was modeled as a chain of links with fixed lengths, therefore fixing the anatomical joint centers of rotation with respect to the vertebra. UMTRI data [67-69] were used to locate the cervical, thoracic, and lumbar spinal joint centers. The model incorporated a uniform distribution of lumbar rotation, ignoring joint center mobility and sacral motion, with the thorax and pelvis moving in a one-to-one counter-rotation. The length of the lumbar spine was increased by 30 mm compared to the UMTRI data, moving the bottom of the pelvis closer to the body contour surface, giving a more realistic tissue thickness of 20 mm compared to UMTRI's 50 mm. The following parameters were then needed to position the model: one to specify the total lumbar curvature (TLC, shown in Figure 16), one to specify the torso recline angle (TRA), one for the head tilt (HA), and the horizontal and vertical positions of the hip joint center (HJC) in space. It was noted that a slouched posture is required for the JOHN model to fit into the SAE contour.

H.

Figure 16: JC

The wo

with legs, sho

this model, g

added to repr

17(b)). Thes

body and pro

similar to the

accounted fo

included, the

realistically p

Figure 17: a) 3

ellipsoids [36].

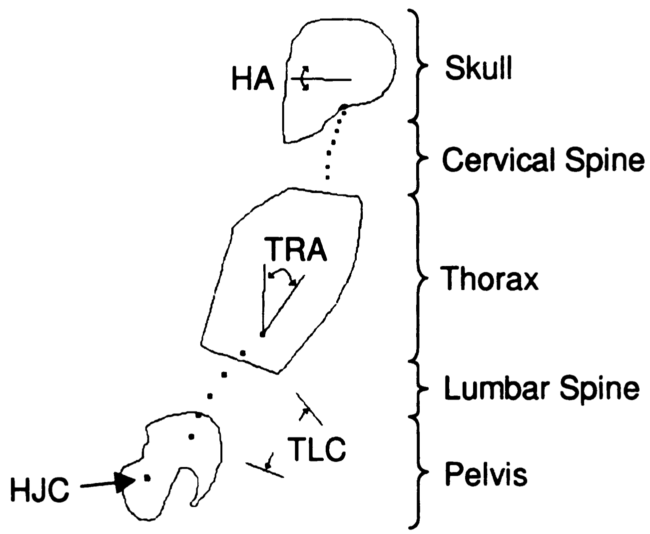
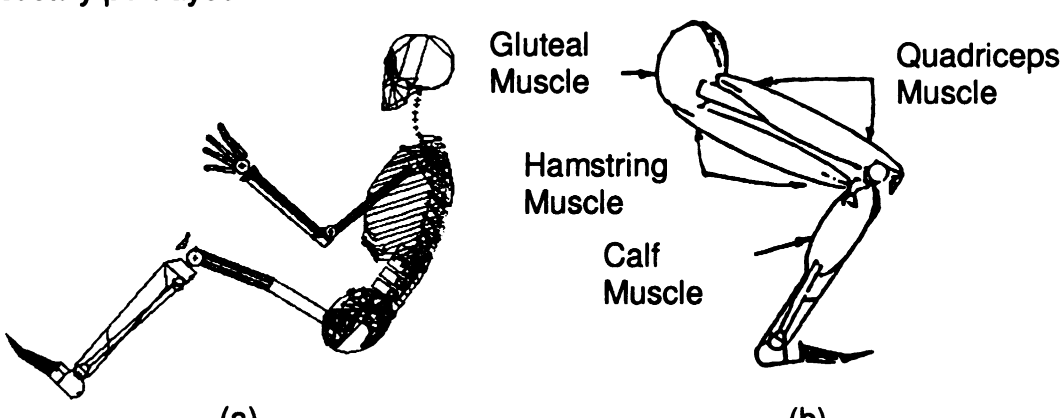


Figure 16: JOHN 2-D computer model [36].

The work of Haas was continued by Boughner [9] to make a 3-D model with legs, shoulders, and arms. A motion program was also created to articulate this model, given parameters that define TLC, TRA, and HA. Ellipsoids were added to represent the muscle groups of the legs and buttocks (refer to Figure 17(b)). These ellipsoids were chosen to represent the underlying contours of the body and provide an easily scalable method of maintaining muscle volume similar to the body. The effect of hamstring tightness on knee and hip angle was accounted for by limiting the lengths of the muscles. Although tendons were included, they were modeled as straight lines, so extreme postures were not realistically portrayed.



(a) (b)

Figure 17: a) 3-D John skeletal model [36] and b) sketch of muscles modeled as ellipsoids [36].

A 2-D t

JOHN compu

were also ad

torso at discr

sized male in

contact.

Figure 18

contour. (

Fr

represen

muscle a

program

sagittal pl

was also e

and large a

A 2-D template was developed by Bush [11, 36] to represent the 2-D JOHN computer model, refer to Figure 18. A vertebral column and back muscles were also added to JOHN 3-D with skin generated to cover the backside of the torso at discrete TLC increments. The skin contours represented an average-sized male in a seated posture with deformed soft tissue due to seat-body contact.

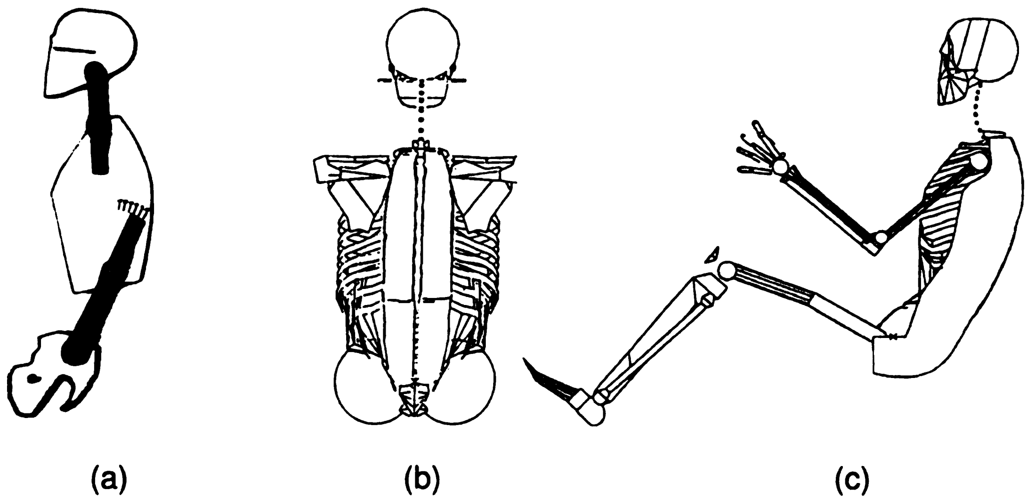


Figure 18: Bush [36] 2-D template, (a), and 3-D JOHN back muscles and skin contour, (b) and (c).

Frost [28] reconfigured the JOHN model to be more anatomically representative of an average-sized adult male skin contour while retaining the muscle and bone definition noted in Bush's model. A contour articulation program was created so that the external skin contour could be articulated in the sagittal plane to match the underlying musculo-skeletal systems. This program was also expanded to include the contours of both the small adult female (JANE) and large adult male (JERRY), shown in Figure 19.

Figure 19: JA

Gedra

ten mid-sized

regions of th

T12) suppor

thorax supp

were compa

necessarily

Furt

computer m

prototyping

the manikin

production

computer m

such as the

support may

separately [2

Figure 19: JANE, JOHN, and JERRY skin contours [34].

Gedraitis [29, 34] studied the postures of the thorax relative to the pelvis in ten mid-sized males who were placed in a test seat that could support various regions of the torso. Positions included a straight back, upper thorax (T6 and T12) support, lower seat back support (S1 and L3), or both the upper and lower thorax support. Findings showed that the subjects could attain postures that were compatible with the JOHN models, but the patterns of motion were not necessarily coupled as in JOHN.

Further development followed when Ekern [23] created 2-D kinetic computer models of the SAE J826 manikin and JOHN, refer to Figure 20. Before prototyping is done, this JOHN model can be used by a seat designer to predict the manikin's position in a seat. JOHN was used to compare a current production seat designed with SAE tools to an articulating prototype seat (BAC computer model). The results of this effort demonstrated that an adjustable seat, such as the BAC [33], can support a greater variety of postures and that a lumbar support may not be as effective as supporting both the torso and pelvis separately [24].

Figure 20: JO

2.4.7 *Current*

The A

(ASPECT) p

to develop a

was prototyp

mid-sized m

manikin (ref

tool and the

Load

Figure 21)

behind and

collect data

weighting

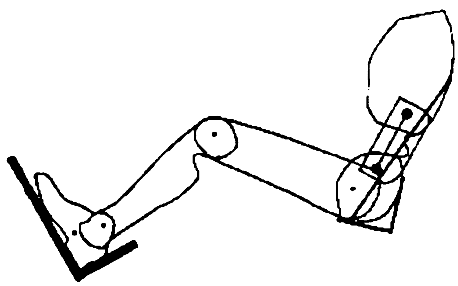


Figure 20: JOHN computer model positioned in BAC computer model [24].

2.4.7 Current Seating Tools

The Automotive Seat and Package Evaluation and Comparison Tools (ASPECT) program was an SAE funded joint venture between MSU and UMTRI to develop an improved three-dimensional testing manikin [4, 5]. This manikin was prototyped with four segments (thorax, lumbar, pelvis, and thigh) to mimic a mid-sized male's shape, size, weight, and movement [4]. Although the ASPECT manikin (refer to Figure 22 (b)) has this capability, it is still a post-construction tool and therefore not as useful in seat design as a computer model.

Load cells were placed in the laboratory version of the BAC seat (refer to Figure 21) to measure the three-dimensional forces that support the thighs, behind and below the pelvis, and the thorax [14]. This seat could then be used to collect data for computer models and to match the prototype ASPECT manikin's weighting to that of a mid-sized male.

Figure 21: La

Bush [

of mid-sized

loads on the

subtracted t

does not ha

data of a pr

of the ASPE

suggested

in Figure 2

these have

Figure 22: AS

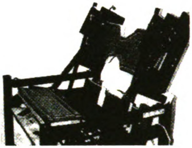
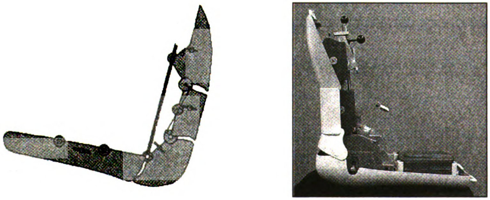


Figure 21: Laboratory BAC with force plates [37].

Bush [12] used the laboratory BAC to measure posture and support forces of mid-sized males at several recline angles and lumbar positions. The average loads on the steering wheel and footplate were converted to mass and subtracted to give the suggested manikin weighting since the ASPECT manikin does not have arms and lower legs. Gregg [30] then compared the experimental data of a prototype ASPECT manikin positioned in the BAC to a computer model of the ASPECT manikin positioned in a model of the BAC in order to validate the suggested manikin weighting. The ASPECT manikin computer model is shown in Figure 22 (a). The forces under the pelvis were the focus of this study since these have the greatest influence on the H-point.



(a) (b)

Figure 22: ASPECT manikin (a) computer model [30] and (b) physical manikin.

One of t

are all useful c

the seat is pro

models were

The easiest w

to incorporat

would increa

while mainta

currently und

library of da

shape with

BAC discus

the feet, thi

examined

The

commerci

predicting

CAD-Erg

places. T

the option

and ergon

features, b

available.

One of the largest drawbacks of the physical seating manikins is that they are all useful only after a seat is constructed. Designers need tools to use before the seat is prototyped in order to save time and money. The JOHN computer models were designed for this purpose, but are not considered "user friendly". The easiest way to handle this drawback while simultaneously adding features is to incorporate the JOHN models into existing industry accepted software. This would increase the model's range of physiques and add some analysis packages while maintaining the posture/positioning features of JOHN. Studies are currently underway to verify the JOHN contours and increase the back contour library of data so that the contours of the back, buttocks, and thighs will change shape with posture changes. Support forces between people and the laboratory BAC discussed previously are being measured. The forces and moments under the feet, thighs, buttocks, behind the pelvis and thorax, and at the hands will be examined for software implementation [38].

The author knows of four main human modeling programs currently commercially available; however, each of these models has limited accuracy in predicting human position and posture. RAMSIS by TecMath AG [56] is a 3-D-CAD-Ergonomics tool for the design and analysis of vehicle interiors and work places. The program offers libraries of multi-national anthropometric data, with the option of creating your own manikin dimensions, and tools for vision, comfort, and ergonomics analysis. Jack [40] by Transom also has the above listed features, but detailed information on this manikin's spinal movement is not available. Use of 3-D animated human manikins is available in the McDonnell

Douglas H

enables el

maintenar

environme

database.

placemen

Ac

examine

represen

alternate

A combi

Figure 2

knowled

Figure 23.

Douglas Human Modeling System (MDHMS) [51] as well; however this program enables electronic simulation/demonstration of assembly, operations, and maintenance in the airline industry and does not pertain to the automotive environment. Although SAFEWORK [65] boasts an advanced anthropometry database, posture prediction, and ergonomic analysis, it is intended for the placement of equipment in a manufacturing environment.

Access to a computer manikin such as RAMSIS enables the user to examine numerous body types, unlike the J826 and ASPECT manikins that only represent the mid-sized male. Computer analysis also allows the designer to alternate between seat designs relatively quickly in order to make comparisons. A combination of the two programs capabilities discussed, and shown below in Figure 23, would produce the best tool for seat designers, given the current knowledge of seating biomechanics.

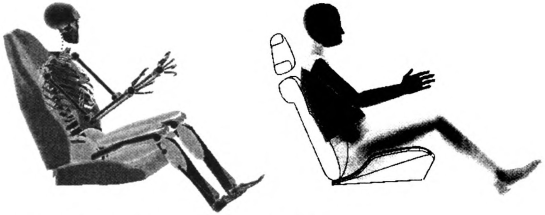


Figure 23: JOHN model [42] and RAMSIS [56].

3. EXPERIMENTAL METHODS – SEAT FACTORS

3.1 Testing Protocol

The following describes the seats selected for this study and the measurements recorded. For further information on characteristics of these seats refer to Bogard [7].

3.1.1 Seat Factors

The automotive seats used in this study were chosen to represent a broad range of seat factors as identified by MSU in the ASPECT program [35], since characteristics of some of these seats, such as seat pan stiffness and lumbar prominence, had already been measured. The H-point and correlations between the targets on the seats (refer to Appendix B for target locations) and the manikin backrest recline angle were measured using a standard J826 manikin [41] and two prototype ASPECT manikins [4] per the corresponding manuals. The centerline contour was traced with a probe (refer to Figure 2) to produce a cross-sectional view of each seat back, with the lumbar supports set to the full on and off positions for these measurements.

3.1.2 Seats

Both the armrests and headrests were removed from the seats to prevent blocking the camera views of the targets in subject testing and to limit the variables affecting the subject's chosen postures. All of the seats were mounted and built up on separate baseboards to attain the specified H-point heights (H30) and cushion angles (L27).

Seat A, a tan leather covered Chrysler LH manufactured by Johnson Controls, Inc. (JCI) had an adjustable paddle-type lumbar support. This seat back had a recline range, as measured with the J826 manikin, of 0 to 65 degrees rearwards from vertical. Refer to Figure 24.

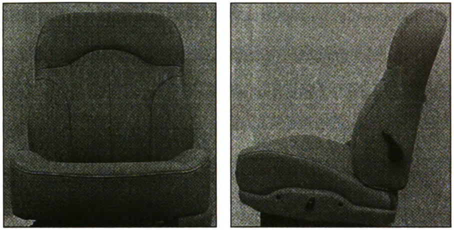


Figure 24: Seat A, the tan LH.

The Chrysler Town and Country, seat B shown in Figure 25, was finished with a gray cloth. This seat also had a paddle-type adjustable lumbar support. The Town and Country was the only true van seat used for this study. This seat back had a recline range, as measured with the J826 manikin, of 22 to 68 degrees rearwards from vertical.

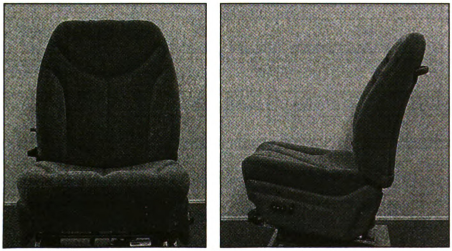
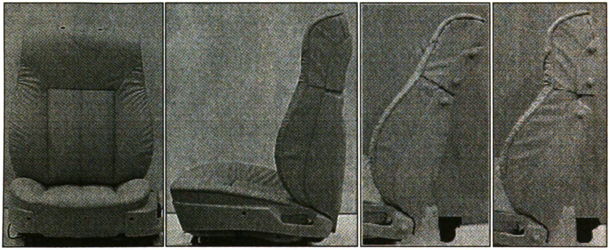


Figure 25: Seat B, the Chrysler Town & Country.

The BMW 7 Series seat, seat C shown in Figure 26, was covered in beige leather with an adjustable bladder lumbar support. The seat back recline ranged from 0 to 70 degrees rearward from vertical as measured with the J826 manikin. The lumbar support height was set to the middle position and then disabled from further adjustment. Since the BMW seat also had an adjustable upper thorax segment, testing on this seat was completed in two positions: with the upper thorax full rearward and full forward, Figure 26 (c) and (d). All manikin measurements for this seat were taken only with the thorax support in the full rearward position since the manikins could not be appropriately placed with their backs against the seat when the thorax support was full forward.



(a) (b) (c) (d)

Figure 26: Seat C, the BMW 7 Series, (c) thorax support fully rearward, (d) thorax support fully forward.

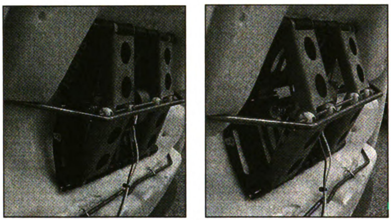
The prototype seat, a modified LH by JCI, seat D is shown in Figure 27, was covered in gray leather and had an adjustable lumbar mechanism shown in Figure 8 below. The seat back recline ranged from 12 to 76 degrees rearward from vertical as measured by the J826 manikin.

pc

test b

instea

Figure 27: Seat D, the modified LH by JCI.



a) b)
Figure 28: Lumbar mechanism in gray LH seat, a) lumbar “off”, b) lumbar “on.”

3.1.3 Test Buck

To match the coordinate system commonly used in the automotive industry, the coordinate system used in this experiment was set with the z-axis pointing upwards, the x-axis posterior, and the y-axis lateral to the right of the test buck, refer to Figure 29. A flat motor track on the baseboard was used, instead of the angled motor of the seat, to keep the seat height (H30) constant when the subject adjusted the seat. An extra spacer board was placed under each seat for the van package. Refer to Tables 1 and 2 for buck dimensions.

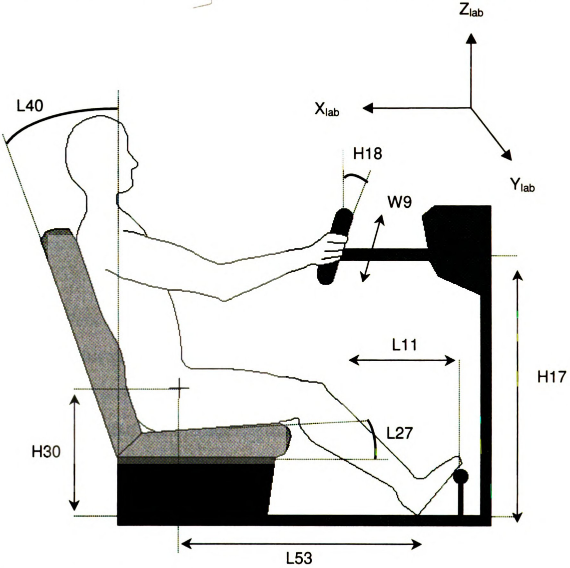


Figure 29: Test buck dimensions.

Table 1: Desired positions for locked package dimensions.

Dimension Description	**SAE #**	*Package A (sedan)*	*Package B (van)*
Seat (J826 manikin H-point) Height	H30*	250 mm	350 mm
Cushion Angle with respect to Horizontal	L27*	13°	13°
Steering Wheel to Toebar (X)	L11	565 mm	535 mm
Steering Wheel to Heel Point (Z)	H17	610 mm	700 mm
Steering Wheel Angle with respect to Vertical	H18	22°	22°
Steering Wheel Diameter (outer)	W9	380 mm	380 mm

* based on J826 manikin measurements.

T

La

d

Table 2: Subject preferred parameters.

Dimension Description	SAE #
H-point to Toebar	L53
Backrest Angle	L40

The Michigan State University Biomechanical Design Research Laboratory (MSU-BDRL) was used to obtain the data for this study. Test buck dimensions were calculated from targets on the test buck to verify these package dimensions. Since the subject was allowed to choose the horizontal positioning of the seat, the front half of the buck was moved closer to the seat for the petite females to account for the short range of motion of the base board motor.

3.1.4 Test Buck Calibration

Data files were collected at various seat back recline angles on each seat to correlate the angles of the SAE manikin to those of the seat targets. The H-point axis of the SAE manikin was targeted for inclusion in Qualisys data collection, along with the torso, as shown in Figure 30. The manikin torso data were used to compare seat back inclinations, while the H-point axis was recorded to determine the actual H30 dimensions. Qualisys data were also collected on the H-point height of the MSU prototype ASPECT manikin in each seat, with lumbar prominence measures collected using both the MSU (version 3) and the JCI (version 5) ASPECT prototypes. Measurements of the H-point height and lumbar prominence were taken from those data sets where the seat backrest recline was set at 24 degrees, as measured by the J826 manikin.

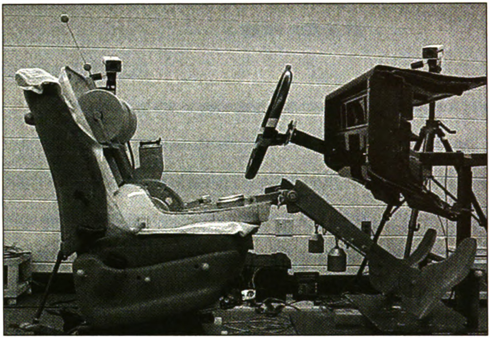


Figure 30: J826 SAE manikin measurements of the test buck and seats.

s

f

Fig

4. SEAT RESULTS

4.1 Seat A (Tan LH)

Probe data of the undeflected midline contours for seat A (Tan production LH) showed a very limited difference from lumbar off to lumbar on. Since this slight difference occurred along the entire back of the seat, it could have been from aligning the probe slightly off-center of the midline where the fabric is sewn. The lumbar support of this seat was kept in the "off" position during subject testing due to the negligible difference in lumbar prominence settings, as can be observed from the side view image shown below in Figure 31. The averages of each manikin reading are given in Table 3.

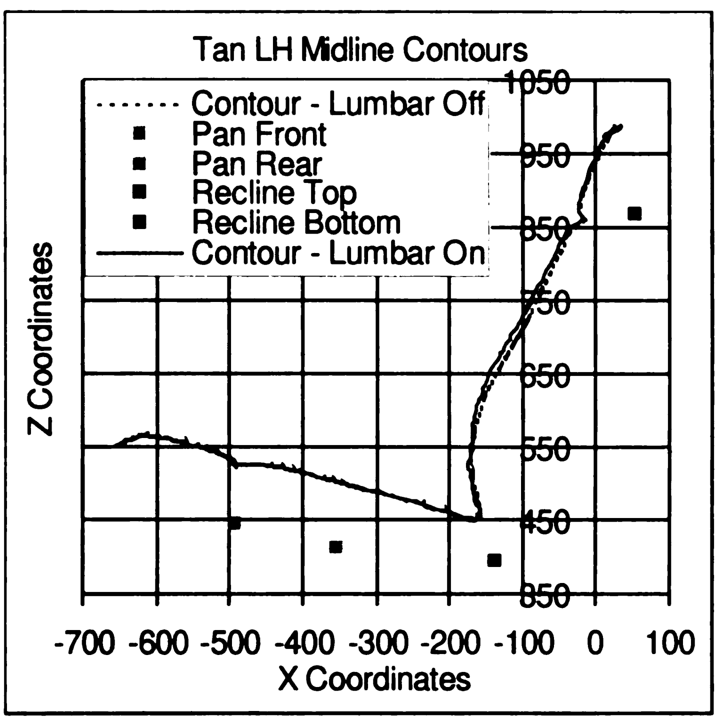


Figure 31: Seat A (Tan LH) midline contours for lumbar off and lumbar on.

Table 3: Actual seat A (Tan LH) manikin measurements:

Dimension Description	SAE #	Actual Positions (Sedan*)		
		J826	MSU ASPECT	JCI ASPECT
Seat (manikin H-point) Height	H30	262 mm	239 mm	---
Cushion Angle	L27	13^o	18^o	18^o
Lumbar Prominence (off/on)	---	---	13 / --- mm	12 / 16 mm

*van package added 95 mm to H30

A correlation was formed for each seat between the seat back recline angle given by the Qualisys targets on that seat and the J826 manikin in order to determine the expected manikin reading from the subject target data during testing. The seat back recline correlation between the J826 manikin and the Qualisys targets for seat A (Tan LH) is shown in equation 4.1.

$$\theta_{J826Manikin} = 1.30 \cdot \theta_{Qualisys} - 4.8^o \quad (4.1)$$

The manikin seat back recline reading and the angle formed by the seat targets did not have a one-to-one ratio due to the difference in pivot points as shown in Figure 32 below.

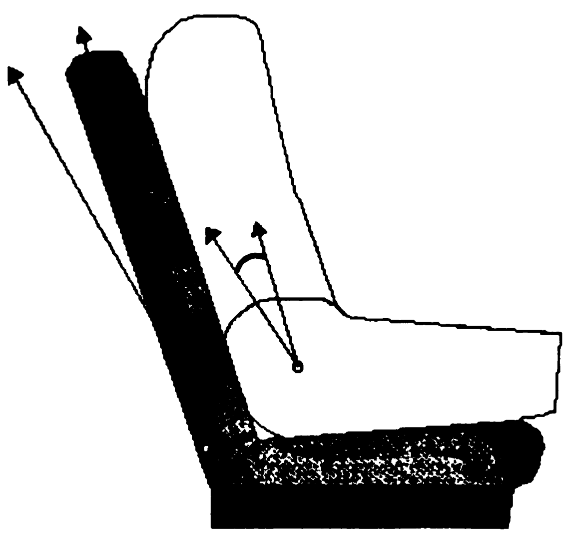


Figure 32: Ratio between J826 manikin back angle reading and recline angle from seat targets.

4.2

(To

give

Figure
lumba

Table
Dim
Seat
Cush
Lumb

*van p

Qualisy

θ_{J826M}

4.2 Seat B (Town and Country)

The contour difference caused by turning on the lumbar support of seat B (Town & Country) is shown in Figure 33. The average manikin readings are given in Table 4.

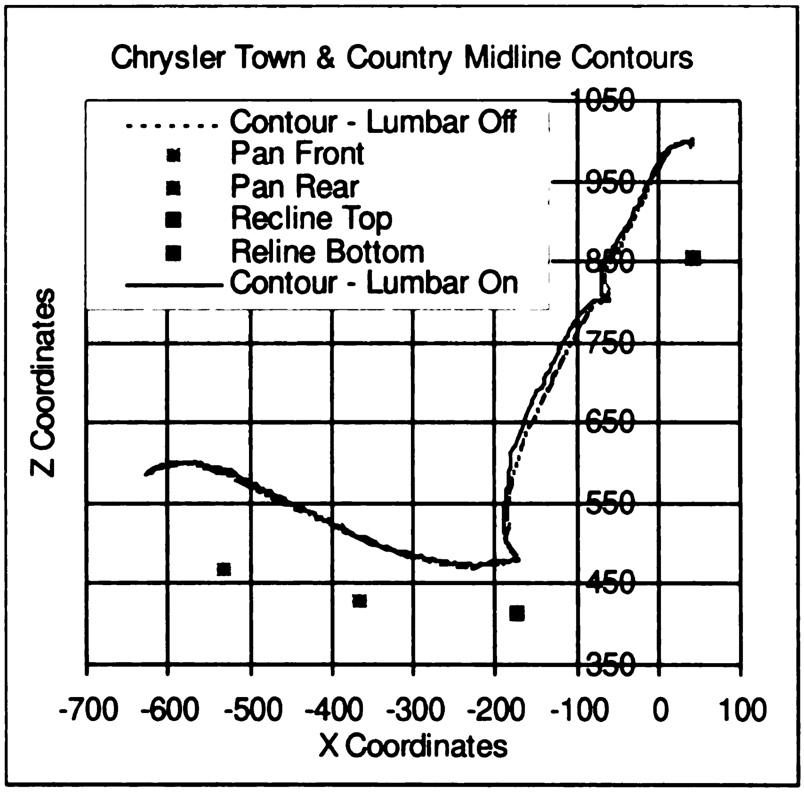


Figure 33: Seat B (Chrysler Town & Country) midline contours for lumbar off and lumbar on.

Table 4: Actual seat B manikin measurements:

Dimension Description	SAE #	Actual Position (Sedan*)		
		J826	MSU ASPECT	JCI ASPECT
Seat (manikin H-point) Height	H30	274 mm	263 mm	---
Cushion Angle	L27	13°	18°	20°
Lumbar Prominence (off/on)	---	---	9.5 / 18.5 mm	15 / 23 mm

*van package added 95 mm to H30

The seat back recline correlation between the J826 manikin and the Qualisys targets for seat B (Town & Country) is shown in equation 4.2.

$$\theta_{J826Manikin} = 1.39 \cdot \theta_{Qualisys} - 14.8^{o} \tag{4.2}$$

4.

be

wa

the

be

Figu

back

previ

Table

Dime
Seat
Cush
Lumb

*van pa

4.3 Seat C (BMW 7 Series)

Seat C (BMW 7 Series) had a very large difference in lumbar prominence between the lumbar fully on and fully off positions. When the lumbar prominence was at its fullest, the lower portion of the backrest fabric also pulled away from the seat pan to form more of a recess in the buttocks region, shown in Figure 34 below.

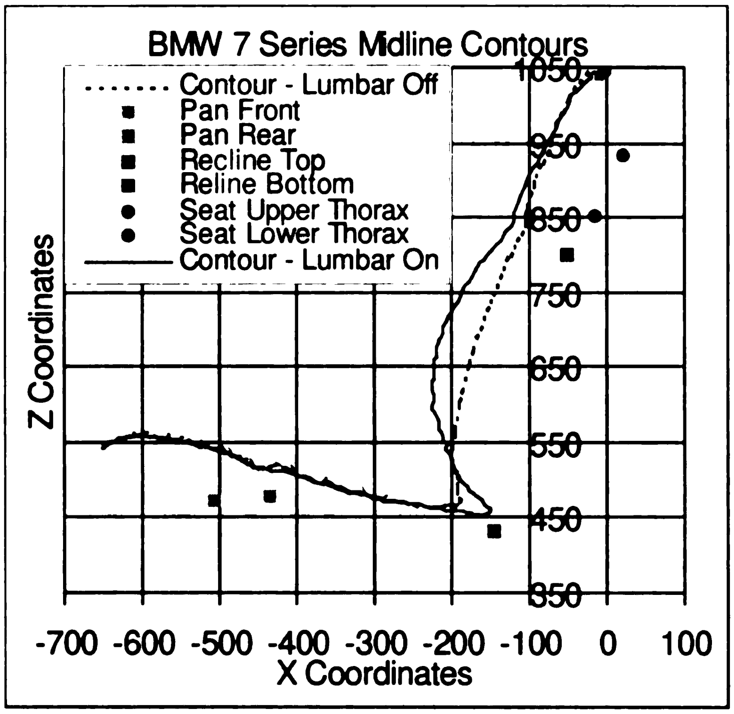


Figure 34: Seat C (BMW) midline contour for lumbar off and lumbar on.

These measurements were recorded with the upper thorax support of the backrest in the rearward position so as not to interfere with the manikin as previously mentioned, refer to page 39. Manikin readings are given in Table 5.

Table 5: Actual seat C manikin measurements:

Dimension Description	**SAE #**	**Actual Position (Sedan*)**		
		J826	**MSU ASPECT**	**JCI ASPECT**
Seat (manikin H-point) Height	H30	273 mm	260 mm	---
Cushion Angle	L27	13°	16°	15°
Lumbar Prominence (off/on)	---	---	13 / maximum	7 / 25.5 mm

*van package added 95 mm to H30

Qu

θ_j

4.4

with

and

give

Figu

shown

produ

The seat back recline correlation between the J826 manikin and the Qualisys targets for seat C (BMW) is shown in equation 4.3.

$$\theta_{J826Manikin} = 1.35 \cdot \theta_{Qualisys} - 2.2^{o} \qquad (4.3)$$

4.4 Seat D (Gray LH)

Seat D (Gray LH) always had a large prominence in the lumbar region with only a small difference at the top of the lumbar bulge between the fully on and off lumbar support positions (refer to Figure 35). The manikin readings are given below in Table 6.

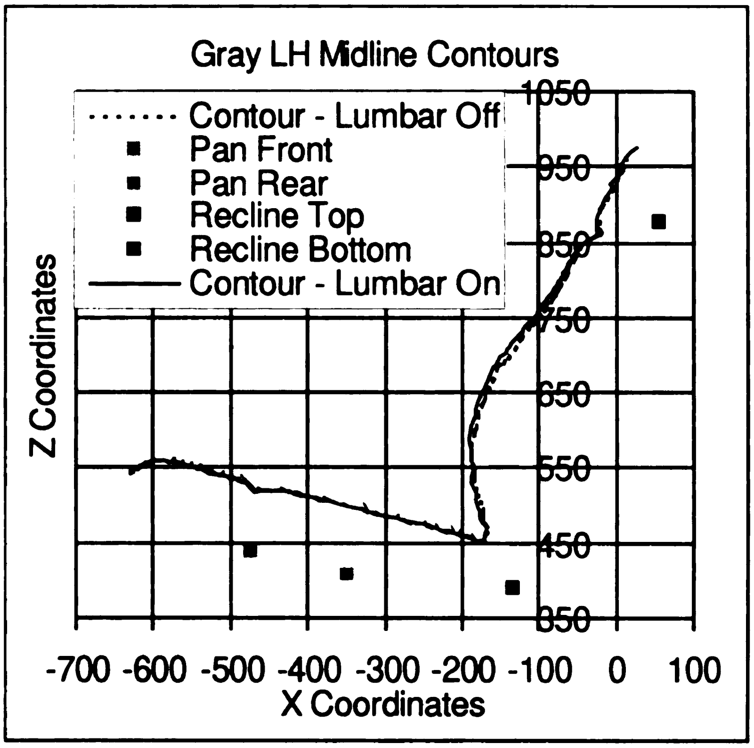


Figure 35: Seat D (Gray LH) midline contour for lumbar off and lumbar on.

Below are the dimensions of the lumbar support mechanism of seat D shown previously in Figure 28. It was expected that this mechanism would produce a larger change in lumbar prominence than shown in the previous cont

the f

fabri

not v

Lumb

Figure

Table

Dime
Seat (
Cushi
Lumb

*van pa

Qualisy

θ_{JR26M}

contour. However, the lack of differences in contours may be due to the fact that the fabric was taught enough to conceal changes in lumbar support under the fabric, therefore not revealing significant contour differences when the seat was not weighted.

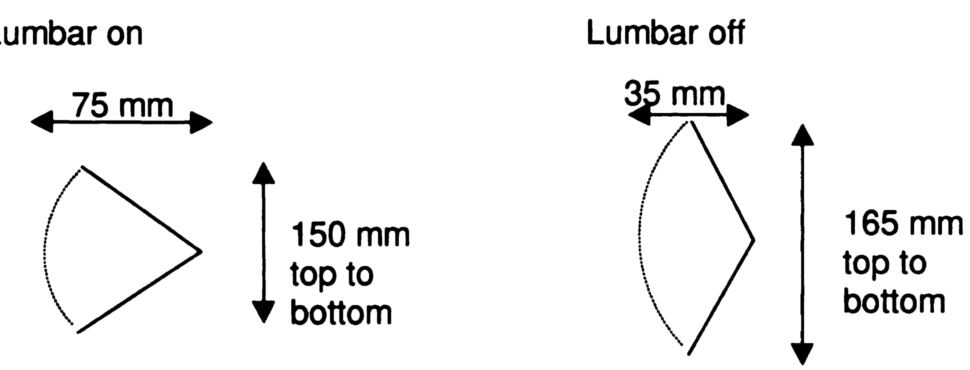


Figure 36: Measurements of internal lumbar mechanism of seat D.

Table 6: Actual seat D manikin measurements:

Dimension Description	**SAE #**	**Actual Position (Sedan*)**		
		J826	**MSU ASPECT**	**JCI ASPECT**
Seat (manikin H-point) Height	H30	268 mm	258 mm	---
Cushion Angle	L27	13°	15°	14°
Lumbar Prominence (off/on)	---	---	22.5 / maximum	17.5 / 23.5 mm

*van package added 95 mm to H30

The seat back recline correlation between the J826 manikin and the Qualisys targets for seat D (Gray LH) is shown in equation 4.4.

$$\theta_{J826Manikin} = 1.27 \cdot \theta_{Qualisys} - 3.1^{o} \tag{4.4}$$

5.1

An

lum

the

that

add

visi

thro

test

subj

othe

toeb

foot

used

dash

dash

using

vision

driver

the po

5. EXPERIMENTAL METHODS – SUBJECT TESTING

5.1 Testing Protocol

This protocol was developed with the assistance of Ron Roe of Anthrodynamics [63] and Hartmut Speyer of TecMath to address the affects of lumbar prominence on posture in automotive seats.

Each test subject was allowed to choose the horizontal fore/aft position of the seat and the seat back recline angle for each lumbar prominence setting so that he/she was in the most comfortable position possible. Package factors addressed in this study included seat height, hand position, foot position, and vision task. As stated earlier, variations in seat height were accomplished through two vehicle package settings, sedan and van. Two hand positions were tested to represent both the driver and passenger postures, one trial with the subject holding the steering wheel in the ten and two o'clock positions and the other with the subject's hands resting on his/her lap. Both feet were placed on a toebar for the driver trials, similar to using pedals, and flat on the horizontal footplate for the passenger trials. A dashboard from an Oldsmobile sedan was used for this setup (refer to Figure 43). However, it was necessary to cut the dashboard in half with only the driver's side used for testing since the complete dash was difficult to make stable or allow room for camera placement. Since using a TV would cause a glare and interfere with the Qualisys cameras, the vision task was simplified to focusing on an eye level poster of a road. Both the driver and passenger positions were tested since it has been suggested [47] that the postural constraints of driving may require that the driver's seat has greater ph

be

5.

Ta

of

fen

hea

Tab

Tab

Fe

Ma

Res

were

and

indiv

physical support and contouring than the passenger's seat. However, it should be noted that all of the seats used in this study were intended for the driver.

5.1.1 Test Subjects

Test subject selection was based on NATICK [52] groupings as shown in Tables 7 and 8 below. These criteria were chosen to represent the full spectrum of the adult population. Groupings included petite, light females, petite, ample females, medium height and weight females and males, tall, light males, and tall, heavy males.

Table 7: Anthropometric groups (30 subjects total).

		Stature	
Weight	*5th*	*50th*	*95th*
5th	5 Females		5 Males
50th		5 Females & 5 Males	
95th	5 Females		5 Males

Table 8: Ideal ranges of anthropometric groups.

	%	Stature	Weight
Females	5	59-61 in. / 150-155 cm	95-115 lbs. / 43-52 kg.
	50	63-65 in. / 160-165 cm	125-145 lbs. / 57-66 kg.
	95	67-69 in. / 170-175 cm	160-180 lbs. / 73-82 kg.
Males	5	63-65 in. / 160-165 cm	125-145 lbs. / 56-66 kg.
	50	68-70 in. / 172-177 cm	160-180 lbs. / 73-82 kg.
	95	72-74 in. / 182-189 cm	205-225 lbs. / 93-102 kg.

Testing was performed in accordance with the University Committee on Research Involving Human Subjects under IRB# 99399, approved consent forms were fully explained to and signed by each subject prior to testing. The figures and table below show the spread in anthropometric measurements for all individuals tested.

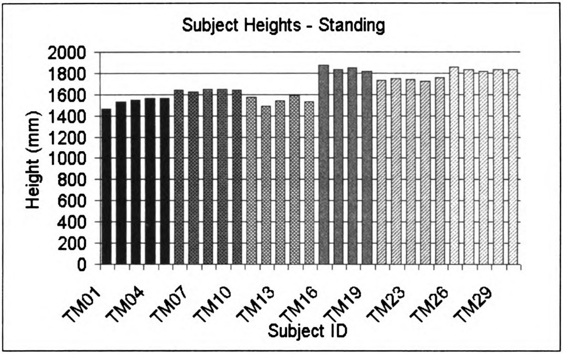


Figure 37: Standing heights of all test subjects (without shoes).

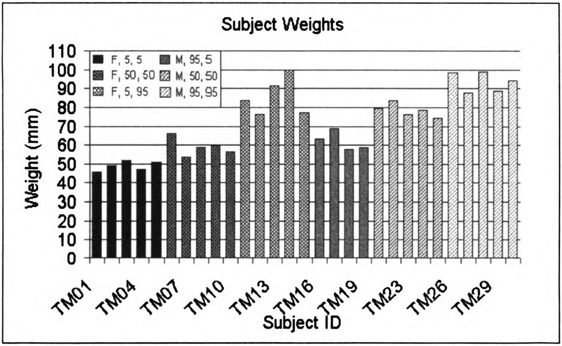


Figure 38: Test subject weights without shoes.

Ta

P
P
A
S
M
Ar
St
Pe
Av
St
Ta
Av
St
Me
Av
Sta
Ta
Ave
Sta

Table 9: Test subject anthropometric groups.

Population Samples	Subject ID	Stature - No Shoes In.	(mm)	Weight Lbs.	(kg)	Age Yrs.
Petite, light females	TM01	57.5	*(1461)*	101	*(46)*	19
	TM02	60.25	*(1530)*	108	*(49)*	21
	TM03	61	*(1549)*	114	*(52)*	19
	TM04	61.75	*(1568)*	104	*(47)*	19
	TM05	61.75	*(1568)*	112	*(51)*	22
Average		60.5	*(1535)*	107.8	*(49.0)*	20.0
Standard Deviation		1.8	*(44.8)*	5.4	*(2.5)*	1.3
Medium females	TM06	64.5	*(1638)*	145.5	*(66)*	21
	TM07	64	*(1626)*	118	*(54)*	49
	TM08	65	*(1651)*	129	*(59)*	20
	TM09	65	*(1651)*	131.5	*(60)*	22
	TM10	64.5	*(1638)*	124.5	*(57)*	19
Average		64.6	*(1641)*	129.7	*(59.0)*	26.3
Standard Deviation		0.4	*(10.6)*	10.2	*(4.6)*	12.6
Petite, ample females	TM11	62	*(1575)*	184	*(84)*	18
	TM12	58.75	*(1492)*	168	*(76)*	74
	TM13	60.5	*(1537)*	201	*(91)*	43
	TM14	62.5	*(1588)*	220	*(100)*	20
	TM15	60.25	*(1530)*	170	*(77)*	76
Average		60.8	*(1544)*	188.6	*(85.7)*	46.4
Standard Deviation		1.5	*(37.9)*	22.0	*(10.0)*	27.9
Tall, light males	TM16	73.75	*(1873)*	139	*(63)*	19
	TM17	72	*(1829)*	152	*(69)*	21
	TM18	72.75	*(1845)*	127	*(58)*	22
	TM19	71.5	*(1816)*	129	*(59)*	22
	TM20	Not Tested				
Average		72.5	*(1841.5)*	136.8	*(62.2)*	21.3
Standard Deviation		1.0	*(24.9)*	11.4	*(5.2)*	1.4
Medium males	TM21	68.25	*(1734)*	174.5	*(79)*	44
	TM22	68.75	*(1746)*	184	*(84)*	24
	TM23	68.5	*(1740)*	168	*(76)*	28
	TM24	67.75	*(1721)*	172.5	*(78)*	20
	TM25	69.25	*(1759)*	163.5	*(74)*	21
Average		68.5	*(1739.9)*	172.5	*(78.4)*	27.3
Standard Deviation		0.6	*(14.2)*	7.7	*(3.5)*	9.9
Tall, heavy males	TM26	73.25	*(1861)*	217	*(99)*	24
	TM27	72.25	*(1835)*	193	*(88)*	22
	TM28	71.5	*(1816)*	218	*(99)*	20
	TM29	72.25	*(1835)*	195	*(89)*	21
	TM30	72	*(1829)*	207	*(94)*	24
Average		72.3	*(1835.2)*	206.0	*(93.6)*	22.5
Standard Deviation		0.6	*(16.2)*	11.8	*(5.4)*	1.9

5.1.2 Anth

Ant

described

anthropom

Research

by TecMa

wearing t

Th

silhouett

This syst

postures

39 belov

progran

Figu

5.1.2 Anthropometric Data Collection

Anthropometric measurements that were recorded during testing are described in Appendix A. These measurements were based on a 1988 anthropometric survey of U.S. Army personnel by the U.S. Army Natick Research, Development, and Engineering Center [52] combined with those used by TecMath for virtual manikin building. Measurements were taken with subjects wearing thin, tight-fitting clothing.

The contour system developed by TecMath [57] was adopted to gather silhouettes so an appropriate anthropometric analysis could later be conducted. This system records a black and white computer image of each subject in three postures against a known and calibrated background space, as shown in Figure 39 below. The subject's outlines were then imported into TecMath's RContour program to build an appropriately sized virtual manikin of that test subject.

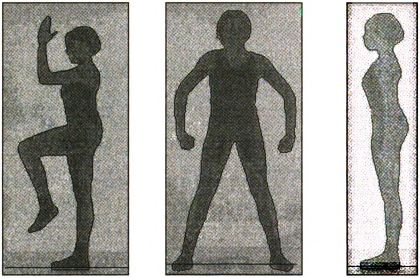


Figure 39: Contour program developed by TecMath and example silhouettes.

5

b

s

a

b

b

s,

cr

Fr

wr

we

pi

de

Fi

5.1.3 Motion Data Collection

A wooden laboratory seat, shown in Figure 40, with an opening in the back, was used to collect reference data of Qualisys marker locations along the spine since these locations were not accessible once the subject was in the automotive seats. This hard seat had approximately the same seat pan and seat back orientation as the automotive seat setup. The subject was seated with the back of the pelvis and lower spine against the seat so that his or her flat lumbar spine could be used as a reference position for JOHN measurements of lumbar curvature as previously discussed. The subject's head was oriented with the Frankfort plane nearly horizontal, by means of aligning the appropriate landmarks with a level, when the reference seat data were collected. The subject's feet were placed on a flat block at a comfortable distance and close to the sagittal plane of the body. The reference seat gives a J826 manikin cushion angle of 10 degrees and a manikin back angle of 24 degrees.

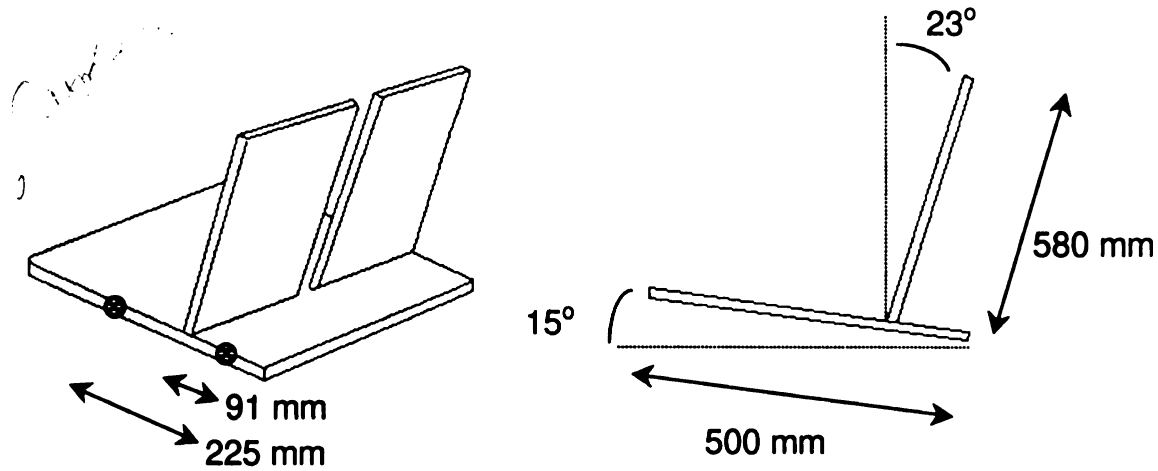


Figure 40: Reference hard seat dimensions.

Once anthropometric measurements were taken, the subject was targeted and tested in Seat A (tan LH), Seat B (Town & Country), Seat C (BMW with thorax fully forward and then fully rearward), and Seat D (Gray LH). Targets were applied while the subject was seated in order to reduce errors from skin movement. In each seat the subject was tested in both the sedan and van seat heights with the lumbar support in the fully on and the fully off positions. Each of these cases was then alternated between driver and passenger, for a total of eight conditions per seat. Each test subject was allowed to sit in a preferred position with respect to seat horizontal position and backrest recline angle. The subject was only allowed to adjust the steering wheel tilt if the wheel was too close to his or her thighs to be comfortable. Both of the subject's feet were placed on the toe bar during the driver condition since a sagittally symmetric analysis was used for this study. Occasionally, one of the petite females could not reach the toebar comfortably so a wooden block was placed in front of the toebar so the subject could achieve comfortable leg positions.

Advice was not given to the subject regarding placement of the buttocks in the seat or choice of backrest recline angle, since the objective was to have the subject in his or her preferred position. However, to discourage severely slouched postures the initial position of the seat was with the backrest fully upright and the seat adjusted too close to the steering wheel and toebar. The test subject was asked to scoot forward in the seat, away from the backrest, while lumbar adjustments were made to help ensure that adjustments in posture were made between trials. Since the test conditions were static, only one second of c

so

the

var

5.1.

and

Tab

Ref
Sea
Sea

C7

T8

T12

L1

L3

Mid-F

Hard

seat fr

and re

(left sic

Figure

of data, collected at 12 Hz, was necessary. The test conditions were randomized so that half of the subjects started with the lumbar support in the off position, and the other half in the on position. Testing also alternated between the sedan and van packages. The order in which the seats were selected was randomized.

5.1.4 Targeting Setup

Target locations used in the reference hard seat files are listed in Table 10 and shown in Figure 41 below.

Table 10: Target locations for reference trials.

Reference Seat	Test Subject
Seat Pan Front	Sternal Notch
Seat Pan Rear	Mid-sternum
	C7 (Seventh cervical vertebrae)
	T8 (Eighth thoracic vertebrae)
	T12 (Twelfth thoracic vertebrae)
	L1 (First lumbar vertebrae)
	L3 (Third lumbar vertebrae)
	Left ASIS and Right ASIS
	Mid-PSIS
	Right Thigh
	Right Knee (Lateral Femoral Epicondyle)
	Right Ankle (Lateral Maleolous)
	Right Ball of Foot
	Right Shoulder (Acromion Process)
	Left Head (Temple) and Right Head (Temple)
	Forehead (1 cm above Glabella)

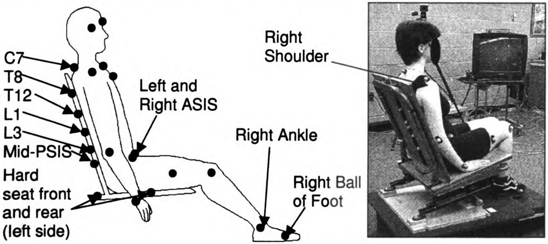


Figure 41: Reference hard seat and targeted subject.

angl

as L5

as sh

land

Tabl

Ref
Sea
Rec
Righ
Buc
Buck

Figure 42

The automotive seats were also targeted to calculate the seat back recline angle and horizontal position of the seat relative to other package factors, such as L53, of each trial. Various bony landmarks of the test subject were targeted as shown in Figure 42 and Table 11 below. The importance of these particular landmarks has been discussed.

Table 11: Target locations for seat testing.

Reference Seat	**Test Subject**
Seat Pan Front and Rear	Sternal Notch
Recline Top and Bottom	Mid-Sternum
Right Toe Bar	C7
Buck Front and Rear	Left ASIS and Right ASIS
Buck Top	Mid-Thigh
	Right Knee (Lateral Femoral Epicondyle)
	Right Ankle (Lateral Maleolous)
	Right Ball of Foot
	Right Shoulder (Acromion Process)
	Right Elbow (Humeral Lateral Condyle)
	Right Wrist (Ulnar Condyle)
	Left Head (Temple) and Right Head (Temple)
	Forehead (1 cm above Glabella)

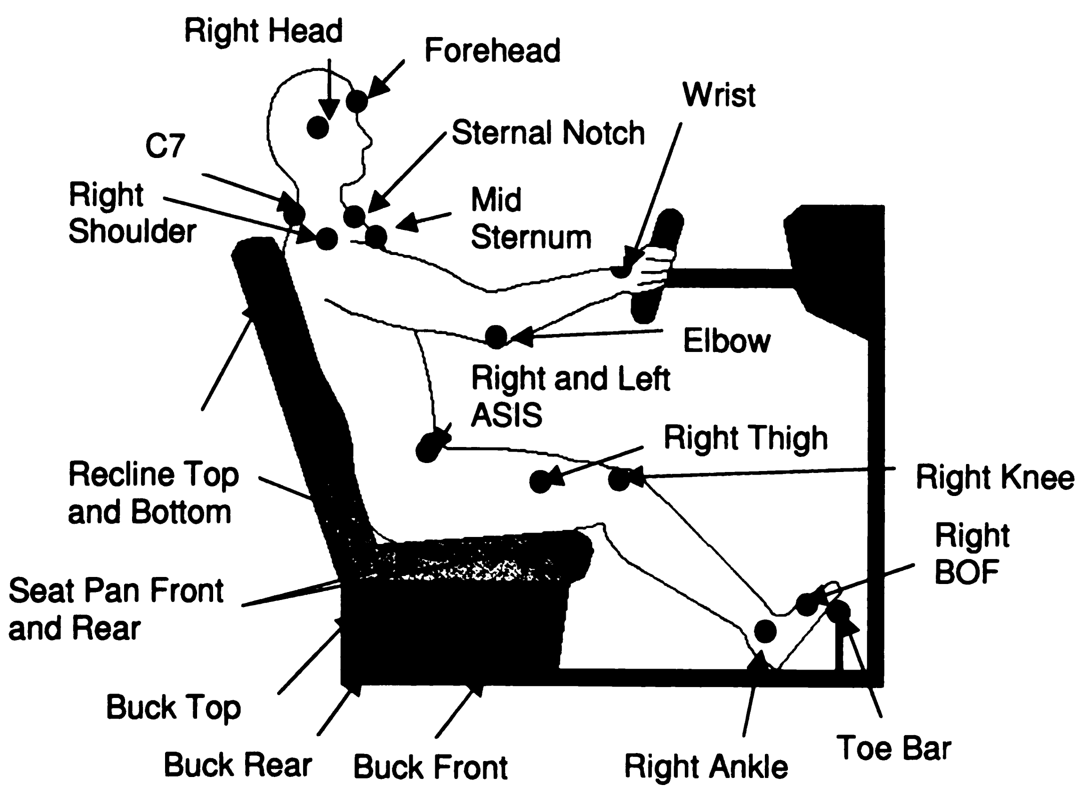


Figure 42: Targeted subject in test buck.

Fi
st

5.

by

th

as

In

we

The photographs below show the entire set up of the test buck .

(a) (b) (c)

Figure 43: a) Test buck set up in van condition. b) Vision task. c) Dashboard and steering wheel.

5.2 Calculations

The main goal of this analysis was to measure how postures are affected by seat and package factors. To accomplish this goal, the relative orientation of the pelvis and thorax were examined. A point on the pelvis (the hip joint center as discussed on page 13) was included to locate the person in the seat. Information on the lumbar curvature, and orientations of the head, legs, and arms were also included to provide a complete analysis.

5.2.1 Rotat

Befo

align the X

maintaine

frame, ar

test buck

targets o

system,

X_{ab}

Figure

Positio

was cr

positio

$\hat{X}_{Buck}$

Referen

targets

5.2.1 Rotation to Sagittal Plane

Before calculations were performed, targets on the test buck were used to align the X-axis of the buck with that of the calibrated lab space so that all data maintained a common reference point and orientation. The targets on the buck frame, and those on the hard seat of the reference files, formed the X-axis of the test buck, with the positive direction pointing rearwards. It was assumed that the targets on the calibration structure were level, within the error of the collection system, so that only a rotation about the vertical Z-axis was necessary.

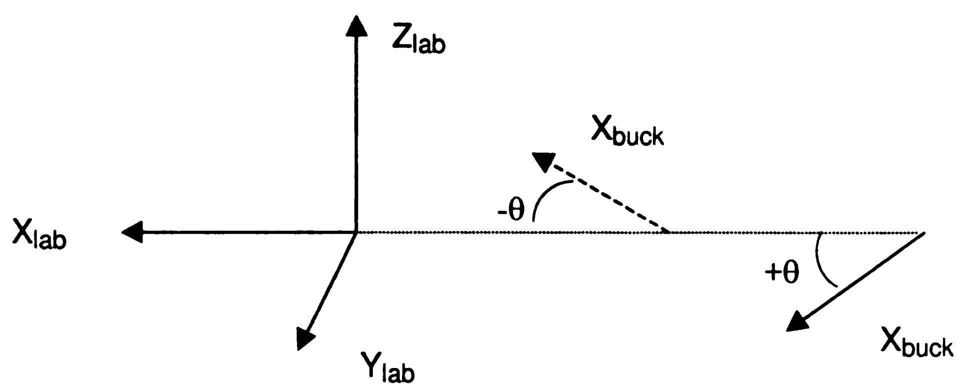


Figure 44: Rotation of test buck to align with lab coordinates.

Position vectors will be noted with the use of an "R." The x-axis of the test buck was created to point positive posterior using equation 5.1. R_{Buck_rear} is the position vector of the rear target on the buck in the buck coordinate system.

$$\hat{X}_{Buck} = \hat{R}_{Buck\_rear/Buck\_front} = \frac{R_{Buck\_rear} - R_{Buck\_front}}{\left|R_{Buck\_rear} - R_{Buck\_front}\right|} \qquad (5.1)$$

Reference files were rotated with the above method, except the front and rear targets of the buck were reversed since the subject was facing the opposite c

u

e

s

s

θ

θ

T

co

th

re

po

R

5.2

line

fron

orde

Refe

direction to view the spine in those trials. In the following equations, ACos will be used in place of arc cosine. The angles used to align the data are defined in equations 5.2 and 5.3. Y_{Lab} is a unit vector for the y axis of the lab coordinate system. X_{Buck} and $X_{HardSeat}$ are unit vectors for the x axes of the buck and hard seat.

$$\theta_{Align} = 90^o - ACos\left(\hat{Y}_{Lab} \cdot \hat{X}_{Buck}\right) \tag{5.2}$$

$$\theta_{Align} = 180^o - \left(90^o - ACos\left(\hat{Y}_{Lab} \cdot \hat{X}_{HardSeat}\right)\right) \tag{5.3}$$

The position vectors of each target were then rotated to align them with the lab coordinate system from the calibration structure. The origin was also moved so that all points were relative to a common reference point, the rear buck target, refer to equation 5.4. R′ is a modified position vector. With R being the original position vector to each target.

$$R' = \begin{bmatrix} Cos\theta_{Align} & Sin\theta_{Align} & 0 \\ -Sin\theta_{Align} & Cos\theta_{Align} & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot R - \begin{bmatrix} Cos\theta_{Align} & Sin\theta_{Align} & 0 \\ -Sin\theta_{Align} & Cos\theta_{Align} & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot R_{Buck\_rear} \tag{5.4}$$

5.2.2 Head Tilt

Head tilt was defined as the sagittal plane angle between horizontal and a line from the temple target to the forehead target. The angle that was calculated from these targets in the reference file was subtracted from the seat trials in order to reference the head tilt target angle to the Frankfort plane orientation, Refer to Figure 4.

5.2.3 Elbow Angles

For the driver positions, the elbow angle was calculated as the angle between the segments of the arm as in Figure 45 below, using the definition of the dot product of the relative vectors for each segment. $R_{Shoulder/Elbow}$ is a vector from the elbow target to the shoulder target.

$$\theta_{Elbow} = ACos\left(\frac{R_{Shoulder/Elbow} \cdot R_{Wrist/Elbow}}{|R_{Shoulder/Elbow}| \cdot |R_{Wrist/Elbow}|}\right) \quad (5.5)$$

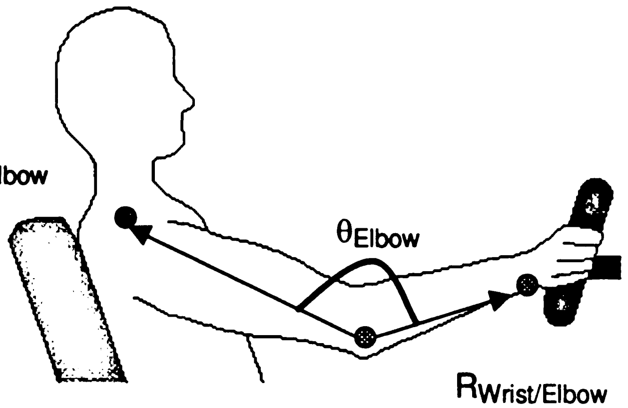


Figure 45: Elbow angle definition.

The splay angle for the arms was determined by rotating the plane formed by the wrist, the elbow, and the shoulder around a vector from the shoulder to the wrist until the arm plane was vertical. Then the normal vector to the arm plane was given by equation 5.6.

$$\hat{n}_{Arm} = \frac{R_{Wrist/Elbow} \times R_{Shoulder/Elbow}}{|R_{Wrist/Elbow} \times R_{Shoulder/Elbow}|} \quad (5.6)$$

The normal to the vertical plane with the shoulder and wrist was defined by equation 5.7.

$$\hat{n}_{Vertical} = \frac{R_{Z\_Buck} \times R_{Shoulder/Wrist}}{|R_{Z\_Buck} \times R_{Shoulder/Wrist}|} \quad (5.7)$$

The angle between these normal vectors of each plane gives the angle between the planes, referred to as the splay angle shown in Figure 46.

$$\theta_{ArmSplay} = ACos(\hat{n}_{Arm} \cdot \hat{n}_{Vertical}) \quad (5.8)$$

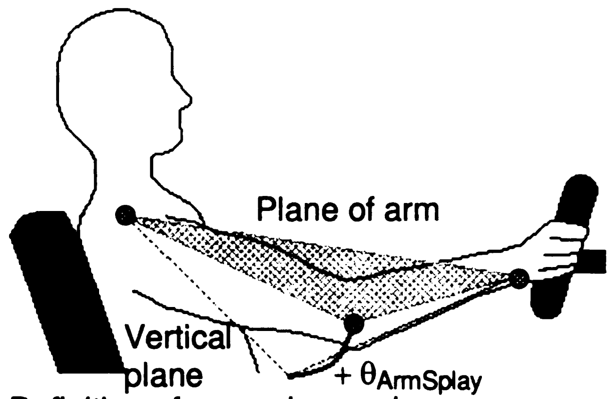


Figure 46: Definition of arm splay angle.

5.2.4 Hip Joint Center

The right and left anterior superior iliac spines (ASIS), the midpoint of the posterior superior iliac spines (PSIS), and the knee targets were used to calculate the right hip joint center (HJC) from these target locations and the anthropometric measurements of the pelvis. Since the subject was allowed to sit in a preferred position, the location of the buttocks needed to be related to the seat pan to determine the subject's location in the seat. A comparison was therefore made between a target on the seat and the HJC of the test subjects. Because this offset varies by seat and lumbar positioning, a relation between human HJC location and seat factors will later be examined to determine if this relation is predictable.

The right hip joint center was calculated from the knee and ASIS targets as follows. The pelvis coordinate system and resulting right HJC location were defined from the reference files when the subject was in the wooden seat. The distances between the right knee and the right HJC and the right ASIS and right HJC were then calculated to later locate the HJC in the seat trials.

For the sake of clarity, vectors in the pelvis coordinate system are denoted by lowercase letters (r) while vectors in the laboratory coordinate system are in uppercase (R). The target and estimated tissue thickness ($L_{External}$) were first accounted for to get a closer match to Marchinda's study [49] on defleshed cadavers. Tissue thickness was estimated as 8mm [5], with approximately an inch added to account for heavier subjects. The thickness of the target backing, shown in Figure 1(a), also had to be accounted for; giving a distance from the target center to the underlying bony landmark defined in equation 5.9.

$$L_{External} = \frac{SphereThickness}{2} + Tissue + Backing \tag{5.9}$$

Since the reference files contained target data for both the front and back of the pelvis, these data could be used to estimate the defleshed location of the pelvis targets. The above length was subtracted towards the center of the body beginning with a vector from the right ASIS to midway between the left and right PSIS landmarks (refer to Figure 47).

$$\hat{R}_{Right} = \frac{R_{midPSIS} - R_{RASIS}}{\left|R_{midPSIS} - R_{RASIS}\right|} \tag{5.10}$$

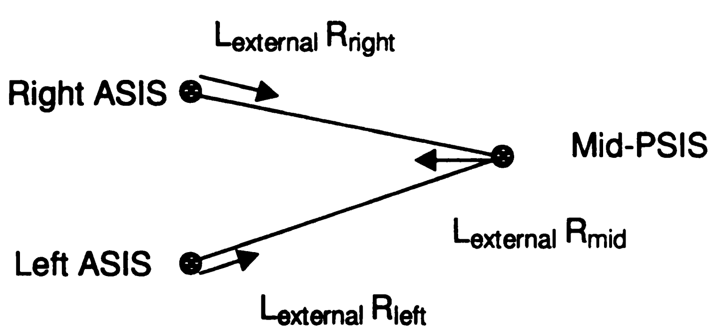


Figure 47: Estimated locations of pelvis landmarks (top view).

T

L

U

L

T

A

R

Th

m

th

at

ta

y

Th

be

R

Cr

the

inf

z

Then the estimated location of the right ASIS bony landmark was:

$$RASIS_{Actual} = R_{RASIS} + L_{External} \cdot \hat{R}_{Right} \tag{5.11}$$

Using the same method, the estimated location of the left ASIS was therefore:

$$LASIS_{Actual} = R_{LASIS} + L_{External} \cdot \frac{R_{midPSIS} - R_{LASIS}}{\left|R_{midPSIS} - R_{LASIS}\right|} \tag{5.12}$$

The estimated location of the actual PSIS landmark was taken from both of the ASIS target locations.

$$\hat{R}_{mid} = \frac{-\left(\hat{R}_{Right} - \hat{R}_{Left}\right)}{\left|\hat{R}_{Right} - \hat{R}_{Left}\right|} \tag{5.13}$$

The actual location of the midPSIS landmark was estimated by equation 5.14.

$$midPSIS_{Actual} = R_{midPSIS} + L_{External} \cdot \hat{R}_{mid} \tag{5.14}$$

Using the new pelvis landmark locations, the y-axis (positive medial from the right to the center of the pelvis) of the pelvis coordinate system with the origin at the right ASIS was then defined, with respect to buck coordinates, by the ASIS targets as follows (refer to Figure 48).

$$\hat{y}_{Pelvis} = \frac{R_{LASIS} - R_{RASIS}}{\left|R_{LASIS} - R_{RASIS}\right|} \tag{5.15}$$

The vector from the right ASIS (origin of pelvis coordinate system) to midway between the right and left ASIS was given by equation 5.16.

$$R_{midASIS/PSIS} = \left(R_{RASIS} + \frac{R_{LASIS} - R_{RASIS}}{2}\right) - R_{PSIS} \tag{5.16}$$

Crossing the vector from the PSIS midpoint to the ASIS midpoint into the y-axis then formed the z-axis of the pelvis. The resulting z-axis was then positive inferior.

$$\hat{z}_{Pelvis} = \frac{\hat{y}_{Pelvis} \times R_{midASIS/PSIS}}{\left|\hat{y}_{Pelvis} \times R_{midASIS/PSIS}\right|} \tag{5.17}$$

Finally, crossing the y and z-axes to form a right-handed coordinate system, with the x-axis positive posterior formed the x-axis of the pelvis.

$$\hat{x}_{Pelvis} = \hat{y}_{Pelvis} \times \hat{z}_{Pelvis} \tag{5.18}$$

The resulting pelvis coordinate system, along with intermediate vectors and target locations, is shown below in Figure 48.

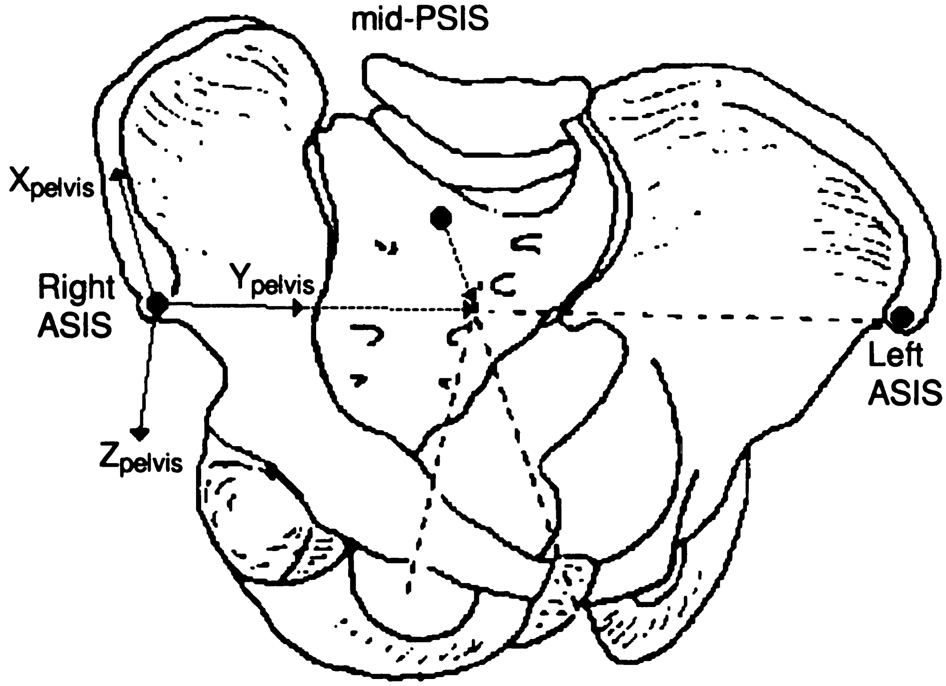


Figure 48: Pelvis coordinate system (solid arrows) with intermediate vectors (dashed arrows) and targets [6].

The method of estimating the right HJC, developed by Marchinda, *et al.*, [49], was adopted for this study. This method uses the measured pelvic width (PW), pelvic height (PH), and pelvic depth (PD), refer to Appendix A, to locate the HJC in the pelvis coordinate system. The right HJC is located posterior, medial, and inferior to the right ASIS, as shown above in Figure 48. In the pelvis coordinate system the HJC was located according to equation 5.19.

$$r_{HJC} = \begin{pmatrix} 0.34 * PD \\ 0.14 * PW \\ 0.79 * PH \end{pmatrix} \tag{5.19}$$

The HJC in the pelvis coordinate system was then transformed to the buck coordinate system.

$$R_{HJC} = \begin{bmatrix} x_{Pelvis\_i} & y_{Pelvis\_i} & z_{Pelvis\_i} \\ x_{Pelvis\_j} & y_{Pelvis\_j} & z_{Pelvis\_j} \\ x_{Pelvis\_k} & y_{Pelvis\_k} & z_{Pelvis\_k} \end{bmatrix} \cdot r_{HJC} + R_{RASIS} \tag{5.20}$$

It was assumed that the legs remained in relatively the same position with the pelvis between the reference hard seat and the automotive seats. Therefore the reference sagittal (x-z) dimensions between the right ASIS, right knee and right HJC could be used to estimate the location of the right HJC in the automotive seats [15]. Refer to Figure 49 below for the following calculations.

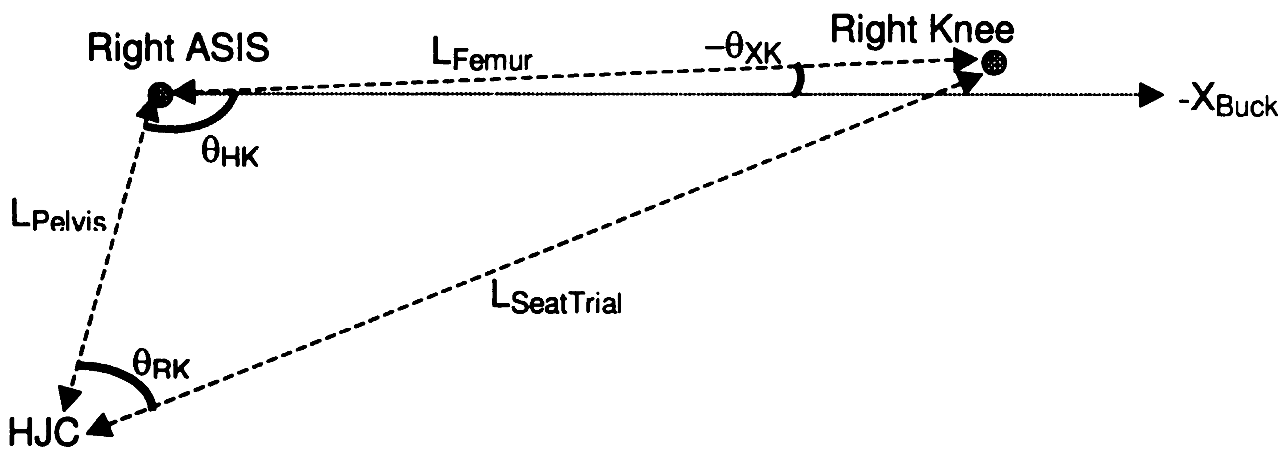


Figure 49: Estimation of the right HJC from seat trial data.

The length of the leg and the pelvis height using the target locations from the reference file are given in equation 5.21 and 5.22.

$$L_{Femur} = \left| R_{HJC} - R_{Knee} \right|_{XZ} \tag{5.21}$$

$$L_{Pelvis} = \left| R_{HJC} - R_{RASIS} \right|_{XZ} \tag{5.22}$$

The length from the right ASIS target to the knee target during the seat trials was defined as follows.

$$L_{SeatTrial} = \left| R_{RASIS} - R_{Knee} \right|_{XZ} \tag{5.23}$$

The above three known lengths were then used to calculate the location of the HJC during the seat trials in the following manner. Equation 5.24 defines the resulting HJC angle between the right ASIS and the right knee.

$$\theta_{RASIS\_Knee} = ACos\left(\frac{L_{SeatTrial}^2 - L_{Femur}^2 - L_{Pelvis}^2}{-2L_{Femur}L_{Pelvis}}\right) \quad (5.24)$$

The angle between the right HJC and knee was also required, refer to Figure 48.

$$\theta_{HJC\_Knee} = ACos\left(\frac{L_{Femur}^2 - L_{SeatTrial}^2 - L_{Pelvis}^2}{-2L_{SeatTrial}L_{Pelvis}}\right) \quad (5.25)$$

To get the estimated HJC location in the buck coordinate system, the X-Z coordinates of a unit vector from the right ASIS to the right knee were rotated by θ_{HK} about the y axis. This was done using a distance equal to the pelvis length, with the right ASIS as a reference point.

$$\begin{pmatrix} HJC_x \\ HJC_y \end{pmatrix} = L_{Pelvis} \cdot \begin{bmatrix} Cos(-\theta_{HK}) & Sin(-\theta_{HK}) \\ -Sin(-\theta_{HK}) & Cos(-\theta_{HK}) \end{bmatrix} \cdot \begin{pmatrix} \hat{R}_{Knee/RASIS\_X} \\ \hat{R}_{Knee/RASIS\_Z} \end{pmatrix} \quad (5.26)$$

Although this estimation was performed sagittally, a y-coordinate was desired to create a full 3-D picture for visualization purposes. The y location of the HJC was therefore estimated from the two ASIS landmarks.

$$HJC_y = 0.14 \cdot PW \cdot \hat{y}_{Pelvis} \quad (5.27)$$

Only the right side was estimated since later analysis was conducted under the assumption that the body was sagittally symmetric. Equation 5.28 was used to determine the location of the right HJC in the buck coordinate system.

$$R_{HJC} = R_{RASIS} \cdot \begin{pmatrix} HJC_x \\ HJC_y \\ HJC_z \end{pmatrix} \quad (5.28)$$

5.2.5 Pelvis Angle

The pelvis angle was calculated as the angle between horizontal and a line connecting the right ASIS and right HJC.

$$\theta_{PelvisAngle} = \theta_{HK} + \theta_{XK} \quad (5.29)$$

The θ_{XK} angle in equation 5.29 was defined by equation 5.30.

$$\theta_{XK} = ACos\left(\hat{Z}_{Buck} \cdot \frac{(R_{Knee} - R_{RASIS})}{|R_{Knee} - R_{RASIS}|} \right) - 90^o \quad (5.30)$$

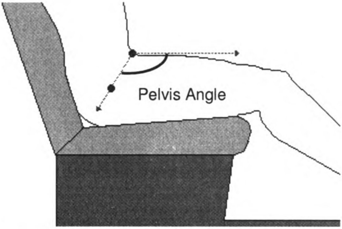


Figure 50: Pelvis angle definition.

5.2.6 Thorax Angle

The thorax angle represents the recline of the ribcage with respect to vertical, with a positive angle being a rearward recline.

$$\theta_{ThoraxAngle} = 90^o - ACos\left(\hat{X}_{Buck} \cdot \frac{(R_{SternalNotch} - R_{MidSternum})_{XZ}}{|R_{SternalNotch} - R_{MidSternum}|_{XZ}} \right) \quad (5.31)$$

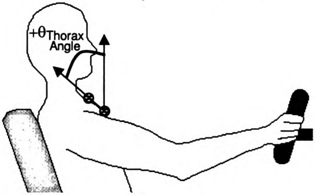


Figure 51: Thorax angle definition.

5.2.7 Openness Angle

The thorax and pelvis angles were added together (plus 90 degrees) to determine the position of the thorax relative to the pelvis, refer to Figure 52. This value is based on that used by Bush [13, 14] although the definition of pelvis angle differs due to available targets. A similar calculation will later be explained that focuses on the angles between the estimated internal spinal joints.

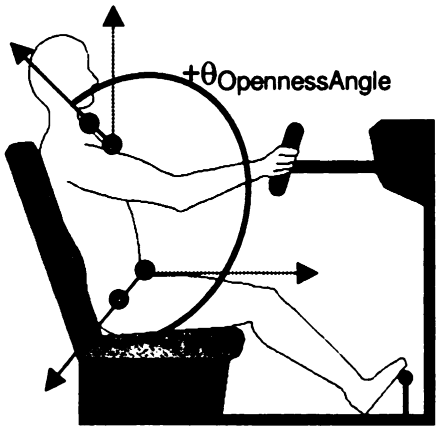


Figure 52: Openness angle definition.

5.2.8 Knee Angles

The knee angle, ankle location relative to HJC, and knee splay angle specified the three-dimensional leg orientation. Although the thigh target could be used in place of the HJC as a backup, this target was not as reliable since it tended to fall off during testing and was subject to excessive tissue movement when the test subject slid into the seat. The knee angle was determined from the dot product between a vector from the knee to the right HJC and from the knee to the ankle. The knee angle is shown below in Figure 53.

$$\theta_{Knee} = ACos\left(\frac{R_{HJC/Knee} \cdot R_{Ankle/Knee}}{\left|R_{HJC/Knee}\right| \cdot \left|R_{Ankle/Knee}\right|}\right) \tag{5.32}$$

Fig

for

rig

Th

$\hat{n}_i$

Th

θ_L

Th

Figu

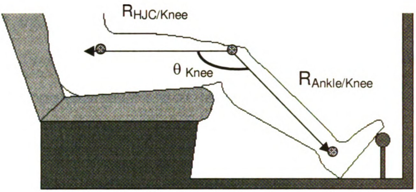


Figure 53: Definition of knee angle.

The splay angle of the knee was calculated as the angle that the plane formed by the HJC, knee and ankle targets is rotated (around a line between the right HJC and ankle) until the plane of the leg is vertical.

The unit normal to the vertical plane was defined with equation 5.33.

$$\hat{n}_{Vertical} = \frac{R_{ZBuck} \times R_{HJC/Ankle}}{\left|R_{ZBuck} \times R_{HJC/Ankle}\right|} \quad (5.33)$$

The resulting splay angle for the leg was defined with equation 5.34.

$$\theta_{LegSplay} = ACos\left(\hat{n}_{Leg} \cdot \hat{n}_{Vertical}\right) \quad (5.34)$$

The knee splay angle is shown below in Figure 54.

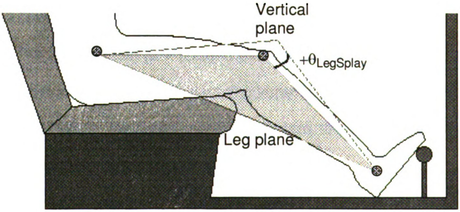


Figure 54: Knee splay angle.

5.2.9

as the

θ_{Ankle}

The c

minu

θ_{Sho}

Fi

5.

es

jo

th

5.2.9 Ankle Angles

Two ankle angles were calculated, the first was similar to the knee angle as the angle between the lower leg and the foot.

$$\theta_{Ankle} = ACos\left(\frac{R_{Knee/Ankle} \cdot R_{Ankle/BallOfFoot}}{\left|R_{Knee/Ankle}\right| \cdot \left|R_{Ankle/BallOfFoot}\right|} \right) \qquad (5.35)$$

The other angle, referred to as the shoe angle, was calculated as the ankle angle minus the reference angle from the flat foot case of the reference files.

$$\theta_{Shoe} = \left\{ 90^o - ACos\left(\hat{Z}_{Buck} \cdot \left(\hat{R}_{BallOfFoot/Ankle}\right)_{SeatTrials}\right)\right\} + \left\{ACos\left(\hat{Z}_{Buck} \cdot \left(\hat{R}_{BallOfFoot/Ankle}\right)_{HardSeat}\right) - 90^o \right\} \qquad (5.36)$$

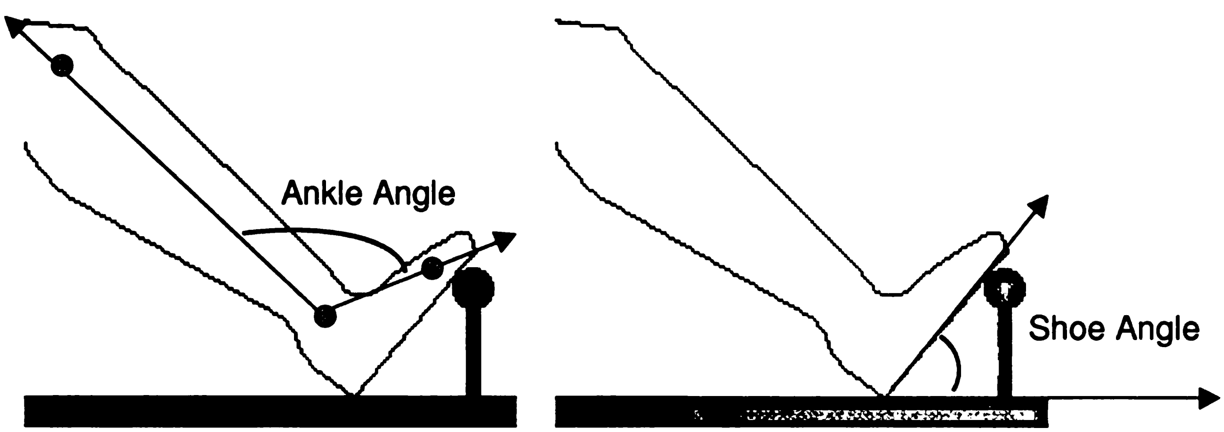


Figure 55: Ankle and shoe angles.

5.2.10 Lower Lumbar Joint Location

The lower lumbar joint (LLJ) location, connecting L5 and S1, was estimated from anthropometric data and target locations similar to that of the hip joint center [49]. In the pelvis coordinate system, the sagittal plane location of the LLJ was given by equation 5.37.

$$r_{LLJ} = \begin{pmatrix} 0.399 * PD \\ -- \\ -0.432 * PH \end{pmatrix} \qquad (5.37)$$

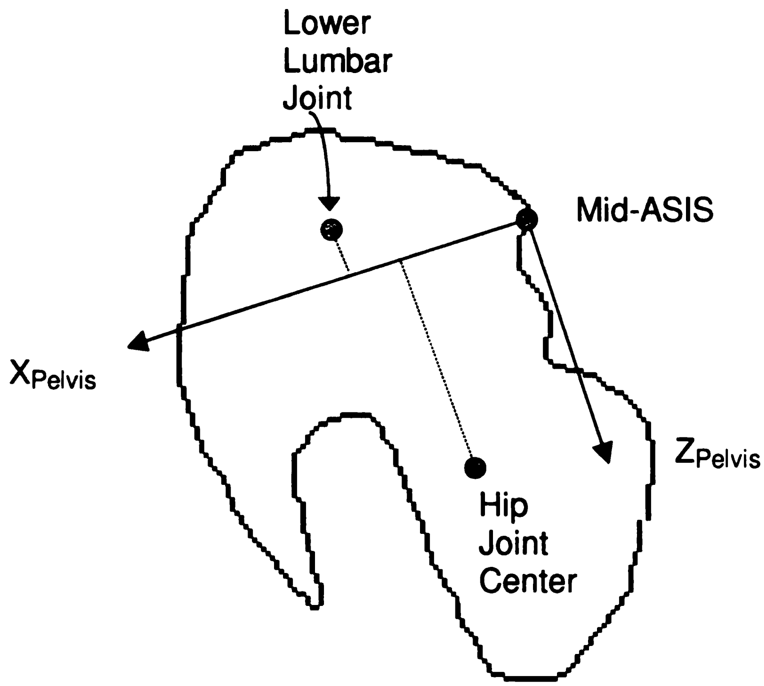


Figure 56: Sagittal view of the lower lumbar joint location in the pelvis coordinate system.

The above location of the lower lumbar joint in the pelvis coordinate system was then transformed back into the buck coordinate system.

$$R_{LLJ} = \begin{bmatrix} x_{Pelvis\_i} & y_{Pelvis\_i} & z_{Pelvis\_i} \\ x_{Pelvis\_j} & y_{Pelvis\_j} & z_{Pelvis\_j} \\ x_{Pelvis\_k} & y_{Pelvis\_k} & z_{Pelvis\_k} \end{bmatrix} \cdot r_{LLJ} + R_{RASIS} \tag{5.38}$$

The sagittal plane angle between the LLJ and right HJC was defined with equation 5.39 and is shown in Figure 57.

$$\theta_{LLJ\_HJC} = ACos\left(\frac{R_{LLJ} - R_{RASIS}}{|R_{LLJ} - R_{RASIS}|} \cdot \frac{R_{HJC} - R_{RASIS}}{|R_{HJC} - R_{RASIS}|} \right) \tag{5.39}$$

Refer to equation 5.40 for the remaining dimension needed to calculate the LLJ location in the seat trials.

$$L_{LowerSpine} = \sqrt{(0.399PD)^2 + (-0.432PH)^2} \tag{5.40}$$

A Y position for the LLJ was estimated only for visualization purposes. Rotating the right HJC to ASIS vector up to the lower lumbar joint by the above theta gives equation 5.41.

$$R_{LLJ} = R_{RASIS} + \left(\frac{R_{LASIS/RASIS}}{2}\right)_y + L_{LowerSpine}\begin{bmatrix} Cos(-\theta_{LLJ/HJC}) & Sin(-\theta_{LLJ/HJC}) \\ -Sin(-\theta_{LLJ/HJC}) & Cos(-\theta_{LLJ/HJC}) \end{bmatrix}\left(\hat{R}_{HJC/RASIS}\right)_{xz} \quad (5.41)$$

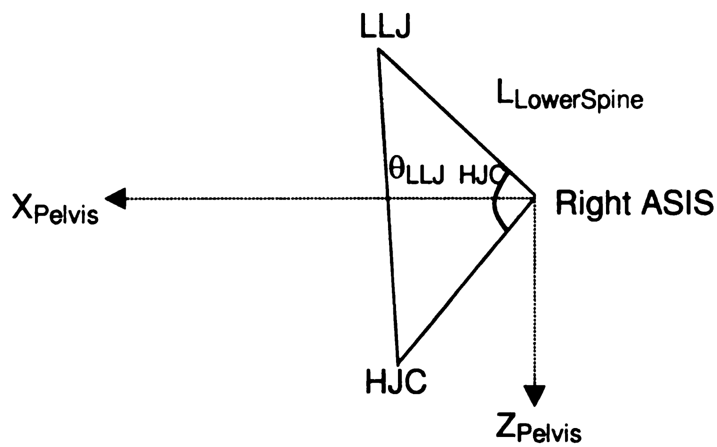


Figure 57: Location of the lower lumbar joint with respect to the HJC and pelvis coordinate system.

5.2.11 Upper Lumbar and Lower Neck Joint Locations

The upper lumbar joint (T12/L1, referred to as ULJ) and lower neck joint (C7/T1, referred to as LNJ) locations were also estimated from anthropometric measurements and target locations using methods of the ASPECT [5] program. The ribcage was assumed to be rigid and aligned with the buck coordinate system.

In order to account for the thickness of the targets and skin tissues, refer to page 64, this estimated thickness was subtracted by bringing the C7 and sternal notch targets towards each other in both the reference and automotive seat trials.

$$\hat{R}_{Chest} = \frac{R_{SternalNotch} - R_{C7}}{\left|R_{SternalNotch} - R_{C7}\right|} \tag{5.42}$$

The new location of the C7 landmark was therefore defined by equation 5.43.

$$C7_{Actual} = R_{C7} + L_{External}\hat{R}_{Chest} \tag{5.43}$$

Equation 5.44 gives the new location of the sternal notch landmark.

$$SternalNotch_{Actual} = R_{SternalNotch} - L_{External}\hat{R}_{Chest} \tag{5.44}$$

The T8 and T12 locations of the reference file were assumed to be in the sagittal plane of the body so a rotation of 90 degrees about the y-axis towards the negative x-axis could be used to move these targets perpendicularly towards the center of the body. The rotated thorax vector was then defined by equation 5.45.

$$\hat{R}_{Thorax} = \begin{bmatrix} Cos(90^o) & Sin(90^o) \\ -Sin(90^o) & Cos(90^o) \end{bmatrix} \left(\frac{R_{T8} - R_{T12}}{\left|R_{T8} - R_{T12}\right|} \right)_{xz} \tag{5.45}$$

The T8 new location was given by equation 5.46.

$$T8_{Actual} = R_{T8} + L_{External}\hat{R}_{Thorax} \tag{5.46}$$

The new T12 location was given by equation 5.47.

$$T12_{Actual} = R_{T12} + L_{External}\hat{R}_{Thorax} \tag{5.47}$$

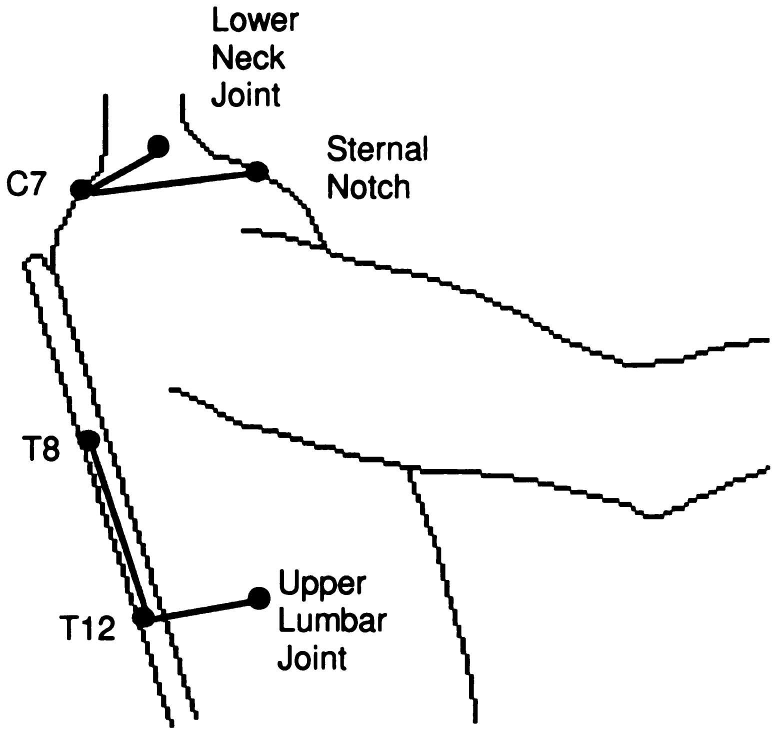


Figure 58: Locations of lower neck and upper lumbar joints.

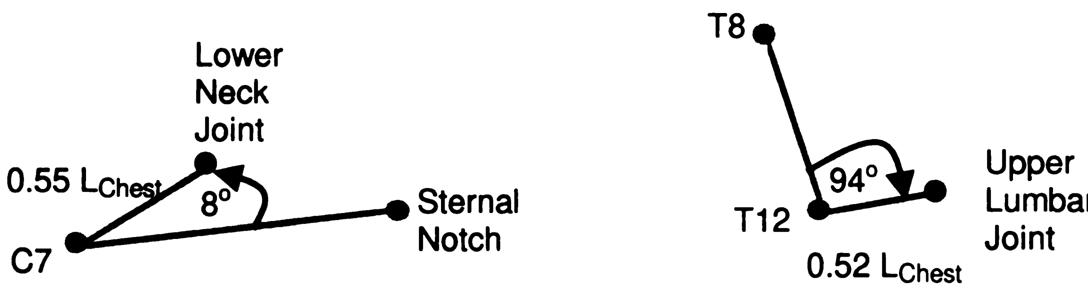


Figure 59: Estimated locations of the lower neck and upper lumbar joints [17].

For both seat and reference trials, using the estimated actual landmark locations, the lower neck joint (LNJ) was then calculated for the automotive seat trials.

$$L_{Chest} = \left| R_{SternalNotch} - R_{C7} \right|_{xz} \tag{5.48}$$

The new unit vector through the chest was defined by equation 5.49.

$$\hat{R}'_{Chest} = \left(\frac{R_{SternalNotch} - R_{C7}}{\left| R_{SternalNotch} - R_{C7} \right|} \right)_{xz} \tag{5.49}$$

The location of the lower neck joint was given by equation 5.50.

$$R_{LNJ} = R_{C7} + \left(\frac{R_{SternalNotch} - R_{C7}}{2} \right)_y + 0.55 \cdot L_{Chest} \begin{bmatrix} Cos(-8^o) & Sin(-8^o) \\ -Sin(-8^o) & Cos(-8^o) \end{bmatrix} \cdot \left(\hat{R}'_{Chest} \right)_{xz} \quad (5.50)$$

Like the HJC, the upper lumbar joint location had to be estimated from a combination of the reference file data and the seat trial chest targets. From reference files, the unit vector through the ribcage was given by equation 5.51.

$$\hat{R}'_{Ribcage} = \left(\frac{R_{T8} - R_{T12}}{\left| R_{T8} - R_{T12} \right|} \right)_{xz} \quad (5.51)$$

Rotating 94 degrees towards the front of the body [5].

$$R_{ULJ/T12} = 0.52 \cdot L_{Chest} \left(\begin{bmatrix} Cos(-94^o) & 0 & Sin(-94^o) \\ 0 & 1 & 0 \\ -Sin(-94^o) & 0 & Cos(-94^o) \end{bmatrix} \cdot \hat{R}'_{Ribcage} \right) \quad (5.52)$$

Equation 5.53 gives the location of the ULJ in the reference files using the estimated defleshed targets.

$$R_{ULJ} = R_{T12} + R_{ULJ/T12} \quad (5.53)$$

The thorax length and angle with respect to the upper chest targets were assumed to remain constant since, for the purposes of this study, the ribcage was assumed to be rigid. As shown in Figure 60 below, the length of the thorax and the angle between the thorax and chest landmarks from the reference files were defined with equations 5.54 and 5.55.

$$L_{Thorax} = \left| R_{ULJ} - R_{LNJ} \right|_{xz} \quad (5.54)$$

$$\theta_{Chest} = ACos\left(\frac{R_{ULJ} - R_{LNJ}}{\left| R_{ULJ} - R_{LNJ} \right|} \cdot \hat{R}'_{Chest} \right)_{xz} \quad (5.55)$$

The unit vector through the chest and thorax were again calculated in the seat trials.

$$\hat{R}'_{Chest} = \left(\frac{R_{SternalNotch} - R_{C7}}{\left| R_{SternalNotch} - R_{C7} \right|} \right)_{xz} \tag{5.56}$$

$$\hat{R}'_{Thorax} = \begin{bmatrix} Cos(-\theta_{Chest}) & Sin(-\theta_{Chest}) \\ -Sin(-\theta_{Chest}) & Cos(-\theta_{Chest}) \end{bmatrix} \cdot \hat{R}_{Chest} \tag{5.57}$$

The y coordinate of the ULJ was estimated as the average of the LNJ and LLJ y-coordinates for visualization purposes. The location of the ULJ in the seat trials was given by equation 5.58.

$$R_{ULJ} = R_{LNJ} + L_{Thorax} \cdot \hat{R}_{Thorax} \tag{5.58}$$

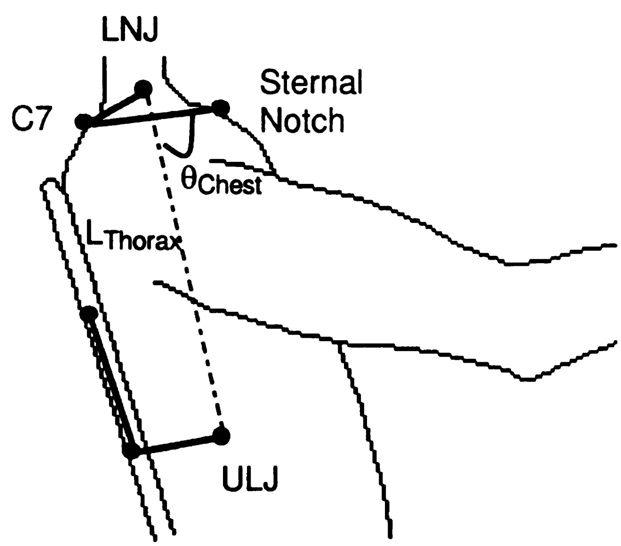


Figure 60: Estimation of the lower neck and upper lumbar joints.

5.2.12 Spinal Link Angles

The link between the lower neck joint and the upper lumbar joint was referenced to vertical and referred to as the thoracic spine link angle (TSLA). The link between the upper lumbar joint and the lower lumbar joint was refere

Final

refere

Figur

θ_{TSL4}

θ_{LSL}

θ_{PL4}

Low
nec

Upp
lumb

Fig

referenced to vertical and referred to as the lumbar spine link angle (LSLA). Finally, the link between the lower lumbar joint and the right hip joint center was referenced to vertical and referred to as the pelvic link angle (PLA) as shown in Figure 61 below.

$$\theta_{TSLA} = 90^o - ACos\left(\hat{R}_{LNJ/ULJ} \cdot \hat{X}_{Buck}\right) \tag{5.59}$$

$$\theta_{LSLA} = 90^o - ACos\left(\hat{R}_{ULJ/LLJ} \cdot \hat{X}_{Buck}\right) \tag{5.60}$$

$$\theta_{PLA} = 90^o - ACos\left(\hat{R}_{LLJ/HJC} \cdot \hat{X}_{Buck}\right) \tag{5.61}$$

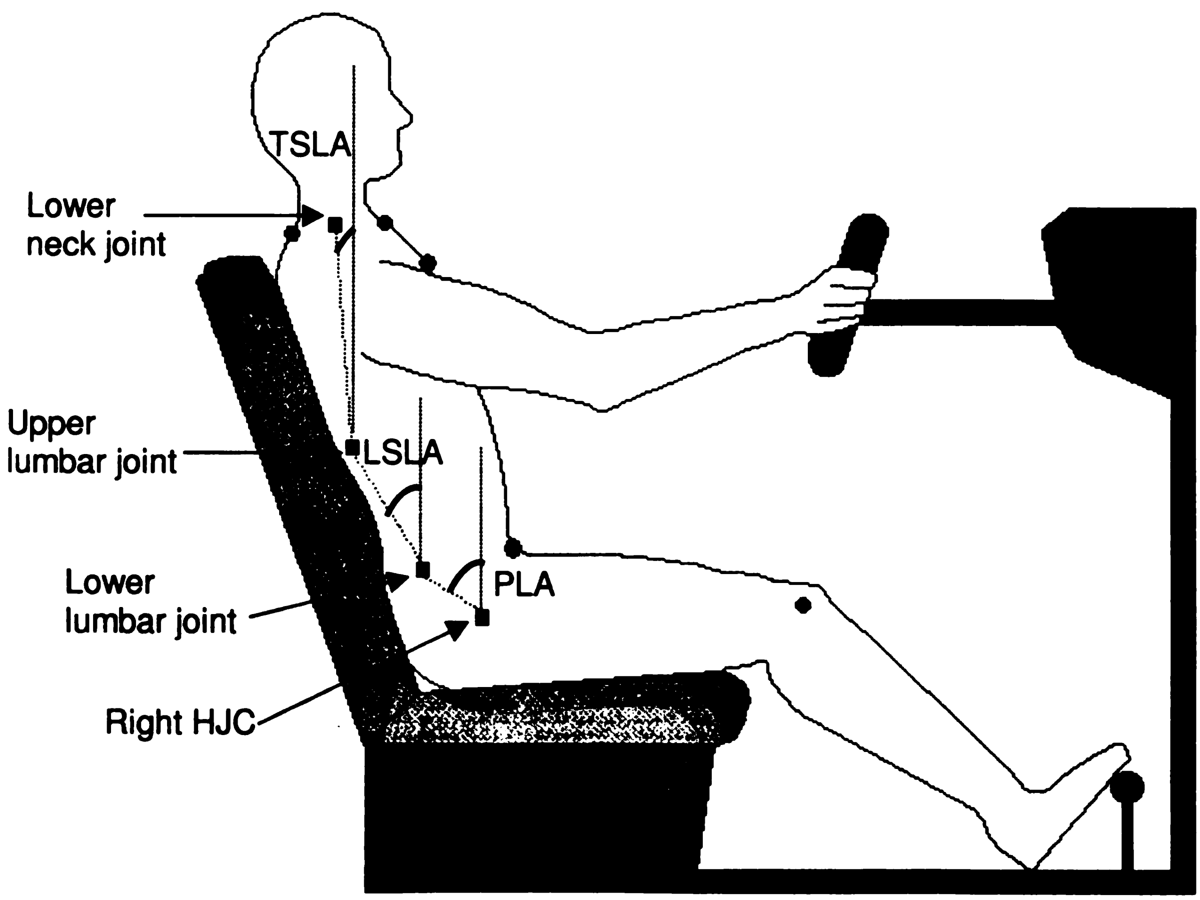


Figure 61: Spinal link angles.

5.2.13 Body Recline Angle

Body recline angle (BRA) is the angle between vertical and a line connecting the sternal notch and the ASIS midpoint.

$$\theta_{BRA} = 90^o - ACos\left(\frac{R_{SternalNotch} - R_{midASIS}}{\left| R_{SternalNotch} - R_{midASIS} \right|} \cdot \hat{X}_{Buck} \right) \qquad (5.62)$$

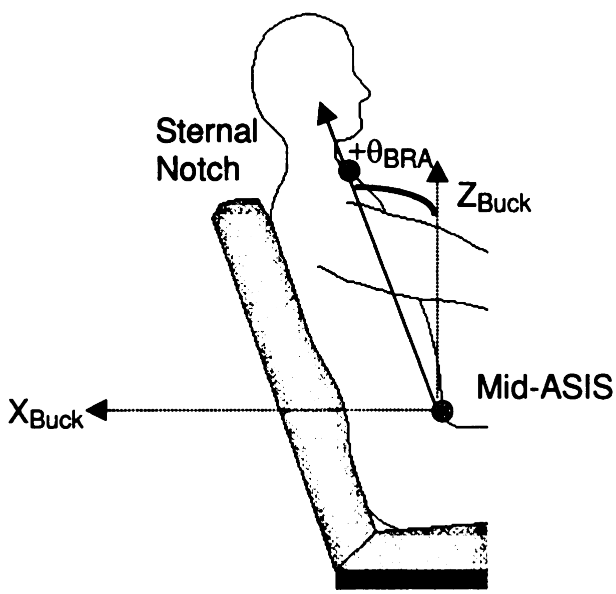


Figure 62: Definition of body recline angle.

5.2.14 Total Lumbar Curvature

The total lumbar curvature (TLC) was calculated as the difference between the sum of the upper lumbar (ULA) and lower lumbar angles (LLA) in the flat back reference seat posture to that chosen by the subject in the automotive seats. This angle is similar to the aforementioned openness angle that was used to examine the relative orientations of the thorax and pelvis. As the posture of the individual in the automotive seat opens more and becomes erect, compared to that individual's posture in the reference seat, this value would increase.

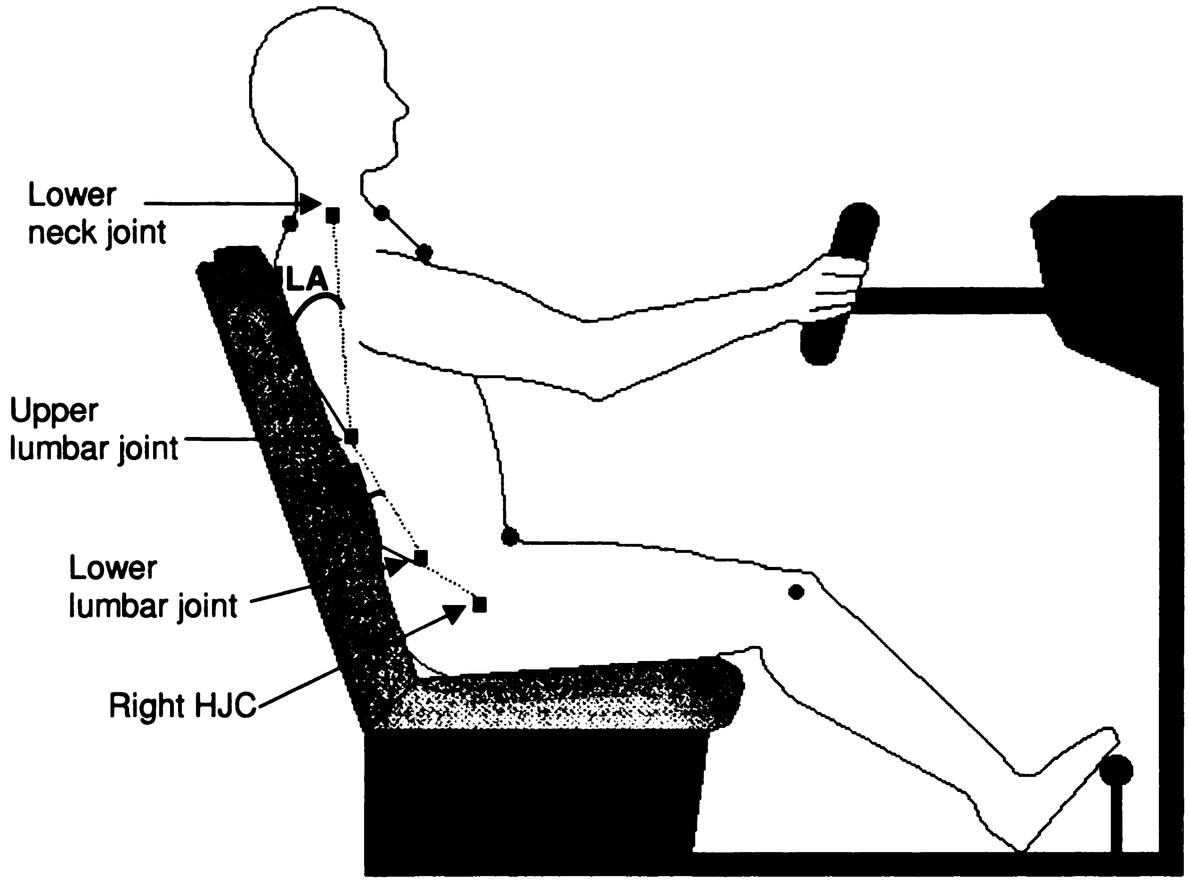


Figure 63: Total lumbar curvature.

For the upper and lower lumbar angles, the angle was taken as positive if the lower link was more in the positive X-direction than the upper link, as shown in Figure 63 above.

$$\theta_{ULA} = ACos\left(\hat{R}_{LNJ/ULJ} \cdot \hat{R}_{ULJ/LLJ}\right) \tag{5.63}$$

$$\theta_{LLA} = ACos\left(\hat{R}_{ULJ/LLJ} \cdot \hat{R}_{LLJ/HJC}\right) \tag{5.64}$$

The total lumbar curvature for the seat trial was therefore:

$$\theta_{TLC} = \left(\theta_{ULA} + \theta_{LLA}\right)_{HardSeat} - \left(\theta_{ULA} + \theta_{LLA}\right)_{SeatTrial} \tag{5.65}$$

6. SUBJECT TESTING RESULTS

Figure 64 shows the possible test conditions as discussed on page 49. Since 72 files for each of the 29 subjects were collected, producing a total of 2088 data files, the results were summarized and only statistical tests are presented here. Examples of numerical values, averaged by anthropometric groups, are listed for discussion purposes, with all averages and standard deviations tabulated in Appendix C.

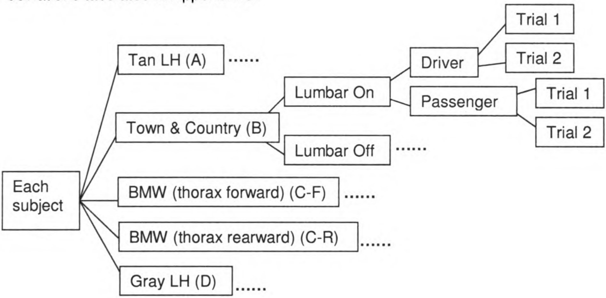


Figure 64: Possible test conditions.

The abbreviations listed in Table 12 will be used when presenting and discussing the results.

Table 12: Abbreviations for anthropometric groups.

Abbreviation	Anthropometric Group
F, 5, 5	Petite, light females (5%* by height, 5% by weight)
F, 50, 50	Mid-sized females (50% by height, 50% by weight)
F, 5, 95	Petite, ample females (5% by height, 95% by weight)
M, 95, 5	Tall, thin males (95% by height, 5% by weight)
M, 50, 50	Mid-sized males (50% by height, 50% by weight)
M, 95, 95	Tall, heavy males (95% by height, 95% by weight)

* Percentiles as defined by NATICK [3], refer to Table 8.

The SigmaStat program [72] was used for statistical testing. ANOVA tests were chosen to first examine the data groupings for normal distributions and equal variances. A one-way repeated measures analysis of variance (RM-ANOVA) test was used to examine differences within anthropometric groupings since this test compares differences within a subject. The same test was used to verify that there were no differences between repeated trials. Although no differences were found in comparisons between repeated trials, all data were treated as distinct measurements for the remaining comparisons. Cases that did not have a normal distribution were analyzed with the repeated measures ANOVA on Ranks; however, this situation was rare. The confidence level was 95% (alpha equal to 0.05). For the majority of cases, data groups were compared with a Tukey Test once the RM-ANOVA test was completed.

Differences between anthropometric groupings were examined using a one-way analysis of variance (ANOVA) test. Again, all data sets were treated as distinct measurements. Cases that were found to not have a normal distribution were examined with the ANOVA on Ranks test. The confidence level was 95% (alpha equal to 0.05). All six anthropometric groups listed above in Table 12 were compared against each other.

The results of this study have been grouped into the following sections: seat settings, extremities, body angles, spinal link angles, head position, procedural effects on subject positioning, and application to computer modeling.

6.1 Selected Seat Positions

Recall that the test subjects were allowed to choose the recline angle of the backrest and the fore/aft position of the seat. Parameters related to these settings were therefore examined to determine if the settings chosen across subjects and seat scenarios were similar.

6.1.1 Seat Back Angle

Results of statistical testing between anthropometric groupings for the subject selected seat back angle (SBA) are shown below in Tables 13 through 17. A total of eight (four for the Tan LH) comparisons were possible for each seat when all cases (sedan, lumbar on, driver, etc.) were summed. Instances in which at least half of the comparisons had statistically significant differences have been shaded. For example, in Table 13 the comparison between tall, light males (M, 95, 5) and tall, heavy males (M, 95, 95) revealed that three of the four conditions had statistically significant differences in SBA between these groups.

Table 13: Occurrences of statistically significant differences in SBA for the Tan LH seat by size groups (four possible in each group).

Totals for Seat Tan LH	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	0
F, 50, 50		1	1	0	0
F, 5, 95			0	0	1
M, 95, 5				0	3
M, 50, 50					0

Table 14: Occurrences of statistically significant differences in SBA for the Town & Country seat by size groups (eight possible in each group).

Totals for Town & Country Seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	0	0	2
F, 50, 50		0	0	1	0
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					2

Table 15: Occurrences of statistically significant differences in SBA for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	3
F, 50, 50		0	0	0	1
F, 5, 95			0	0	1
M, 95, 5				0	3
M, 50, 50					0

Table 16: Occurrences of statistically significant differences in SBA for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	2
F, 50, 50		0	0	0	1
F, 5, 95			0	0	2
M, 95, 5				0	4
M, 50, 50					2

Table 17: Occurrences of statistically significant differences in SBA for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	3	0	0	0	0
F, 50, 50		0	2	0	0
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

Only two of the comparisons between subject groupings for the seat back angle had at least half of the test results showing statistically significant differences. Both of these cases were comparisons between the tall, light males (M, 95, 5) and the tall, heavy males (M, 95, 95). For the Tan LH seat, three of the four cases showed differences between these groups with four out of eight cases in the BMW seat (thorax rearward). SBA averages for the Tan LH differed by a maximum of 2 degrees for these groups. The BMW seat had a maximum difference of 6 degrees. The trend for the Tan LH was not consistent. However, in the BMW seat the tall, heavy male group SBA average consistently showed a more reclined position than that of the average SBA of the tall, light males.

Table 18 below lists the two scenarios in which statistically significant differences were found in comparisons of the seat back angle (SBA) within each anthropometric group. The seat back angle examined here was based on the angle formed between the seat back targets and vertical. This angle was correlated to the J826 manikin to provide a more standard measure acceptable to the automotive industry. However, the J826 manikin could only be used to measure SBA when the lumbar supports were in the off position and the thorax support of the BMW seat was in the rearward position. The J826 manikin correlated back angle is therefore only listed in Appendix C and was not used for statistical testing. Cases that did not have any positive results have been omitted from Table 18. The "lumbar position" column refers to comparisons between the "lumbar off" and "lumbar on" test scenarios. The "Sedan / Van" column lists the results of statistical tests comparing the subject's response to these package settings. Data for all tests shown below were normal and had equal variances. Each test result shown had a maximum of 16 combinations.

Table 18: SBA statistical results (one-way RM-ANOVA).

Seats	**Subject Group**	**Lumbar Position**	**Sedan / Van**
Tan LH, Gray LH (off)	M, 95, 5	4	---
BMW (thorax forward)	F, 50, 50	---	1

The average differences between the Tan LH seat and the Gray LH (lumbar off) seat for the tall, thin males ranged from –3 to +6 degrees of recline. Due to the fact that a quarter of the comparisons showed differences, and the presence of only one other statistically significant result, it was assumed that the differences found in the seat back angle were negligible. Refer to Appendix C for the average and standard deviation values of SBA for each anthropometric grouping.

6.1.2 Toebar to Hip Joint Center Horizontal Distance

The distance from the toebar to the HJC is a measure of the fore/aft position of the pelvis in the context of the given package settings. Recall that the subject was allowed to move the seat while the toebar was fixed. Results of statistical testing between anthropometric groupings for horizontal distances from the toebar to the HJC are shown below in Tables 19 through 23. Instances in which at least half of the comparisons had statistically significant differences have been shaded. For example, in Table 19 all four of the possible conditions comparing the tall, light males (M, 95, 5) to the petite, ample females (F, 5, 95) had statistically significant differences.

Table 19: Occurrences of statistically significant differences in toebar to HJC horizontal distances for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	3	1	4
F, 50, 50		2	2	0	2
F, 5, 95			4	4	4
M, 95, 5				0	0
M, 50, 50					2

Table 20: Occurrences of statistically significant differences in toebar to HJC horizontal distances for the Town & Country seat by size groups (eight possible in each group).

Totals for Town & Country Seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	8	1	8
F, 50, 50		1	5	0	6
F, 5, 95			8	4	8
M, 95, 5				0	0
M, 50, 50					1

Table 21: Occurrences of statistically significant differences in toebar to HJC horizontal distances for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	7	5	8
F, 50, 50		1	2	0	7
F, 5, 95			8	6	8
M, 95, 5				0	0
M, 50, 50					0

Table 22: Occurrences of statistically significant differences in toebar to HJC horizontal distances for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	6	5	8
F, 50, 50		1	2	1	7
F, 5, 95			7	7	8
M, 95, 5				0	0
M, 50, 50					0

Table 23: Occurrences of statistically significant differences in toebar to HJC horizontal distances for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	3	0	8	4	8
F, 50, 50		5	3	0	4
F, 5, 95			8	6	8
M, 95, 5				1	0
M, 50, 50					3

As expected, differences in the horizontal distances from the toebar to the HJC between subject size groupings were most often paired with differences in the average height of the subject groups with no differences found between subject groups of equal height. It was therefore not surprising that the tall, light males (M, 95, 5) differed from the petite females (F, 5, 5 and F, 5, 95), but were not different from the tall, heavy males (M, 95, 95). Refer to Table 24 for an example of these values.

Table 24: Toebar to HJC horizontal distance (mm) group averages for the sedan, lumbar off, driver scenario.

Subject Group	Seat				
	Tan LH	Town & Country	BMW (thorax forward)	BMW (thorax rearward)	Gray LH
F, 5, 5	802	774	775	776	779
F, 50, 50	829	813	847	821	824
F, 5, 95	780	750	762	750	747
M, 95, 5	895	896	923	883	890
M, 50, 50	850	844	890	870	841
M, 95, 95	924	888	942	927	900

Table 25 below lists the results of statistical testing within subject groups on the horizontal distance between the subject's hip joint center (HJC) and the toebar. No results are listed for the driver vs. passenger comparisons because none of these cases produced statistically significant differences. Comparisons in which at least half of the possible 16 cases showed differences have been shaded. Recall that the vertical seat height was set at either the van or sedan package.

Table 25: Toebar to HJC horizontal distance statistical results.

Seats	Subject Group	Lumbar Position	Sedan / Van
Tan LH, Gray LH (off)	F, 5, 5	---	1
	F, 5, 95	---	4
	M, 95, 5	---	1
Town & Country	M, 95, 5	---	6
	M, 50, 50	---	13
	M, 95, 95	---	3
BMW (thorax forward)	F, 50, 50	1	1
	F, 5, 95	---	7
	M, 95, 5	---	10
	M, 50, 50	---	3
	M, 95, 95	---	6
BMW (thorax rearward)	F, 50, 50	1	1
	M, 95, 95	---	7
Gray LH	F, 5, 5	---	5
	F, 5, 95	---	12
	M, 95, 5	---	2
	M, 95, 95	---	4

Differences in package dimensions had the most affect on the horizontal distance between the occupant's HJC and the toebar. Subjects tended to shorten this distance in the van package relative to the sedan package, possibly to achieve a desired knee angle or thigh pressure. For example, the tall, thin males in the BMW seat (thorax forward) moved closer to the toebar an average of 43 to 48 mm from sedan to van. The fact that the average knee angle for this group changed by 1 to 7 degrees and had no statistically significant differences between the sedan and van package settings suggested that the subjects were trying to maintain a particular leg position.

6.1.3 Toebar to Hip Joint Center Vertical Distance

The vertical distance from a fixed reference point, such as the toebar, could be used to examine affects on the HJC location due to differences in tissue thickness under the buttocks. However, no statistically significant differences were found between anthropometric groupings for vertical distances from the toebar to the HJC in the Tan LH, BMW (thorax rearward), or Gray LH seats. Tables 26 and 27 list the remaining comparisons.

Table 26: Occurrences of statistically significant differences in toebar to HJC vertical distances for the Town & Country seat by size groups (eight possible in each group).

Totals for Town & Country Seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	2	0
F, 50, 50		0	0	3	0
F, 5, 95			0	5	0
M, 95, 5				0	0
M, 50, 50					0

Table 27: Occurrences of statistically significant differences in toebar to HJC vertical distances for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	0
F, 50, 50		0	0	1	0
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

The comparisons between the petite, ample females and the mid-sized males are the only comparisons that had statistically significant differences in at least half of the cases. The lack of more significant differences between groups and the lack of consistency in the above results was probably due to the large variation in estimated HJC locations.

Table 28 lists the results of statistical testing within subject groups. All comparisons between sedan and van packages produced statistically significant differences. This was expected since the van package added 95 mm in height to that of the sedan, sedan/van comparisons are therefore not listed in Table 28.

Table 28: Toebar to HJC vertical distance statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	12	---
	F, 50, 50	11	---
	M, 95, 5	14	---
	M, 95, 95	15	---
Town & Country	M, 95, 5	---	1
BMW (thorax forward)	F, 5, 5	15	---
	F, 50, 50	16	---
	M, 95, 5	1	---
	M, 50, 50	15	---
	M, 95, 95	2	---
BMW (thorax rearward)	F, 5, 5	13	---
	F, 50, 50	2	---
	M, 50, 50	14	---
Gray LH	M, 95, 5	2	1
	M, 95, 95	1	---

Since differences found between the Tan and Gray LH seats (lumbar position) are most likely due to differences in the placement of the manikin between these seats, comparisons between the two will therefore not be discussed further in this section. Table 29 lists example values of changes in the toebar to HJC vertical distance related to changes in lumbar prominence for the mid-sized males.

Table 29: Toebar to HJC vertical distances (mm) of mid-sized males in the sedan, driver scenario of the BMW seat (thorax rearward).

Subject ID	**BMW (thorax rearward)**		
	Lumbar Off	**Lumbar On**	**Change (on – off)**
TM21	101	122	21
TM22	110	124	14
TM23	96	115	19
TM24	130	146	16
TM25	116	128	13

Subjects' hip joint centers tended to be higher relative to the toebar with the lumbar on than with the lumbar in the off position. Changes in HJC height could be due to the subject moving forward on the upwardly sloped seat or by a rotation of the pelvis, depending on the initial position. As with the horizontal distance from the HJC to the toebar, the differences found in vertical distances between driver and passenger cases were so rare that it is doubtful these positions have any effect on position of the subject's HJC relative to the toebar.

6.1.4 Horizontal Pelvis Placement Relative to Seat

Two methods of examining the relationship between the location of the subjects' pelves and the seat were used - the horizontal distance from the subject's HJC to the bottom recline target on the seat (further referred to as HJC-

RecBot X), and the differences between the subject's HJC location in each seat and the J826 manikin's H-point location (refer to section 3.1) in the corresponding seats. This relationship was examined since this knowledge would be necessary for human manikin placement in computer modeling of occupant packaging.

The horizontal and vertical distances between the J826 H-point and the HJC of each test subject in each trial were first calculated. These offsets were then statistically analyzed by the same methods as the other parameters. These comparisons would determine similarities between position of humans, relative to the J826 manikin. Results of statistical testing between anthropometric groupings for the horizontal offset between the subject's HJC and the J826 manikin's H-point are given in Tables 30 through 34. The values in parentheses are instances where the HJC-RecBot X coordinate had slightly different results.

For comparisons between the subjects and the manikin, refer to the offset values given in Appendix C. Although the J826 manikin was designed to represent he mid-sized male, discrepancies were found between the manikin H-point and the mid-sized males' HJC. These differences may be due to errors in the estimation of the HJC location.

Table 30: Occurrences of statistically significant differences in horizontal offset between J826 H-point and subject's HJC for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	1	3	2
F, 50, 50		4	1	1	1
F, 5, 95			2	2	2
M, 95, 5				0	0
M, 50, 50					0

Table 31: Occurrences of statistically significant differences in horizontal offset between J826 H-point and subject's HJC for the Town & Country seat by size groups (eight possible in each group).

Totals for Town & Country Seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	6	8	7 (8)
F, 50, 50		8	3	3	3
F, 5, 95			1	0	0
M, 95, 5				0	0
M, 50, 50					0

Table 32: Occurrences of statistically significant differences in horizontal offset between J826 H-point and subject's HJC for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	0	4	0
F, 50, 50		8	0	1	0
F, 5, 95			3	3	7
M, 95, 5				0	0
M, 50, 50					0

Table 33: Occurrences of statistically significant differences in horizontal offset between J826 H-point and subject's HJC for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	0	3 (4)	0
F, 50, 50		2 (3)	0	0	0
F, 5, 95			0	0	4
M, 95, 5				0	0
M, 50, 50					2

Table 34: Occurrences of statistically significant differences in horizontal offset between J826 H-point and subject's HJC for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	6 (7)	4	6
F, 50, 50		5 (6)	3 (4)	2	3 (4)
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

All comparisons between the petite, light females and the petite, ample females had statistically significant differences, with the petite, light females back further in the seat 50-60 mm. This difference was most likely due to the tissue thickness of the subjects, placing the HJC of the ample women further forward. Comparisons between the petite, light women and the mid-sized males showed differences in at least half of the cases. Other comparisons between anthropometric groups were not consistent between seats, but differences between either petite female group and the male groups were prevalent. These differences were most likely due to tissue thickness and pelvis size differences.

Statistical test results within subject groups are listed in Table 35. Cases in which either method produced statistically significant differences in at least half of the cases have been shaded. The values in parentheses represent HJC-RecBot X coordinate result differences.

Table 35: Horizontal offset from J826 H-point to subject's HJC statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	8 (16)	---	---
	F, 50, 50	9 (16)	--- (11)	2
	M, 95, 5	7 (6)	---	---
	M, 50, 50	--- (9)	--- (5)	---
	M, 95, 95	4 (16)	--- (2)	---
Town & Country	M, 95, 5	---	--- (1)	---
	M, 95, 95	---	--- (3)	---
BMW (thorax forward)	F, 5, 5	10 (9)	---	---
	F, 50, 50	16	3 (5)	---
	M, 95, 5	15	1	1
	M, 50, 50	2 (12)	--- (1)	---
	M, 95, 95	--- (1)	---	---
BMW (thorax rearward)	F, 5, 5	12 (13)	---	---
	F, 50, 50	10	---	---
	F, 5, 95	---	4 (---)	---
	M, 95, 5	10	2 (3)	---
	M, 50, 50	--- (6)	---	---
Gray LH	F, 5, 5	12	12 (10)	---
	F, 50, 50	4	1	---
	F, 5, 95	---	6 (---)	---
	M, 95, 5	1	15 (---)	---
	M, 50, 50	--- (3)	--- (5)	---
	M, 95, 95	--- (8)	--- (4)	---

Each seat affected its occupants with either a change in lumbar prominence or through a change in package dimensions. The majority of differences in these parameters occurred in response to changes in lumbar prominence. Changes in HJC height could be due to the subject moving forward on the upwardly sloped seat or by a rotation of the pelvis, depending on the initial position, which would move the HJC along an arced trajectory.

Of the cases where at least half the results were positive, moving the lumbar support to the on position caused the subject's HJC to shift forward by 13-33, 21-37, and 12 mm for the BMW (thorax forward), BMW (thorax rearward), and Gray LH seats, respectively. This forward shift of the HJC was most prevalent for the petite, light females. It should be noted that the lumbar support of the Town & Country seat did not have any significant affect on subject pelvis locations. Refer to Tables 36 and 37 for an example of the changes observed in group averages.

Table 36: HJC-RecBot X coordinate group averages for the sedan, driver, lumbar off (Off) and lumbar on (On) scenarios.

Subject Group	**Seat**					
	BMW (thorax forward)		**BMW (thorax rearward)**		**Gray LH**	
	Off	**On**	**Off**	**On**	**Off**	**On**
F, 5, 5	-169	-190	-190	-215	-179	-191
F, 50, 50	-169	-196	-191	-228	-183	-196
F, 5, 95	-228	-241	-234	-249	-223	-229
M, 95, 5	-184	-207	-209	-233	-209	-222
M, 50, 50	-194	-227	-215	-248	-213	-232
M, 95, 95	-188	-203	-201	-222	-215	-227

Table 37: HJC-RecBot X coordinate group averages for the van, driver, lumbar off (Off) and lumbar on (On) scenarios.

Subject Group	Seat					
	BMW (thorax forward)		BMW (thorax rearward)		Gray LH	
	Off	On	Off	On	Off	On
F, 5, 5	-159	-182	-182	-202	-170	-182
F, 50, 50	-153	-176	-184	-215	-174	-187
F, 5, 95	-218	-226	-222	-230	-217	-224
M, 95, 5	-174	-198	-196	-217	-208	-220
M, 50, 50	-182	-212	-208	-233	-197	-212
M, 95, 95	-180	-196	-189	-208	-204	-216

Differences between packages may be due to differences in the placement of the J826 manikin in these scenarios. In the Gray LH seat the petite, light females' and mid-size females' hip joint centers shifted forward by 9 mm for both lumbar positions in the sedan to van comparison. The BMW seat did not affect either of the heavy test subject groups. The Gray LH seat only significantly affected the petite, light females and the tall, heavy males. When referring to Appendix C offset values, recall that the positive horizontal (X) axis of the test buck pointed rearward, a negative value for the horizontal coordinate therefore means that the subject's HJC is more forward in the seat than the J826 manikin H-point. Refer to Figure 65 for an example of the offset between the subject's HJC and the J826 H-point.

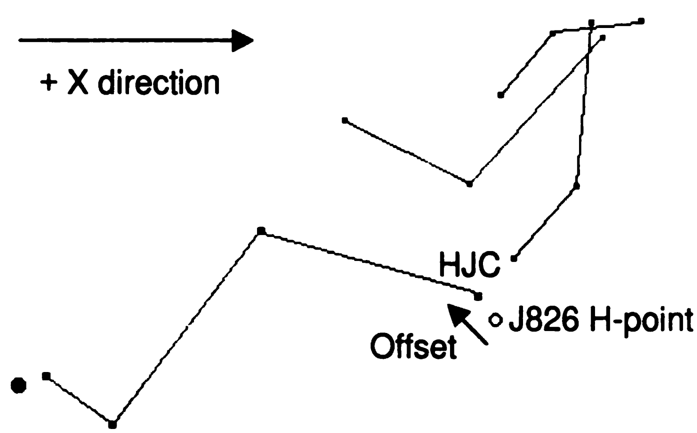


Figure 65: Offset between J826 H-point and subject HJC.

6.1.5 Vertical Pelvis Placement Relative to Seat

In statistical testing between anthropometric groupings only one comparison had a statistically significant difference (using both parameters) – the mid-sized males vs. mid-sized females in the Town & Country seat for the van, lumbar off, driver scenario. It was expected that there would be differences between anthropometric groups simply because each subject group would have a different tissue thickness under and behind their hip joint centers. The lack of differences was most likely due to the large range in HJC estimated locations.

Results of statistical tests on the vertical offset between the subject's HJC and the J826 H-point are listed below in Table 38. The values in parentheses represent HJC-RecBot Z coordinate result differences. Less differences in the HJC-RecBot Z coordinate results occurred due to the fact that this parameter examines a small change in a larger number than the comparison between subject HJC and J826 H-point does.

Table 38: Vertical offset from J826 H-point to subject's HJC statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	16 (---)	1 (---)	---
	F, 50, 50	16 (---)	8 (---)	---
	F, 5, 95	1	---	---
	M, 95, 5	16 (---)	---	---
	M, 50, 50	16 (---)	---	---
	M, 95, 95	6 (---)	---	---
Town & Country	F, 5, 5	---	3 (---)	---
	F, 50, 50	---	1 (---)	---
	M, 95, 5	---	14 (---)	---
BMW (thorax forward)	F, 5, 5	14 (1)	1	---
	F, 50, 50	16 (16)	---	---
	M, 50, 50	12 (16)	---	---
	M, 95, 95	--- (1)	---	---

Table 38 (continued):

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
BMW (thorax rearward)	F, 5, 5	15 (16)	---	---
	F, 50, 50	2 (2)	---	---
	M, 50, 50	11 (14)	---	---
Gray LH	F, 5, 5	---	16 (---)	---
	F, 50, 50	---	16 (2)	---
	F, 5, 95	---	2 (---)	---
	M, 95, 5	9	9 (2)	3 (2)
	M, 50, 50	---	7 (---)	---
	M, 95, 95	--- (2)	9 (---)	---

Differences found for the vertical offset are similar to those of the horizontal offset, with respect to which comparisons were affected by each seat. Refer to Table 39 for HJC-RecBot Z coordinate group averages for the sedan, driver, lumbar off (Off) and lumbar on (On) scenarios. Subjects' hip joint centers tended to be higher with the lumbar on than with the lumbar in the off position, also refer to Table 29. These upward shifts ranged from 9-13, 9-16, and 4 mm for the BMW (thorax forward), BMW (thorax rearward), and Gray LH seats, respectively. Changes in HJC height could be due to the subject moving forward on the upwardly sloped seat or by a rotation of the pelvis, depending on the initial position.

Table 39: HJC-RecBot Z coordinate group averages for the sedan, driver, lumbar off (Off) and lumbar on (On) scenarios.

Subject Group	Seat					
	BMW (thorax forward)		BMW (thorax rearward)		Gray LH	
	Off	On	Off	On	Off	On
F, 5, 5	124	132	131	140	150	152
F, 50, 50	138	147	144	157	161	163
F, 5, 95	133	136	138	142	155	156
M, 95, 5	123	135	131	143	152	156
M, 50, 50	124	137	128	144	157	159
M, 95, 95	126	136	135	145	155	154

6.2 Extremities

6.2.1 Knee Angle

No statistically significant differences were found in the knee angle between subject groups for the Town & Country seat or for the BMW seat. Refer to Tables 40 and 41 for test results in the LH seats. Only the driver position was examined so total combinations available were limited.

Table 40: Occurrences of statistically significant differences in knee angle for the Tan LH seat by size groups (two possible in each group).

Totals for Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	0
F, 50, 50		1	1	0	0
F, 5, 95			0	0	0
M, 95, 5				0	1
M, 50, 50					0

Table 41: Occurrences of statistically significant differences in knee angle for the Gray LH seat by size groups (four possible in each group).

Totals for Town &	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	1	0	0
F, 50, 50		0	1	0	0
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

Since positive test results on differences between size groups were limited, and those present lacked consistency between seats, differences in the knee angle due to subject anthropometry were assumed negligible.

Table 42 below lists the outcomes of statistical testing on knee angles within subject groups. No statistically significant differences were found for comparisons between lumbar positions. The "Driver / Passenger" column lists the results of statistical tests comparing the subject's response to these arm and leg positions.

Table 42: Knee angle statistical results (one-way RM-ANOVA).

Seats	Subject Group	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	---	14
	F, 50, 50	---	9
	F, 5, 95	---	15
	M, 95, 5	---	10
	M, 50, 50	---	10
	M, 95, 95	---	8
Town & Country	F, 5, 5	---	16
	F, 50, 50	---	4
	F, 5, 95	---	14
	M, 95, 5	---	16
	M, 50, 50	1	16
	M, 95, 95	---	3
BMW (thorax forward)	F, 5, 5	---	15
	F, 50, 50	---	16
	F, 5, 95	1	15
	M, 95, 5	---	15
	M, 50, 50	---	16
	M, 95, 95	---	2
BMW (thorax rearward)	F, 5, 5	---	9
	F, 50, 50	---	10
	F, 5, 95	---	10
	M, 95, 5	---	13
	M, 50, 50	---	8
Gray LH	F, 5, 5	---	14
	F, 50, 50	---	5
	F, 5, 95	---	16
	M, 95, 5	---	14
	M, 50, 50	---	15
	M, 95, 95	---	4

The majority of differences between driver and passenger positions were statistically significant as expected since the driver position would open the knee angle due to the foot constrained to the toebar. However, in many cases the subject stretched out his/her legs in the passenger position so there was not a statistically significant difference between driver and passenger positions. This was particularly noticeable for the large males. Changes in the average knee angle ranged from 3 to 18 degrees, increasing from passenger to driver. The interesting finding here is that package variation (sedan/van) only affected the knee angle in two comparisons. This lack of statistically significant differences suggests that either the range of seat height tested in this study was not large enough to affect the knee angle of the occupants, or the subjects positioned the seat so that the knee angle was consistent. Combined with the previous results on HJC placement, the lack of differences in knee angle supports the notion that the subjects slid forward in the seat.

6.2.2 Knee Splay Angle

Results of statistical comparisons of the knee splay angle between subject groups are listed in Tables 43 through 47. This parameter was only examined in the driver position.

Table 43: Occurrences of statistically significant differences in knee splay angle for the Tan LH seat by size groups (two possible in each group).

Totals for the Tan LH seat	**F,**	**F, 5, 95**	**M, 95, 5**	**M, 50, 50**	**M, 95, 95**
F, 5, 5	0	0	1	1	1
F, 50, 50		0	1	1	1
F, 5, 95			1	1	0
M, 95, 5				0	0
M, 50, 50					0

Table 44: Occurrences of statistically significant differences in knee splay angle for the Town & Country seat by size groups (four possible in each group).

Totals for Town & Country Seat	**F, 50, 50**	**F, 5, 95**	**M, 95, 5**	**M, 50, 50**	**M, 95, 95**
F, 5, 5	0	0	2	1	1
F, 50, 50		0	2	1	1
F, 5, 95			2	0	1
M, 95, 5				0	0
M, 50, 50					0

Table 45: Occurrences of statistically significant differences in knee splay angle for the BMW (thorax forward) seat by size groups (four possible in each group).

Totals for BMW Seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	2	2	0
F, 50, 50		0	2	2	2
F, 5, 95			2	2	2
M, 95, 5				0	0
M, 50, 50					0

Table 46: Occurrences of statistically significant differences in knee splay angle for the BMW (thorax rearward) seat by size groups (four possible in each group).

Totals for BMW Seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	1	1
F, 50, 50		0	2	1	2
F, 5, 95			1	1	2
M, 95, 5				0	0
M, 50, 50					0

Table 47: Occurrences of statistically significant differences in knee splay angle for the Gray LH seat by size groups (four possible in each group).

Totals for the Gray Seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	2	1	1
F, 50, 50		0	2	2	2
F, 5, 95			2	1	1
M, 95, 5				0	0
M, 50, 50					0

It should be noted that all of the differences found between subject groups were when the seats were set at the sedan height. There was little variation within subject groups, with all group average splay angles ranging from 24 to 29 degrees. Although the differences found between males and females particularly for the tall, thin males were relatively consistent, the differences found were very small (refer to Appendix C) and were probably due to body shape differences.

Results of statistical tests within subject groups for the knee splay angle are listed in table 48.

Table 48: Knee splay angle statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	11	16	3
	F, 50, 50	8	16	6
	F, 5, 95	7	16	5
	M, 50, 50	---	12	---
Town & Country	F, 5, 5	4	16	---
	F, 50, 50	8	16	---
	F, 5, 95	7	16	5
	M, 50, 50	---	12	---
BMW (thorax forward)	F, 5, 95	8	16	---
	M, 50, 50	---	12	---
	M, 95, 95	---	6	---
BMW (thorax rearward)	F, 5, 5	---	4	---
	F, 50, 50	13	16	1
	F, 5, 95	12	16	---
	M, 50, 50	---	8	1
	M, 95, 95	---	6	---
Gray LH	F, 5, 5	9	16	---
	F, 50, 50	12	16	---
	F, 5, 95	12	16	---
	M, 50, 50	---	13	---
	M, 95, 95	---	1	---

Changes in knee splay angle from lumbar off to lumbar on were within 3 degrees, and quite often were not sufficient to even produce differences in the group averages. Knee splay angles increased from the sedan to the van package by 2-11, 3-11, 2-12, 2-10, and 3-13 degrees for the Tan LH, Town & Country, BMW (thorax forward), BMW (thorax rearward), and Gray LH seats, respectively. The taller males tended to have the least amount of change. In the sedan seat height the subjects would have had their legs reaching forward more than in the van package, thereby reducing the splay angle of the leg.

6.2.3 Shoe Angle

Recall that the ankle angle was referenced to the hard seat data in order to estimate the angle that the shoe made with the floor. The shoe angle was used in statistical testing instead of the ankle angle as it has more relevance to automotive applications. Differences between the driver and passenger cases were not tested since in the passenger position the subject had his/her feet flat on the footplate. Statistical tests performed to examine differences between subject groups had three positive results: petite, light females compared to tall, heavy males and tall, thin males compared to tall, heavy males – both in the Town & Country seat, and mid-sized males (M, 50, 50) compared to tall, heavy males in the Gray LH seat. Since these results correspond to one-eighth of the possible positive results, changes in shoe angle due to subject anthropometry were considered negligible.

Table 49 below lists the outcomes of statistical testing on shoe angles within subject groups. No positive results were found for any of the comparisons between lumbar positions. Cases in which at least half of the comparisons had statistically significant differences have been shaded.

Table 49: Shoe angle statistical results (one-way RM-ANOVA).

Seats	**Subject Group**	**Sedan / Van**
Tan LH, Gray LH (off)	F, 5, 5	2
	F, 50, 50	4
	F, 5, 95	7
	M, 50, 50	4
	M, 95, 95	2
Town & Country	F, 5, 5	8
	F, 50, 50	8
	F, 5, 95	8
	M, 50, 50	7
	M, 95, 95	3

Table 49 (continued):

Seats	Subject Group	Sedan / Van
BMW (thorax forward)	F, 5, 5	1
	F, 50, 50	2
	F, 5, 95	2
	M, 95, 95	6
BMW (thorax rearward)	F, 5, 5	4
	F, 50, 50	3
	M, 50, 50	2
	M, 95, 95	1
Gray LH	F, 50, 50	2
	F, 5, 95	5
	M, 95, 95	2

The shaded cases listed above may be partly due to the petite females needing an extra foot block to support their feet, as mentioned in the protocol description. However, this would not explain why the mid-sized females had statistically significant differences in shoe angle with changes in package settings. The differences found may be due to the subject being more concerned about her leg and pelvis position, and therefore sacrificing a comfortable foot position. Average shoe angles for the females in the Town & Country seat decreased by approximately 9 degrees from the sedan to the van position. Since in the van package the horizontal distance between the steering wheel and the toebar was less, the subjects may have been able to relax their lower legs more and lower their toes in the van package. In the sedan package the shorter subjects would have had to either stretch out their legs to reach the toebar or have the steering wheel too close to their bodies.

6.2.4 Elbow Angle

Refer to Tables 50 through 54 for statistical test results on the elbow angle for comparisons between subject groups. Only the driver position was examined so total combinations available were limited.

Table 50: Occurrences of statistically significant differences in elbow angle for the Tan LH seat by size groups (two possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	2	2	2
F, 50, 50		0	2	0	1
F, 5, 95			2	1	2
M, 95, 5				0	0
M, 50, 50					0

Table 51: Occurrences of statistically significant differences in elbow angle for the Town & Country seat by size groups (four possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	4	3	4
F, 50, 50		0	3	0	2
F, 5, 95			4	0	2
M, 95, 5				2	0
M, 50, 50					0

Table 52: Occurrences of statistically significant differences in elbow angle for the BMW seat (thorax forward) by size groups (four possible in each group).

Totals for the BMW (thorax forward) seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	4	4	4
F, 50, 50		0	2	0	0
F, 5, 95			4	3	4
M, 95, 5				0	0
M, 50, 50					0

Table 53: Occurrences of statistically significant differences in elbow angle for the BMW seat (thorax rearward) by size groups (four possible in each group).

Totals for the BMW (thorax rearward) seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	2	3	4	4	4
F, 50, 50		0	2	0	0
F, 5, 95			3	0	0
M, 95, 5				0	0
M, 50, 50					0

Table 54: Occurrences of statistically significant differences in elbow angle for the Gray LH seat by size groups (four possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	3	0	4	4	3
F, 50, 50		0	2	0	0
F, 5, 95			4	0	0
M, 95, 5				1	0
M, 50, 50					0

Statistically significant differences in elbow angle were found when comparing the petite, light females and tall, thin males with groups of the opposite gender for all seats tested. Occasionally differences were also found for both petite female groups compared to the remaining subject groups.

Although the dashboard was set relatively low, the petite, light females may have had to sit close to the wheel to see over the dash, which would reduce the distance that their arms needed to extend. There may also be differences due to driving habits. It was noticed in testing that the males preferred to have their arms stretched out more. The horizontal distance between the steering wheel and the footplate could have played a role in these findings if this distance was too large for the petite females and too short for the tall males. Table 55 lists an example of group averages for the elbow angle. These values seem to be correlated to subject heights, although this would account for the statistically significant differences between tall, thin males and petite, ample females, it does not explain the differences found between petite, light females and petite, ample females. The differences found suggest that the elbow angle was dependant on both the height and weight of the subjects; however, this presumption was not consistent between genders. Figure 66 shows an example of the subject's arm positions.

Table 55: Elbow angle group averages for the sedan, lumbar off, driver scenario.

Subject Group	Seat				
	Tan LH	Town & Country	BMW (thorax forward)	BMW (thorax rearward)	Gray LH
F, 5, 5	93°	95°	85°	86°	86°
F, 50, 50	106°	108°	111°	103°	109°
F, 5, 95	101°	107°	98°	104°	101°
M, 95, 5	136°	141°	131°	130°	137°
M, 50, 50	119°	117°	120°	116°	114°
M, 95, 95	129°	128°	124°	122°	121°

(a) (b) (c)

Figure 66: Example of variation in elbow angles between subject groups; (a) subject TM01, (b) subject TM14, (c) subject TM17.

The van versus sedan comparison for the BMW seat (thorax forward) of the tall, thin male grouping was the only condition with any statistically significant differences in elbow angles within subject groups. Since only one of the sixteen combinations had a significant difference, changes in this parameter were assumed negligible.

6.2.5 Arm Splay Angle

During testing the arms were positioned to be out of the camera view of the hip targets in the passenger position, therefore only the driver positions of the arms were examined. Tables 56 through 60 list the results of statistical testing between anthropometric groups.

Table 56: Occurrences of statistically significant differences in arm splay angle for the Tan LH seat by size groups (two possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	2	2	1	2
F, 50, 50		1	1	0	2
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

Table 57: Occurrences of statistically significant differences in arm splay angle for the Town & Country seat by size groups (four possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	4	1	4
F, 50, 50		4	4	0	3
F, 5, 95			0	0	0
M, 95, 5				1	0
M, 50, 50					1

Table 58: Occurrences of statistically significant differences in arm splay angle for the BMW seat (thorax forward) by size groups (four possible in each group).

Totals for the BMW (thorax forward) seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	4	1	3
F, 50, 50		1	3	0	1
F, 5, 95			0	0	0
M, 95, 5				0	0
M, 50, 50					0

Table 59: Occurrences of statistically significant differences in arm splay angle for the BMW seat (thorax rearward) by size groups (four possible in each group).

Totals for the BMW (thorax rearward) seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	4	1	3
F, 50, 50		2	2	0	0
F, 5, 95			0	1	0
M, 95, 5				0	0
M, 50, 50					0

Table 60: Occurrences of statistically significant differences in arm splay angle for the Gray LH seat by size groups (four possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	4	0	1
F, 50, 50		2	2	0	0
F, 5, 95			0	1	0
M, 95, 5				1	0
M, 50, 50					0

The majority of the statistically significant differences in arm splay angle were found between the petite, light females and the mid-sized females when compared to the petite, ample females and tall males. The petite, light females, mid-sized females, and mid-sized males had arm splay values in the 15 to 20 degree ranges. Group averages for the petite, ample females and the tall males were closer to 30-35 degrees.

No statistically significant differences were found within the subject groups. Refer to Appendix C for arm splay values.

6.3 Body Angles

Three measures were used for evaluating the overall spinal position. The body recline angle (BRA) was defined as the angle between vertical and the line connecting the sternal notch and the ASIS midpoint. The openness angle was defined as the sum of the thorax and pelvis angles with ninety degrees between the thorax and pelvis measurements included. The third body angle, total lumbar curvature (TLC), differs from the other two parameters mainly because TLC is referenced to the flat spine position of the hard seat, refer to page 80 for a description.

6.3.1 Body Recline Angle

No statistically significant differences were found in the comparisons between subject groups for either thorax position of the BMW seat. The remainder of test results for comparisons between subject groups are listed below in Tables 61 through 63.

Table 61: Occurrences of statistically significant differences in body recline angle for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	**F, 50, 50**	**F, 5, 95**	**M, 95, 5**	**M, 50, 50**	**M, 95, 95**
F, 5, 5	0	0	0	0	0
F, 50, 50		0	0	0	0
F, 5, 95			0	0	1
M, 95, 5				0	0
M, 50, 50					0

Table 62: Occurrences of statistically significant differences in body recline angle for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	**F, 50, 50**	**F, 5, 95**	**M, 95, 5**	**M, 50, 50**	**M, 95, 95**
F, 5, 5	0	0	0	0	1
F, 50, 50		0	0	0	1
F, 5, 95			0	0	4
M, 95, 5				0	0
M, 50, 50					1

Table 63: Occurrences of statistically significant differences in body recline angle for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	1	0
F, 50, 50		0	0	0	2
F, 5, 95			0	0	1
M, 95, 5				0	1
M, 50, 50					2

The comparison between petite, ample females and tall, heavy males for the Town & Country seat was the only test set that produced positive results in at least half of the cases. The average BRA for the tall, heavy males was less than that of the petite, ample females by 2 to 7 degrees. The lack of statistically significant differences supported the idea that the BRA measure is a broad parameter to describe the relative orientation between the upper thorax and the pelvis. This parameter does not provide any information about what happens along the spine in between the neck and pelvis. This measure should only be used as a general indication of overall body recline.

Table 64 below lists the results of statistical testing for the body recline angle (BRA). Cases that did not have any positive results, such as all cases for both of the LH seats, have been omitted from this table. Comparisons between sedan/van packages and driver/passenger positions did not have any statistically significant differences. These results indicated that, in general, subjects sat at similar body reclines between test conditions, which is supported by the similar findings for the seat back angle.

Table 64: BRA statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position
Town & Country	F, 50, 50	1
BMW (thorax forward)	F, 5, 5	11
	F, 50, 50	2
	M, 95, 5	10
BMW (thorax rearward)	F, 5, 5	1
	M, 95, 5	1
	M, 50, 50	5

BRA differences were not found for either heavy subject group. The only differences found in BRA were between lumbar positions, with the BMW seat producing almost all of the statistically significant differences in BRA, particularly for the thorax fully forward setting. Group averages increased 1 to 6 degrees from lumbar off to lumbar on for the statistically significant cases. In order for the BRA value to increase, the subject would have to have his/her torso back further than his/her pelvis. Since the SBA values did not exhibit this same change from lumbar off to lumbar on, the subjects must have either sat in more erect postures, or slid his/her pelvis forward in the seat with the lumbar on and leaned against the upper backrest.

6.3.2 Openness Angle

Recall that the second measure for evaluating the overall spinal position was the openness angle. Because the openness angle is based on the pelvis and thorax angles, discussion on these parameters will follow. Results of statistical testing between anthropometric groupings for openness angle are shown below in Tables 65 through 69. A total of 8 (4 for seat Tan LH) comparisons were possible for each seat when all cases (sedan, lumbar on, driver, etc.) were summed.

Table 65: Occurrences of statistically significant differences in openness angle for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	4	0	0
F, 50, 50		4	4	0	0
F, 5, 95			4	4	4
M, 95, 5				4	4
M, 50, 50					0

Table 66: Occurrences of statistically significant differences in openness angle for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	8	0	2
F, 50, 50		8	8	0	0
F, 5, 95			8	8	8
M, 95, 5				5	2
M, 50, 50					0

Table 67: Occurrences of statistically significant differences in openness angle for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	8	0	0
F, 50, 50		8	8	0	0
F, 5, 95			8	8	8
M, 95, 5				6	3
M, 50, 50					0

Table 68: Occurrences of statistically significant differences in openness angle for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	8	0	3
F, 50, 50		8	5	0	1
F, 5, 95			8	8	8
M, 95, 5				8	7
M, 50, 50					1

Table 69: Occurrences of statistically significant differences in openness angle for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	8	0	2
F, 50, 50		8	8	0	1
F, 5, 95			8	8	8
M, 95, 5				6	2
M, 50, 50					1

Differences in openness angle occurred when extreme weight variations were present, such as with the majority of comparisons between the tall, thin males and the petite, ample females. The petite, ample females were found to have a statistically significant difference from all other groups in all possible cases. The tall, thin males differed from the petite females in all cases, with differences in comparisons against the mid-sized males also prevalent.

Table 70 lists the results of statistical tests performed on the openness angle within each subject group. There were 16 possible combinations for the comparisons listed, with the tabulated values giving the number of positive results. The shaded regions are those instances when at least half of the comparisons produced statistically significant differences.

Table 70: Openness angle statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	---	15	1
	F, 50, 50	---	12	---
	F, 5, 95	---	5	---
	M, 50, 50	---	10	---
Town & Country	F, 5, 5	---	14	2
	F, 50, 50	1	11	---
	F, 5, 95	---	1	---
	M, 95, 5	---	7	---
	M, 50, 50	---	15	1
BMW (thorax forward)	F, 5, 5	13	12	---
	F, 50, 50	2	4	---
	M, 50, 50	---	1	---
	M, 95, 95	---	1	---
BMW (thorax rearward)	F, 5, 5	4	2	---
	F, 5, 95	---	7	---
	M, 95, 5	---	1	1
	M, 50, 50	---	4	---
	M, 95, 95	---	4	---
Gray LH	F, 5, 5	4	16	---
	F, 50, 50	---	16	---
	F, 5, 95	---	8	---
	M, 50, 50	---	14	3

The petite, light females showed a statistically significant difference in thirteen of the sixteen possible comparisons of lumbar on versus lumbar off for the BMW seat with the thorax support in the forward position. For this scenario, the group average openness angle increased by 7 to 10 degrees as lumbar changed from off to on. This size group also had statistically significant differences in openness angle due to lumbar support in a quarter of the cases for the BMW seat (thorax rearward) and the Gray LH seat. These average group increases ranged from 7 to 9 degrees for the BMW seat and 2 to 5 degrees for the Gray LH seat. The remaining positive results for lumbar position comparisons were considered negligible.

Statistically significant differences in openness angles were quite often found between the van and sedan packages as shown in Table 70. Because the seat was 95 mm higher in the van package than in the sedan package, this difference was most likely due to a change in the pelvis angle, required to keep the lower leg in the same position. A change in seat height would produce a change in knee angle, leading to a change in hamstring length and thereby changing the pelvis angle. Overall, openness angles in the van package were found to be larger than those of the sedan package. Differences in the group averages ranged from 4-10 degrees, 3-8 degrees, 3-10 degrees, 3-12 degrees, and 4-10 degrees for the Tan LH, Town & Country, BMW (thorax forward), BMW (thorax rearward), and Gray LH seats, respectively. The changes in openness angle are potentially due to changes in the pelvis inclination that are relatable to the tension in the hamstrings. An interesting point in this portion of the analysis is that the BMW seat with the thorax support in the rearward position had relatively low occurrences of statistically significant differences compared to the other seats. For example, the petite, light females (F, 5, 5) had 15, 14, 12, 2, and 16 positive statistical test results for the Tan LH, Town & Country, BMW (thorax forward), BMW (thorax rearward), and Gray LH seats, respectively. The fact that slightly fewer significant differences were found with the BMW (thorax forward) seat than the others may have resulted from limited occupant movement due to the thorax support pushing on the occupant. It was surprising that the BMW (thorax rearward) seat did not have more statistically significant differences in openness due to the test conditions. This lack of differences suggested that the BMW (thorax rearward) seat may have placed the occupants in a satisfactory posture that allowed access to the steering wheel, toebar, and vision task.

The occasional differences found in the driver versus passenger comparisons were assumed negligible.

6.3.3 Pelvis Angle

Tables 71 through 75 below list the results of statistical tests between anthropometric groups for the pelvis angle.

Table 71: Occurrences of statistically significant differences in pelvis angle for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	3	4	3	0
F, 50, 50		3	4	2	0
F, 5, 95			4	4	4
M, 95, 5				0	3
M, 50, 50					0

Table 72: Occurrences of statistically significant differences in pelvis angle for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	6	8	6	0
F, 50, 50		6	6	6	0
F, 5, 95			8	7	8
M, 95, 5				1	2
M, 50, 50					3

Table 73: Occurrences of statistically significant differences in pelvis angle for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	6	7	6	4
F, 50, 50		6	5	1	1
F, 5, 95			8	8	8
M, 95, 5				0	0
M, 50, 50					0

Table 74: Occurrences of statistically significant differences in pelvis angle for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	7	8	4	2
F, 50, 50		7	5	0	1
F, 5, 95			8	8	8
M, 95, 5				1	0
M, 50, 50					0

Table 75: Occurrences of statistically significant differences in pelvis angle for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	2	8	6	0
F, 50, 50		2	4	2	0
F, 5, 95			8	8	8
M, 95, 5				0	0
M, 50, 50					0

No differences were found in pelvis angle between the petite, light females and the mid-sized females. The majority of comparisons between the tall, thin males and all female groups had statistically significant differences. The petite, ample females differed from the males in all but one comparison and differed from the other females often. It is most likely that the differences found are related to the height and weight not being proportionate, as this would affect the tissue thickness surrounding the pelvis. Overall, males had smaller pelvis angles than females. This difference suggests that females tend to sit with their pelvises more upright, with the heavier females in the most upright position. Refer to Table 76 for an example of the pelvis angle differences found between groups. Recall that the pelvis angle was the sagittal plane angle between horizontal and a line connecting the right ASIS and the right HJC, refer to Figure 50. An increase in pelvis angle indicated a forward rotation of the pelvis.

Table 76: Pelvis angle group averages in degrees for the sedan, lumbar off, driver (D) and passenger (P) scenarios.

Subject Group	**Seat**									
	Tan LH		**Town & Country**		**BMW (thorax forward)**		**BMW (thorax rearward)**		**Gray LH**	
	D	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**
F, 5, 5	87	83	86	84	87	85	89	85	89	85
F, 50, 50	87	83	86	84	87	84	89	82	87	84
F, 5, 95	99	94	97	94	99	97	98	96	99	95
M, 95, 5	78	74	79	77	81	78	81	77	81	78
M, 50, 50	80	76	80	77	84	79	84	81	80	77
M, 95, 95	85	81	84	81	86	82	86	83	86	83

Table 77 lists the results of statistical testing within anthropometric groups for the pelvis angle.

Table 77: Pelvis angle statistical results (one-way RM-ANOVA).

Seats	**Subject Group**	**Lumbar Position**	**Sedan / Van**	**Driver / Passenger**
Tan LH, Gray LH (off)	F, 5, 5	---	16	4
	F, 50, 50	---	16	3
	F, 5, 95	---	16	2
	M, 95, 5	---	10	---
	M, 50, 50	---	14	---
Town & Country	F, 5, 5	---	16	---
	F, 50, 50	---	16	---
	F, 5, 95	---	16	---
	M, 95, 5	---	16	6
	M, 50, 50	---	16	4
	M, 95, 95	---	16	1

Table 77 (continued):

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
BMW (thorax forward)	F, 5, 5	1	16	---
	F, 50, 50	---	14	---
	F, 5, 95	---	11	---
	M, 95, 5	---	15	5
	M, 50, 50	---	15	7
	M, 95, 95	---	13	6
BMW (thorax rearward)	F, 5, 5	---	4	---
	F, 50, 50	---	7	---
	F, 5, 95	---	16	1
	M, 95, 5	---	13	5
	M, 50, 50	---	14	4
	M, 95, 95	---	13	3
Gray LH	F, 5, 5	---	16	2
	F, 50, 50	---	16	6
	F, 5, 95	---	16	---
	M, 95, 5	---	14	2
	M, 50, 50	---	16	---
	M, 95, 95	---	16	2

Only one case (petite, light females, BMW seat - thorax forward) was found to have a statistically significant difference between the lumbar positions and was considered negligible.

The pelvis angle was affected by the change in package in most cases without noticeable discrimination between subject groupings. Group averages increased from the sedan to the van seat height by 4-10, 4-9, 3-9, 3-10, and 4-9 degrees for the Tan LH, Town & Country, BMW (thorax forward), BMW (thorax rearward), and Gray LH, respectively. This is probably due to the difference in seat heights as previously mentioned for the changes found in openness angle. These findings support the idea that changes in seat height affect the pelvis orientation, most likely through differences in tension on the hamstring muscles that span from the knees to the hips. Recall that the pan angles of the seats were fixed at 13 degrees at the beginning of this study using the J826 manikin and the seat back angle did not have any significant differences between package settings.

Statistically significant differences were found more often for the driver versus passenger comparison than in the openness angle where the driver position had larger pelvis angles than the passenger position. This may have resulted with a lowering of the knee to reach the toebar, which could move the ASIS slightly forward. In the driver position, the occupant would also be more alert and focused on the vision task, therefore sitting more erect with the pelvis rotating slightly forward. The shorter subjects may have had to sit more erect to see over the dashboard completely. Refer back to Table 76 for example values.

6.3.4 Thorax Angle

Tables 78 through 82 list the results of statistical tests on the thorax angle between anthropometric groups.

Table 78: Occurrences of statistically significant differences in thorax angle for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	1	3	0	0
F, 50, 50		1	4	0	0
F, 5, 95			4	0	4
M, 95, 5				4	0
M, 50, 50					0

Table 79: Occurrences of statistically significant differences in thorax angle for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	7	0	0
F, 50, 50		3	1	0	0
F, 5, 95			8	0	4
M, 95, 5				6	0
M, 50, 50					1

Table 80: Occurrences of statistically significant differences in thorax angle for the BMW (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	8	0	1
F, 50, 50		3	0	0	0
F, 5, 95			8	0	8
M, 95, 5				8	0
M, 50, 50					0

Table 81: Occurrences of statistically significant differences in thorax angle for the BMW (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	3	4	0	0
F, 50, 50		4	0	0	0
F, 5, 95			8	3	6
M, 95, 5				5	0
M, 50, 50					0

Table 82: Occurrences of statistically significant differences in thorax angle for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	3	1	0	0
F, 50, 50		1	4	0	0
F, 5, 95			8	0	7
M, 95, 5				4	0
M, 50, 50					1

In all cases, the petite, ample females relative to the tall, thin males had statistically significant differences. None of the comparisons between the mid-sized females against the petite, light females, mid-sized males or tall, heavy males had statistically significant differences. There were also no differences found in comparisons between petite, light females against mid-sized males or between tall, thin males and tall, heavy males. Differences in a parameter such as thorax angle, which is highly dependant on the mid-sternum target location, were most likely due to weight variations of the subject and basic anatomical differences as shown in Figure 67 below. It is therefore recommended that a parameter of this nature should only be used to compare differences within a subject.

(a) (b) (c)

Figure 67: Variation in thorax angles due to subject anthropometry; (a) subject TM03, (b) subject TM14, (c) subject TM17.

Table 83 lists the results of statistical testing on the thorax angle data for each subject group. No statistically significant differences were found for comparisons between sedan and van packages or between the driver and passenger positions.

Table 83: Thorax angle statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position
Tan LH, Gray LH (off)	M, 95, 5	1
Town & Country	F, 50, 50	1
BMW (thorax forward)	F, 5, 5	9
BMW (thorax rearward)	F, 5, 5	3
	F, 50, 50	1
	M, 50, 50	1

It should be noted that no difference was produced in the thorax angle when the arms were raised or lowered, as in the driver/passenger comparisons. The BMW seat produced the majority of the statistically significant differences in the thorax angle. The change in thorax angle due to lumbar prominence was most notable with the petite, light females (F, 5, 5). In the BMW seat (thorax forward), this group had an average thorax angle of approximately 38 degrees for lumbar off with this average increasing to 44 degrees for lumbar on, similar values were found for this seat with the thorax in the rearward position. Increases in the thorax angle could have been caused by the subject arching his/her lumbar spine resulting in a rearward rotation of the thorax or pivoting at the hips to rotate the thorax rearward. However, the HJC-RecBot X results, discussed previously, suggested that this groups' increase in thorax angle was due to the forward shift in HJC. Refer to Appendix C for the average and standard deviation values for each anthropometric grouping.

6.3.5 Total Lumbar Curvature

Recall that the total lumbar curvature (TLC) was calculated as the difference between the sum of the upper lumbar (ULA) and lower lumbar (LLA) angles in the flat back reference seat posture to that chosen by the subjects in the automotive seats. Unlike the previous body angles, this measure is based on the estimated internal joint locations. Upon examination of the TLC values, it was noticed that there was large variability within each subject group. The method of estimating the HJC and spine joint centers was further examined and it was noticed that an offset in TLC between the reference flat back data and the automotive seat data had developed, with different values for each subject. Therefore, the reference data was used in both the reference and the automotive seat calculations. The difference between the resulting TLC values for each subject was then considered the offset between these HJC estimation methods and subtracted from the TLC of each automotive seat analysis. Table 84 below lists an example of the subject TLC values before and after this modification.

Table 84: Original and modified TLC values for petite, light females (F, 5, 5) in the Gray LH, sedan, lumbar on, passenger scenario.

	Original	Modified
TM01	-26	-7
	-26	-7
TM02	4	21
	3	21
TM03	-7	-3
	-4	0
TM04	5	6
	4	4
TM05	-8	-4
	-4	0
Average	*-6*	*3*
Standard Deviation	*11.5*	*10.4*

The method described above tightened the data slightly, with the standard deviation reduced from 11.5 to 10.4. This alteration also produced more positive TLC values. Although the comparative accuracy of these methods is relatively unknown, the trends in TLC are preserved within each subject through the various test conditions.

Tables 85 through 87 below list the results of statistical tests between anthropometric groups. There were no statistically significant differences between subject groups for the BMW seat.

Table 85: Occurrences of statistically significant differences in TLC for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	1	0	0	1	0
F, 50, 50		3	0	0	0
F, 5, 95			0	1	0
M, 95, 5				0	0
M, 50, 50					0

Table 86: Occurrences of statistically significant differences in TLC for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	7	0	0	4	0
F, 50, 50		3	0	0	0
F, 5, 95			0	2	0
M, 95, 5				0	0
M, 50, 50					0

Table 87: Occurrences of statistically significant differences in TLC for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	0
F, 50, 50		1	0	0	0
F, 5, 95			0	2	0
M, 95, 5				0	0
M, 50, 50					0

Differences between TLC values for each anthropometric group were not consistent across seats. Although it is possible that these groups were affected by seats differently, the lack of consistency across seats suggests that there were either no differences in TLC due to subject anthropometry or the wide variability of TLC within each subject group precluded accurate testing between groups.

Table 88 lists the results of statistical testing on TLC within subject groups.

Table 88: TLC statistical results (one-way RM-ANOVA).

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Tan LH, Gray LH (off)	F, 5, 5	---	8	---
	F, 50, 50	---	12	---
	F, 5, 95	---	5	---
	M, 95, 5	2	11	3
	M, 50, 50	---	5	---
	M, 95, 95	---	2	---

Table 88 (continued):

Seats	Subject Group	Lumbar Position	Sedan / Van	Driver / Passenger
Town & Country	F, 5, 5	---	14	---
	F, 50, 50	---	14	---
	F, 5, 95	---	4	---
	M, 95, 5	---	13	2
	M, 50, 50	---	16	1
	M, 95, 95	---	5	---
BMW (thorax forward)	F, 5, 5	9	14	---
	F, 50, 50	---	6	---
	M, 50, 50	---	9	2
	M, 95, 95	---	4	---
BMW (thorax rearward)	F, 50, 50	---	2	---
	F, 5, 95	---	1	---
	M, 95, 5	---	9	2
	M, 50, 50	4	6	2
	M, 95, 95	---	6	---
Gray LH	F, 5, 5	3	13	---
	F, 50, 50	---	15	---
	F, 5, 95	---	10	1
	M, 95, 5	---	13	5
	M, 50, 50	---	16	---
	M, 95, 95	---	2	---

The petite, light females in the BMW seat (thorax forward) had statistically significant differences in TLC between lumbar off and lumbar on, with increases of 1 to 14 degrees. Changes in package had the greatest affect on TLC. This is most likely due to changes in pelvis orientation previously discussed in the analysis of the openness and pelvis angles. Table 89 lists example values of the changes in TLC with respect to package settings for the mid-sized males in the Gray LH seat.

Table 89: Changes in mid-sized male TLC between packages (van minus sedan) of the Gray LH seat.

	Lumbar Off		Lumbar On	
	Passenger	Driver	Passenger	Driver
TM21	---	---	3	11
	10	7	12	5
TM22	15	3	9	10
	13	9	6	5
TM23	6	7	10	7
	3	6	6	10
TM24	4	7	7	0
	5	5	9	---
TM25	---	7	8	6
	8	8	10	7

6.4 Spinal Link Angles

6.4.1 Thoracic Spine Link Angle (TSLA)

Recall that the link between the estimated lower neck joint and the upper lumbar joint was referenced to vertical and referred to as the thoracic spine link angle (TSLA). Tables 90 and 91 list the results of statistical tests between anthropometric groups for the TSLA. No differences were found between these groups for the Tan LH, Town & Country, or the BMW (thorax rearward) seats.

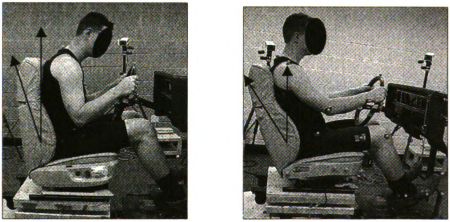
Table 90: Occurrences of statistically significant differences in TSLA for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	5	0	0	0
F, 50, 50		2	0	0	0
F, 5, 95			7	3	0
M, 95, 5				0	0
M, 50, 50					0

Table 91: Occurrences of statistically significant differences in TSLA for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	1	0	0
F, 50, 50		0	0	0	0
F, 5, 95			1	0	0
M, 95, 5				0	3
M, 50, 50					0

The fact that few differences for the Gray LH, and none for the Tan LH, Town & Country, or the BMW (thorax rearward), occurred suggested that there were either no significant differences in behavior due to the size and shape of the occupant or the large range in initial values of TSLA relative to actual values limited the effectiveness of statistical tests. The BMW seat (thorax forward) may have produced a statistically significant difference in TSLA between the petite, ample females and the tall, thin males because with the thorax support fully forward these groups had trouble adjusting the seat. Many subjects found the thorax forward position particularly uncomfortable and were forced to adjust either their position in the seat or the recline of the seat in order to tolerate this seat setting. The subject group average seat back angle values increase by 5 to 8 degrees from the thorax rearward to the thorax forward condition. Figure 68 below illustrates the awkward position in which this seat placed many of the subjects.



(a) (b)

Figure 68: Subject TM26 in the BMW seat (thorax forward); (a) initial position, (b) increased recline to accommodate upper thorax position.

Table 92 lists the results of statistical tests TSLA within each subject group. No statistically significant differences were found for the sedan/van comparisons.

Table 92: TSLA statistical results.

Seats	Subject Group	Lumbar Position	Driver / Passenger
Tan LH, Gray LH (off)	M, 95, 5	2	2
BMW (thorax forward)	F, 5, 5	1	---
	F, 50, 50	3	---
BMW (thorax rearward)	F, 5, 5	3	---
	F, 50, 50	1	---
	M, 95, 5	1	---
	M, 50, 50	2	---
Gray LH	F, 5, 5	1	---
	M, 50, 50	1	---

The average group values for TSLA increased by 1 to 5 degrees from lumbar off to lumbar on. A statistically significant difference was again most often found for the BMW seat; however, the greatest occurrence was 3 out of 16 cases, which was considered negligible. Refer to Appendix C for TSLA group averages and standard deviations.

6.4.2 Lumbar Spine Link Angle (LSLA)

Recall that the link between the estimated upper lumbar joint and the lower lumbar joint was referenced to vertical and referred to as lumbar spine link angle (LSLA). Tables 93 through 97 list the results of statistical tests on the LSLA between anthropometric groups.

Table 93: Statistically significant differences in LSLA for the Tan LH seat by size groups (four possible in each group).

Totals for the Tan LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	0	3	0
F, 50, 50		1	0	0	0
F, 5, 95			1	0	3
M, 95, 5				0	0
M, 50, 50					2

Table 94: Statistically significant differences in LSLA for the Town & Country seat by size groups (eight possible in each group).

Totals for the Town & Country seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	0	1	0
F, 50, 50		8	0	0	0
F, 5, 95			3	1	5
M, 95, 5				0	0
M, 50, 50					0

Table 95: Statistically significant differences in LSLA for the BMW seat (thorax forward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax forward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	0	0	0	0
F, 50, 50		0	0	0	0
F, 5, 95			1	0	1
M, 95, 5				1	0
M, 50, 50					1

Table 96: Statistically significant differences in LSLA for the BMW seat (thorax rearward) by size groups (eight possible in each group).

Totals for the BMW seat (thorax rearward)	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	4	0	1	0
F, 50, 50		2	0	1	0
F, 5, 95			1	0	1
M, 95, 5				1	0
M, 50, 50					0

Table 97: Statistically significant differences in LSLA for the Gray LH seat by size groups (eight possible in each group).

Totals for the Gray LH seat	F, 50, 50	F, 5, 95	M, 95, 5	M, 50, 50	M, 95, 95
F, 5, 5	0	8	0	6	1
F, 50, 50		0	0	0	0
F, 5, 95			1	0	0
M, 95, 5				0	0
M, 50, 50					0

The majority of statistically significant differences occurred between the petite, light and petite, ample females. Although these results may suggest differences in LSLA due to weight, no differences were found between the tall, thin males and the tall, heavy males. The least differences were found in the BMW seat, with practically no differences when the thorax support was in the forward position. The petite, ample females' PLA is smaller than the petite, light females' PLA but the petite, ample females had larger LSLA than the petite, light females. This difference suggests that the petite, ample females sat with more upright pelves.

Statistical results within subject groups for the lumbar spine link angle (LSLA) produced only two positive cases. Both of these cases occurred in the tall, thin male (M, 95, 5) grouping for the change in lumbar prominence of the BMW seat with the thorax support fully forward. The small number of statistically significant differences implies that either none of the variations addressed in this study alter the LSLA parameter or the variability between subjects prevented appropriate comparisons between subjects.

6.4.3 Pelvis Link Angle (PLA)

Recall that the link between the estimated lower lumbar joint and the hip joint center was referenced to vertical and referred to as pelvic link angle (PLA). The changes in the pelvic link angle (PLA) were not examined as these changes behaved essentially equal and opposite to the pelvis angle. Similar statistical results were obtained as for the pelvis angle. The pelvis angle was chosen for examination over the pelvis link angle because the PLA was based on multiple joint location estimations and was more likely to have compounded errors. PLA values are listed in Appendix C.

6.5 Head Position

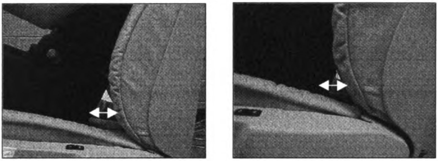
The angle that the subjects' heads deviated from having the Frankfort plane horizontal, as in the reference files, was examined to determine if the test scenarios altered the subjects' sagittal head movement.

Only two cases had statistically significant head tilt results for comparisons between subject groups. This difference occurred between the mid-sized females and the tall, heavy males in the sedan, lumbar off, passenger and sedan, lumbar off, driver positions for the BMW seat (thorax forward). Head Tilt values are listed in Appendix C.

There were also only two statistically significant cases of head tilt results for comparisons within subject groupings: one case for the lumbar comparisons and one case for the driver/passenger comparisons of the mid-sized female (F, 50, 50) group in the BMW seat (thorax rearward). These differences were assumed to be negligible due to the lack of positive results and the fact that the test subject may not have remained focused on the visual task or one of the temple targets fell off and was not reset properly.

6.6 Procedural Effects on Subject Positioning

Once testing was begun it was noticed that the test subjects often sat forward in the seat when the lumbar support was very prominent as shown in Figure 69. An extra test condition was therefore added to the protocol to examine the effects of test procedure on posture.



(a) (b)
Figure 69:Test subject positioning in the BMW; (a) subject TM08, (b) subject TM22.

In the extra condition the subject was instructed to sit with his/her hips as far into the seat as possible and then to adjust the fore/aft position of the seat and the backrest recline to the most comfortable position. This extra condition was performed in the BMW seat (thorax support full rearward) in the sedan package with the arms and legs in the driver position. The lumbar support was set to the full on position. A paired t-test was then used to examine any differences between this extra condition and the corresponding standard position.

Table 98 shows the results of this comparison, refer to Appendix C for actual parameter values.

Table 98: Comparison of standard testing protocol to having the subject's hips fully against the seat.

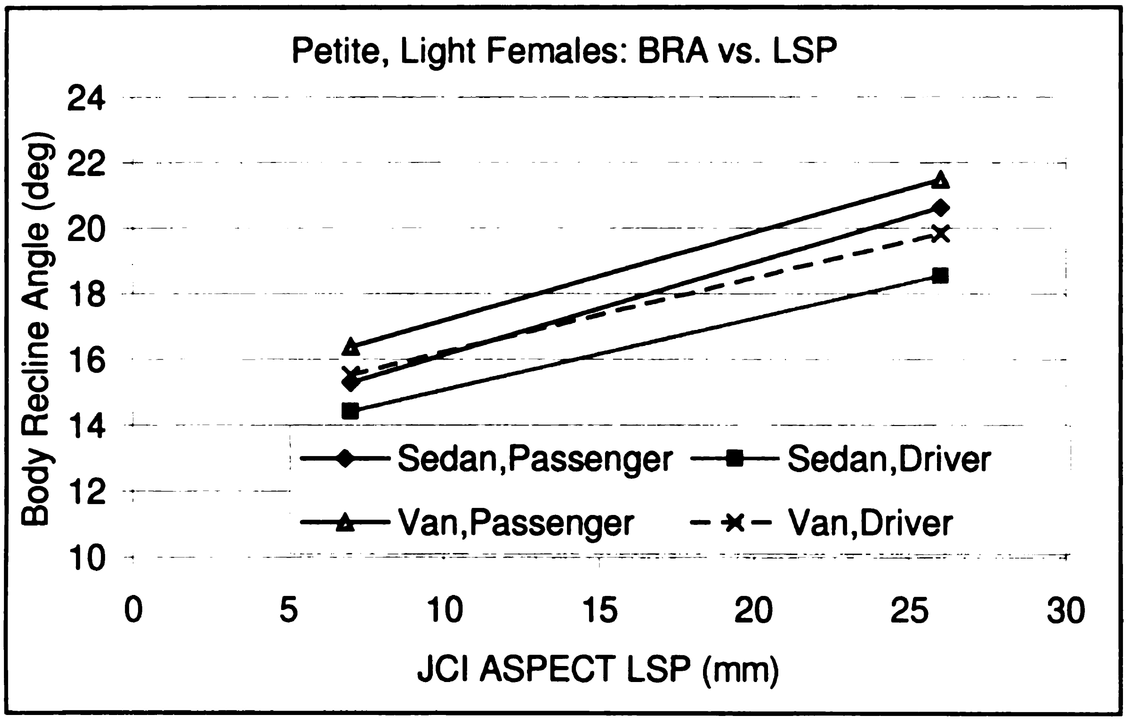
Parameter	T-test Outcome	Range of Difference*	Average Difference*
SBA	---	-5 to +3 degrees	0 degrees
Toebar to HJC X	Yes	-16 to 46 mm	+18 mm
Toebar to HJC Z	---	-10 to 9 mm	-1 mm
J826 Offset X	Yes	-7 to 44 mm	+19 mm
J826 Offset Z	---	-11 to 9 mm	-1 mm
Knee Angle	Yes	-2 to 19 degrees	+7 degrees
Knee Splay Angle	---	-10 to 2 degrees	-1 degree
Shoe Angle	---	-4 to 10 degrees	+2 degrees
Elbow Angle	---	-6 to 23 degrees	+3 degrees
Arm Splay Angle	---	-4 to 6 degrees	+2 degrees
BRA	Yes	-6 to +2 degrees	-2 degrees
Openness Angle	Yes	-6 to +10 degrees	+3 degrees
Pelvis Angle	Yes	-1 to +11 degrees	+4 degrees
Thorax Angle	---	-8 to +3 degrees	-2 degrees
TLC	---	-6 to 26 degrees	+5 degrees
TSLA	---	-5 to +3 degrees	-1 degree
LSLA	Yes	-9 to +2 degrees	-3 degrees
PLA	Yes	-11 to +1 degrees	-5 degrees
Head Tilt	---	-15 to +11 degrees	1 degree
HJC-RecBot X	Yes	-7 to 44 mm	+19 mm
HJC-RecBot Z	---	-11 to 9 mm	-1 mm

* Differences determined by subtracting the standard data from the extra condition data.

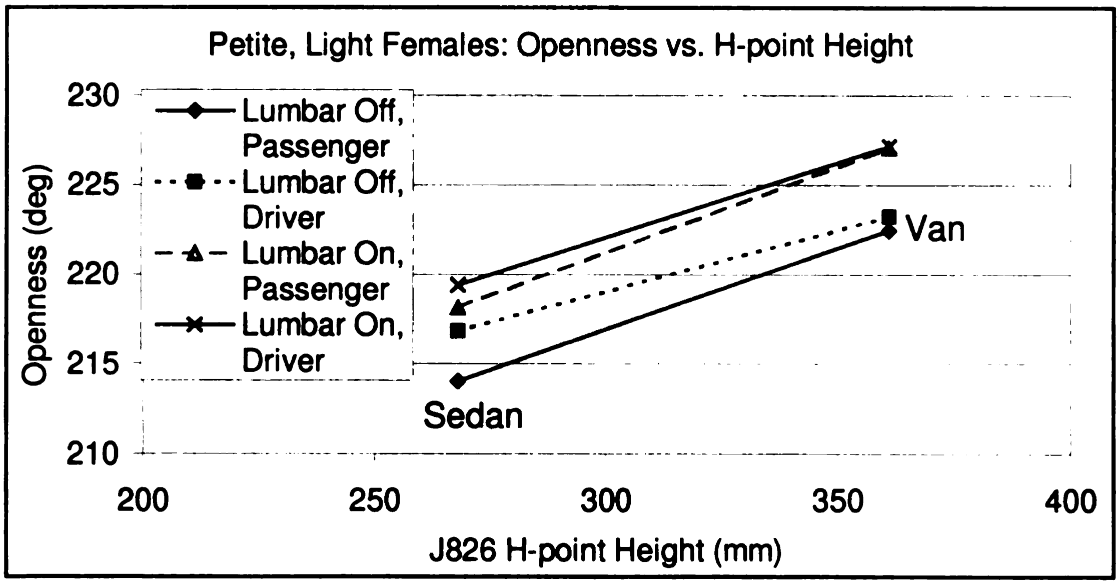
No statistically significant differences were found in the subject's upper body positions. Results of comparisons between the subject's preferred and the extra condition show that the HJC was back further in the seat for the extra instructed cases. This was expected since this is precisely what the subjects were instructed to do. Some of the subjects had to move back into the seat by as much as 44 mm (HJC-RecBot X) in order to contact the seat back. The slight increase in knee angle is most likely the result of the subject moving back into the seat but not adjusting the fore/aft position of the seat. The body recline angle (BRA) decreased since the subjects moved their pelves back into the seat without adjusting the seatback recline angle (SBA). This would bring the ASIS targets on the pelvis more under the sternal notch target, reducing this angle. The increase in pelvis angle indicates a forward rotation of the hips. This is confirmed by the decrease in pelvis link angle (PLA). The additional decrease in the lumbar spine link angle (LSLA) supports the expected results of a more lordotic posture when the subject was required to sit with his/her hips fully into the seats.

6.7 Application to Computer Modeling

To simplify computer modeling of human postural responses to a seat it is desirable to relate human posture parameters to seat factor measures available in industry. The user could then describe a seat with particular parameters and quickly see how each alteration would affect occupant posture. The following figures illustrate how correlations between manikin readings and occupant positioning could potentially be determined. Figure 70 is a plot of the ASPECT manikin lumbar support prominence (LSP) measure against the body recline angle of human subject testing results. Figure 71 is a plot of manikin H-point height (sedan and van) against the subjects' openness angles. Seat factor measurements are currently being studied [7] to determine the appropriateness of such comparisons.



(a)



(b)

Figure 70: Comparison between human and manikin response to a seat.

7. CONCLUSIONS

Several production and prototype seats have been designed to incorporate the current information on healthy seating characteristics, particularly with regard to lumbar support. However, it has been suggested [58] that people may not use the available backrest and lumbar supports in accordance with the designs. This study examined occupant posture and how it is affected by seat and package factors for a range of subject sizes. Following is a summary and conclusions on this study.

7.1 Summary

7.1.1 Seat Positions

Except for a few instances between subject groups, all differences were considered negligible in comparisons of the seat back angle (SBA), meaning in general all subjects chose similar SBA. The tall, heavy males consistently chose slightly more reclined positions than the tall, light males. Differences within each subject were considered negligible.

In examining relative distances from the toebar to the hip joint center (HJC) the horizontal distance was related to the height of the subjects, which in turn is related to the leg length and necessary leg room. Some differences were also found between package settings, with the HJC closer to the toebar in the higher van setting. This difference was most likely the result of the subjects' tendency to seek particular knee angles or thigh pressures. The HJC also moved upwards (away from toebar) from lumbar off to lumbar on. These changes would occur because the subjects slid forward on the upwardly sloped seat and rotated their hips, which would increase the HJC height due to the arced travel path of the HJC.

Differences between the HJC and a fixed reference point on the seat - either the J826 H-point or the bottom recline target on the seat – were also examined. It was assumed that differences between groups were due to the size of each subject's pelvis and the tissue surrounding it. Moving the lumbar support to the full on position caused the subjects' hip joint centers to shift forward, away from the seat. The HJC also shifted slightly upward as discussed in relation to the toebar. These results agree with the findings of Reed's study [59], using an experimental seat, that found that an increase in lumbar prominence shifted the occupant's HJC forward and upward. However, Reed's findings from two seat positions that differed by 25 mm of lumbar prominence indicated that the HJC had a ratio of approximately 11:3 for horizontal and vertical movement while results of the present study indicate this ratio to be closer to 7:3. It should be noted that these ratios are in terms of millimeters of movement and the relationship between the prominences tested in these two studies is unknown.

7.1.2 Extremities

The elbow and arm splay angles were found to be most affected by the driving habits of individuals and possibly the occupant's visibility. No differences in arm position between test conditions were found.

The knee angle was larger for driver than passenger conditions, due to the foot being constrained by the toebar in the driver position, thereby opening the knee angle. The knee splay angles were larger in the van package than sedan package. Less knee splay in the sedan package would result since the legs reached forward more, leading to limited available positions. Differences between subjects were considered to be due to body shape differences, although it should be noted that all of the differences found between subject groups occurred when the seats were set at the sedan height.

7.1.3 Body Angles

The body recline angle (BRA) is a broad measure of the relative orientation between the thorax and pelvis and does not provide information regarding the spine. This parameter should therefore only be used as a measure of overall body recline, similar to the seat back angle measure of the seats. A few differences in BRA were found between lumbar settings for the petite, light females and the tall, thin males in the BMW seat (thorax forward). The fact that no changes occurred in SBA, and the HJC shifted forward, indicated that with the lumbar on, these subjects slid their hips forward in the seat and leaned back with their torsos. The lack of many statistically significant differences in BRA suggested that most subjects sat at similar reclines throughout the test conditions. This lack of differences is consistent with the SBA findings.

A few changes in the petite, light females' openness angles occurred in response to changes in lumbar prominence. However, the majority of statistically significant changes in openness angle occurred in response to changes in package dimensions, with the larger openness angles paired to the van package. Differences in openness angle varied by subject weight. The BMW (thorax rearward) had the least differences, which suggested that this seat may have been satisfactory for visibility and controls reach in most test conditions.

Pelvis angles were found to depend on package settings, with the top of the pelvis rotated more forward (larger angles) in the van package. This finding was most likely due to changes in knee angle, hamstring length, and resulting pelvis orientation. Recall that the pan angle of the seat was fixed and no differences were found in the selected SBA. Differences between subjects were expected to have resulted from different tissue thickness on the back of the pelvis.

Differences in thorax angles between subjects were due to weight and anatomical differences. The petite, light females had a more reclined thorax (larger angle) for the lumbar on, relative to the lumbar off, condition of the BMW (thorax forward) seat. This finding resulted from these subjects sliding forward in the seat and then leaning back.

Changes in package had the most affect on the total lumbar curvature, possibly by altering the length of the hamstrings. The findings of more open postures in the van package than in the sedan correlate well with Reed's assumption [59] that lower seat heights would cause less lordosis.

7.1.4 Spinal Link Angles

There were practically no changes in either the thoracic spinal link angle (TSLA) or the lumbar spinal link angle (LSLA) corresponding to any of the comparisons tested. Angles relative to arbitrary reference axes did not appear to have as significant correlations to seat and package factors as measures of the relative orientations of body segments. However, the spinal link parameters produced values that were extremely small, with the magnitude of these values typically smaller than the range between subjects. The estimated joint locations used in determining the spinal link angles also had too much variation between subjects for appropriate statistical testing. Further examination of applications of these spinal link methods is needed to determine what factors significantly contribute to errors in the estimations involved.

7.1.5 Protocol

Comparisons between the extra test condition, when subjects were instructed to sit with the pelvis fully against the seat, and the subject selected posture conditions found that body angles and pelvis orientation changed while the thorax orientation remained constant. This combination resulted in a more lordotic posture when the subjects had their hips fully against the seat. It is therefore possible to produce more seated lordosis; however, the results of subject selected positions indicated that people would not choose lordotic postures on their own, given the seat designs tested.

7.2 Comments

Lordotic seated postures have been shown to be healthier, less stressful, and therefore desirable [2, 17, 48, 79]. In the current study it is unknown whether the subjects slid away from the lumbar supports because they were awkward, the subjects disliked the seatback contour, or because the lumbar prominences, and corresponding seat contours, were truly uncomfortable. Occupants may need to be educated or trained on the proper use, and location relative to the spine, of lumbar supports. In a future study it may be wise to train the subjects on the proper use of a lumbar support and then perform the seat tests on a different day, or to only use test subjects who have previously had back problems and are familiar with lumbar support devices. Although education and experience may be an issue, it is also likely that the method used to promote lumbar lordosis is not the most natural match to the human body. Referring back to the principles of the biomechanically articulated chair [45], it may be better to promote lumbar lordosis by positioning the ribcage and pelvis, without pressing on the lumbar spine.

The petite, light females were found to be more sensitive to the seat and package settings than the other groups. The BMW seat also tended to produce significantly more differences in occupant posture than the other seats. The Town & Country lumbar support did not have a significant affect on pelvis location; however large differences in pelvis locations were found in the LH and BMW seats. This was surprising given the similar ASPECT manikin lumbar support prominence readings of the Gray LH and Town & Country seats.

In Reed's study [59] no differences were found in the tested parameters between subject size groupings, except for the pelvis angle. Reed found that the top of the subjects' pelves were rotated forward an average of 10 degrees more for the large males than the mid-sized males. This study found a similar difference, depending on the seat and test condition examined. However, Reed also found this trend of pelvis rotation between the small females and the mid-sized females; however, no significant differences were found between the pelvis angles of these groups in the present study. The appropriateness of comparisons between these studies is questionable since Reed grouped subjects only by stature and the test conditions are not the same.

7.3 Future Work

Expanded seat and package factors should be examined because the current methods using the ASPECT manikin may not be sufficient to describe the seat contours. The loaded, in-use contours of the seat pan and backrest should also be examined since they are the critical factors in chair comfort [79], unlike the undeflected probe contours available in this study. Additional characterizations of lumbar supports using the ASPECT manikin are currently being studied by Bogard [7] and need to be examined for correlations with the subject results of the present study. Correlations between manikin measurements and human responses would speed the design process while limiting prototype expenses.

The improvement and addition of armrests would provide useful information regarding the weight bearing capacity and postural influences of arm support and may affect occupant responses to the rest of the seat. In the automotive environment the driver's posture is not necessarily symmetric, as in this study, and may produce negative impacts on occupant posture.

It would be interesting to study the affects on posture of adjustable seat heights, particularly for the passenger, who does not normally have this option. If a seat is too high then the occupant either doesn't have his or her feet on the floor, which causes pressure under the thighs, or slides down in the chair so the back is fully flexed [70]. The same problems can occur if the seat depth is too large. Seat height is particularly important for short individuals, such as the petite, light females in this study, because a seat that is too high may not provide easy access to foot controls while a seat that is too low may prevent adequate visibility over the dashboard.

APPENDIX A

ANTHROPOMETRIC MEASUREMENTS

Note: Identification numbers are based on NATICK [52] Identifier. Modifications to these measurements are listed after the original description. All measurements were taken while the subject was wearing shoes, with the height and weight also measured without shoes. Measurements denoted by ™ are at the request of TecMath.

Standing measurements

Bispinous Breadth (ASIS/pelvic width) ™

The straight-line distance between the right and left anterior superior iliac spine landmarks. The subject stands looking straight ahead with the heels together and the weight distributed equally on both feet. (14)

Chest Depth

The horizontal distance between the front and back of the chest, at the level of the mid-sternum and sternal notch. 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. (36)

*Modifications: Used mid-sternum and sternal notch levels instead of the right bustpoint.

Chest Breadth ™

The maximum horizontal breadth of the chest at the level of the right bustpoint on women or the nipple on men. The subject stands erect looking straight ahead with the heels together, the weight distributed evenly on both feet. The measurement is taken at the maximum point of quiet respiration. (32)

Stature ™

The vertical distance from a standing surface to the top of the head. The subject stands erect with the head in the Frankfort plane. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration. (99)

Trochanteric Height

The vertical distance between a standing surface and the trochanterion landmark on the upper side of the right thigh. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. (107)

Pelvis Height

The vertical distance between the inter-ASIS and the pubic center. The subject stands erect looking straight ahead.

Hip Breadth
The horizontal distance between the lateral buttock landmarks on the sides of the hips. The subject stands erect with the heels together and the weight distributed equally on both feet. (65)

Waist circumference (natural indentation) ™
The horizontal circumference of the waist at the level of its natural indentation is measured with a tape passing over right and left waist (natural indentation) landmarks. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. (113)

Foot Breadth ™
The maximum breadth of the right foot is measured from the right fifth-metatarsophalangeal-protrusion landmark to the first metatarsophalangeal protrusion. (50)

Weight™
The weight of the subject is taken to the nearest half pound. (124)

Seated measurements
Acromial Height, Seated
The vertical distance between a sitting surface and the acromion landmark on the tip of the right shoulder. 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 quiet respiration. (3)

Acromial-Humeral Length
The distance between the acromion landmark on the tip of the right shoulder and the humeral landmark on the right elbow. The subject sits erect. The shoulders and upper extremities are relaxed with the forearms and hands extended forward horizontally with the palms facing each other. (4)

Biacromial Breadth
The distance between the right and left acromion landmarks at the tips of the shoulders. The subject sits erect. 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 taken at the maximum point of quiet respiration. (10)

Buttock-Knee (Front) Length™
The horizontal distance between the most posterior point on either buttock and the anterior point of the right knee. The subject sits erect. The thighs are parallel and the knees flexed 90 degrees with the feet in line with the thighs. (26)

Hip Breadth, Seated
The distance between the lateral points of the hips or thighs (whichever are broader) is measured. The subject sits erect with the feet and knees together. (66)

Cervicale Height, Seated
The vertical distance between a sitting surface and the cervicale (C7) landmark on the spine at the base of the neck. The subject sits erect looking straight ahead. The thighs are parallel and the knees are flexed 90 degrees. The measurement is taken at the maximum point of quiet respiration. (31)

Forearm-Hand Length
The horizontal distance between the back of the right humeral landmark of the elbow to the ulnar condyle of the wrist. The subject sits erect with the upper arms hanging at the sides and the right elbow flexed 90 degrees. The hand is held out straight with the palm facing forward. (54)
*Modification: Used humeral landmark and wrist instead of tip of elbow and tip of middle finger.

Forearm Circumference
The circumference of the flexed forearm is measured in a plane perpendicular to the long axis of the forearm. The subject stands with the upper arm extended forward horizontally, the elbow flexed 90 degrees, and the fist tightly clenched and held facing the head. (52)

Lateral Femoral Epicondyle Height
The vertical distance between a footrest surface and the lateral-femoral-epicondyle landmark on the outside of the right knee. The subject sits erect with the heels together and the weight distributed equally on both feet. (74)
*Modification: This measurement was taken while the subject was seated instead of standing.

Lateral Malleolus Height
The vertical distance between a footrest surface and the lateral malleolus landmark on the right ankle. The subject sits erect with the heels together and the weight distributed equally on both feet. (75)
*Modification: This measurement was taken while the subject was seated instead of standing.

Knee Height, Seated™
The vertical distance from a footrest surface to the suprapatella landmark at the top of the right knee. The subject sits with the thighs parallel, the feet in line with the thighs, and the knees flexed 90 degrees. (73)

Height, Seated™
The vertical distance between a sitting surface and the top of the head. The subject sits erect with the head in the Frankfort plane. The thighs are parallel and the knees are flexed 90 degrees with the feet in line with the thighs. The measurement is made at the maximum point of quiet respiration. (93)

T12 Height
The vertical distance between a sitting surface and the T12 landmark of the spine. 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 thighs are parallel and the knees are flexed 90 degrees. The measurement is taken at the maximum point of quiet respiration. (A1)

S1 Height
The vertical distance between a sitting surface and the S1 landmark of the spine. 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 thighs are parallel and the knees are flexed 90 degrees. The measurement is taken at the maximum point of quiet respiration. (A2)

Pelvic Depth (ASIS to PSIS)
The horizontal distance between the anterior superior iliac spine and the posterior superior iliac spine landmarks. The subject sits erect looking straight ahead. (A3)

Frontal Arm Reach
The horizontal distance between the acromion landmark and the tip of the middle finger. The subject sits erect with the arms fully extended forward. (A4)

Tragion Height
The vertical distance between a sitting surface and the tragion landmark of the right ear. The subject sits erect with the head in the Frankfort plane. The shoulders and upper arms are relaxed and the forearms and hands are extended forward horizontally with the palms facing each other. The thighs are parallel and the knees are flexed 90 degrees. The measurement is taken at the maximum point of quiet respiration. (A5)

Head Breadth
The maximum horizontal breadth of the head above the attachment of the ears is measured. (60)

Head Length
The distance from the glabella landmark between the browridges to the posterior point on the back of the head is measured. (62)

Head Height
The distance from the highest point of the head to the bottom of the chin is measured. (A6)

Additional Landmarks (not measured)
Infraorbitale
The undepressed skin surface point obtained by palpating the most inferior margin of the eye socket.

Tragion
Undepressed skin surface point obtained by palpating the most anterior margin of the cartilaginous notch just superior to the tragius. Of the ear (located at the upper edge of the external auditory meatus).

Standing Measurements

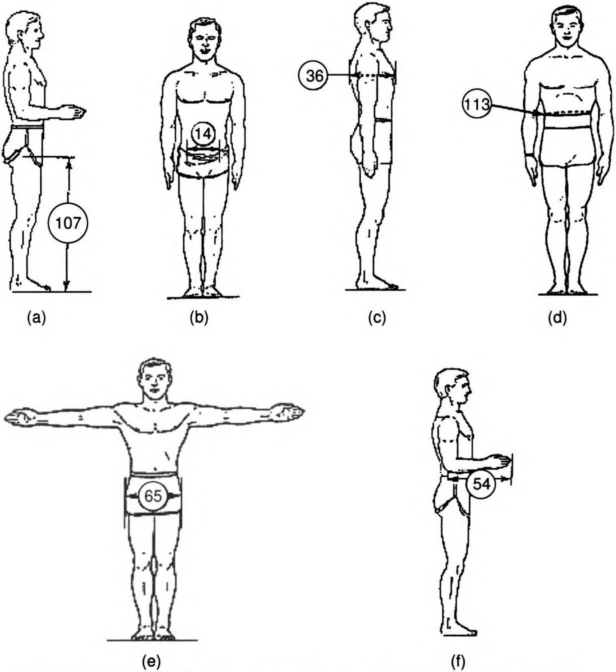


Figure 71: Standing anthropometric measurements. (a) trochanteric height, (b) bispinous breadth, (c) chest depth, (d) waist circumference, (e) hip breadth, (f) forearm-hand length.

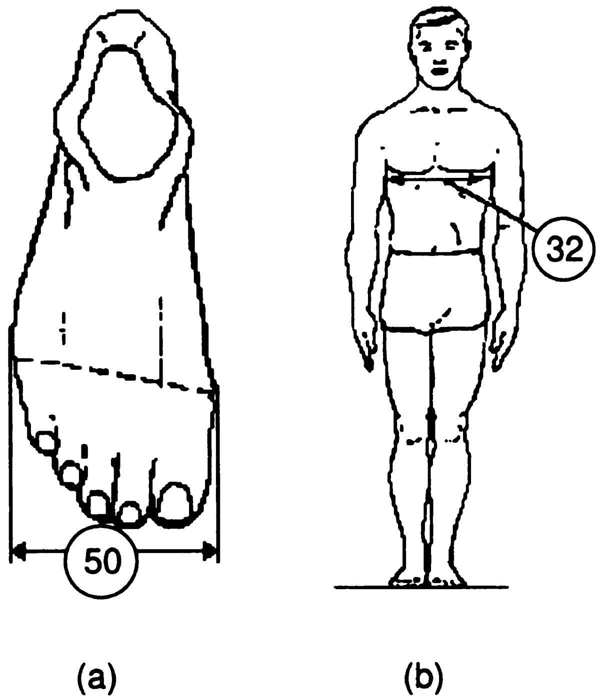


Figure 72: Standing anthropometric measurements, (a) foot breadth, (b) chest breadth.

Seated Measurements

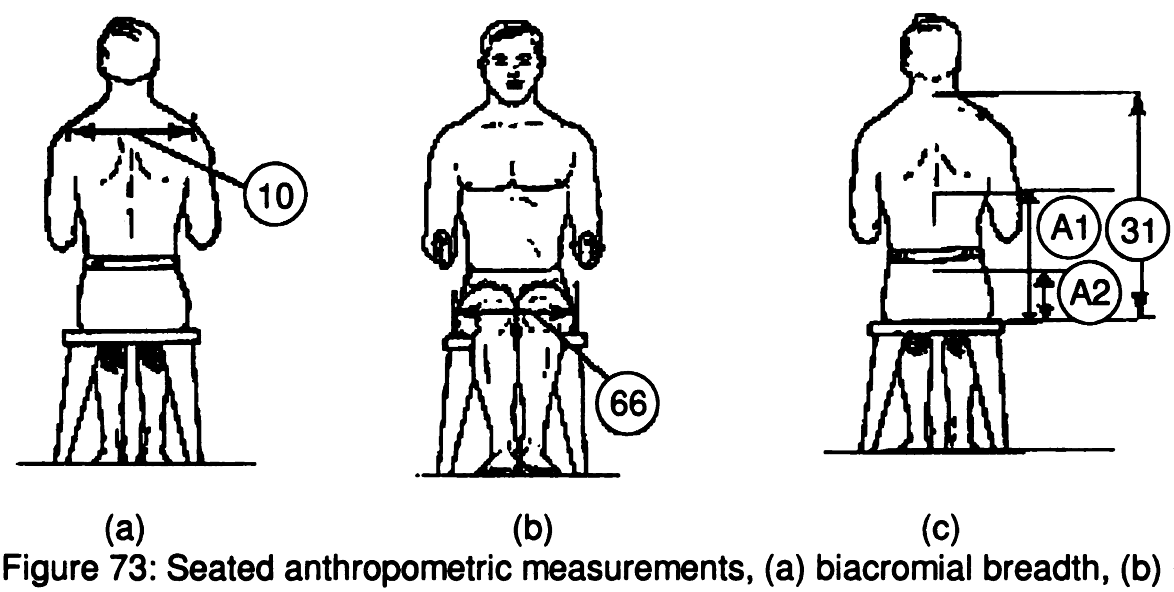


Figure 73: Seated anthropometric measurements, (a) biacromial breadth, (b) hip breadth, (c) C7, T12, and S1 heights.

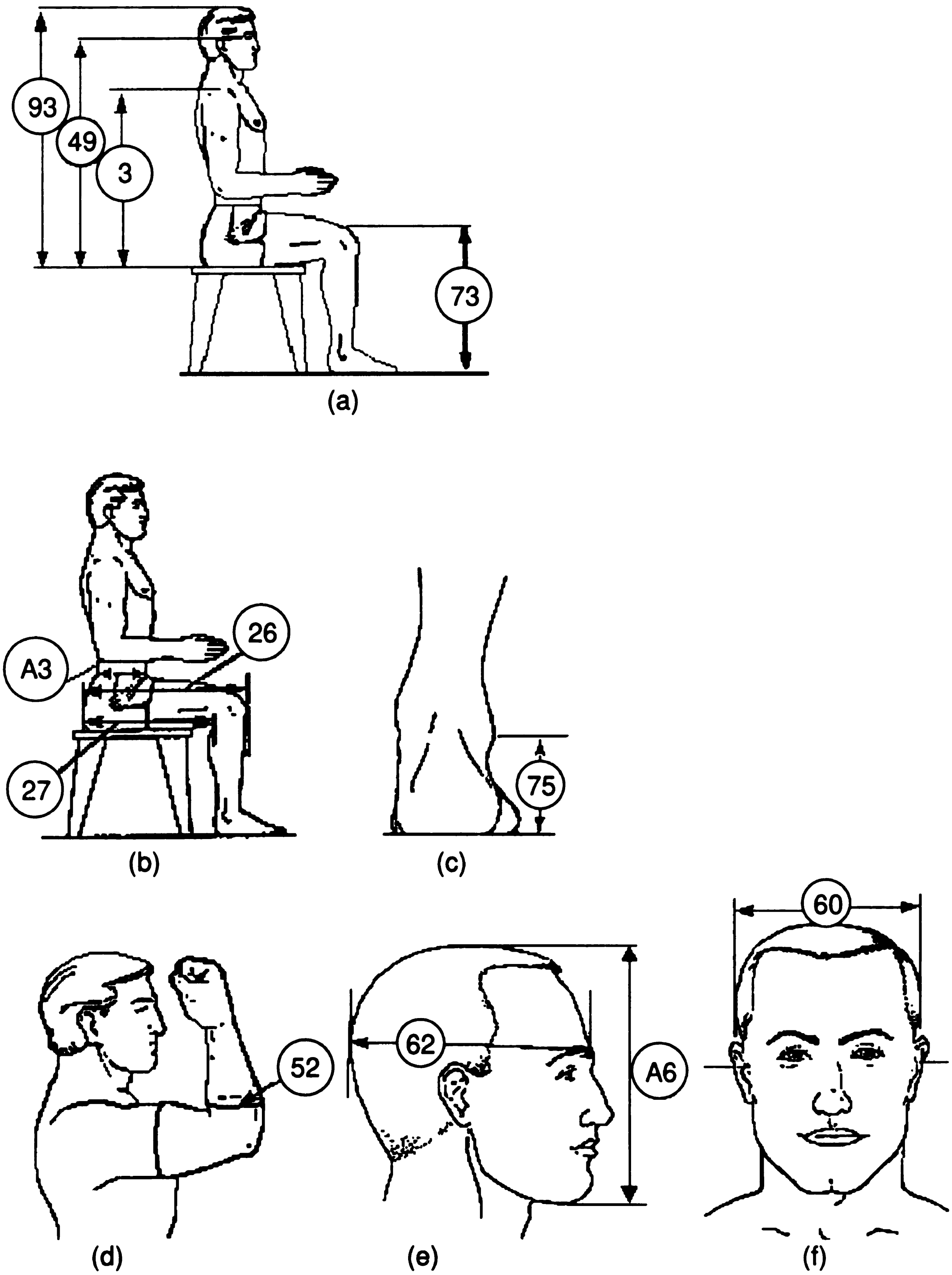


Figure 74: Seated anthropometric measurements, (a) heights of the shoulder, head, and knee, (b) leg lengths, (c) ankle height, (d) forearm circumference, (e) and (f) head dimensions.

APPENDIX B

SEAT TARGETING

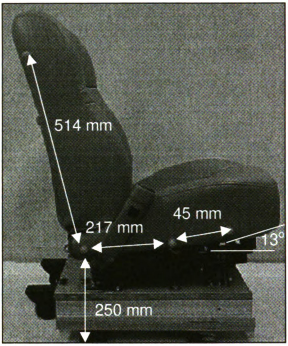


Figure 75: Targeting of Seat A (Tan LH).

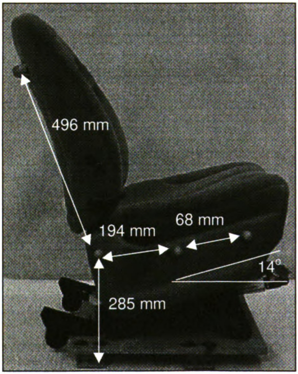


Figure 76: Targeting of Seat B (Chrysler Town & Country).

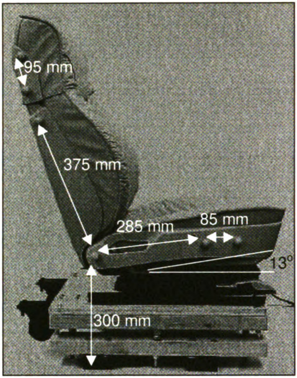


Figure 77: Targeting of Seat C (BMW 7 Series).

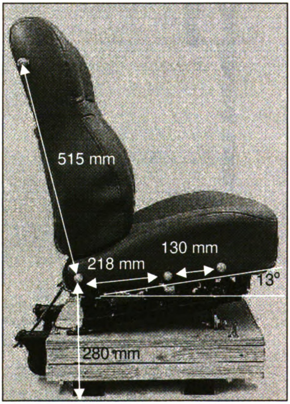


Figure 78: Targeting of Seat D (Gray LH).

APPENDIX C

GROUP AVERAGES AND STANDARD DEVIATIONS

Table 99: Seat back angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	20	19	19	18
	StDev	2	3	3	3
F, H50, W50	Avg	19	19	20	19
	StDev	2	2	2	2
F, H5, W95	Avg	17	17	16	16
	StDev	1	1	0	0
M, H95, W5	Avg	19	19	21	20
	StDev	2	3	4	4
M, H50, W50	Avg	21	22	22	22
	StDev	4	3	3	3
M, H95, W95	Avg	21	19	20	18
	StDev	4	3	3	3

Table 100: Seat back angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	11	11
TM05	18	18
TM09	19	17
TM12	13	12
TM13	11	11
TM14	12	11
TM15	11	10
TM17	11	11
TM18	22	20
TM19	13	10
TM26	18	23
TM28	12	12
TM29	12	13
TM30	18	15

Table 101: Seat back angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	26	26	26	26	25	25	25	25
	StDev	2	1	2	1	0	0	1	0
F, H50, W50	Avg	26	26	26	26	25	25	25	25
	StDev	1	1	1	1	0	0	0	0
F, H5, W95	Avg	28	26	28	27	25	25	25	25
	StDev	4	2	4	2	0	0	0	0
M, H95, W5	Avg	27	26	27	26	27	27	26	26
	StDev	1	1	1	1	1	1	1	1
M, H50, W50	Avg	27	27	28	27	28	27	28	27
	StDev	2	1	2	1	3	1	3	1
M, H95, W95	Avg	27	27	28	26	27	26	27	26
	StDev	2	1	2	1	1	0	1	0

Table 102: Seat back angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	20	19	21	19	21	20	22	20
	StDev	4	4	4	4	4	4	4	4
F, H50, W50	Avg	22	21	21	19	23	22	22	22
	StDev	5	4	5	4	5	4	4	4
F, H5, W95	Avg	17	17	17	17	17	17	17	17
	StDev	2	2	2	2	2	2	2	2
M, H95, W5	Avg	21	21	21	21	23	22	22	22
	StDev	3	4	3	4	3	3	3	3
M, H50, W50	Avg	23	22	23	21	22	22	22	21
	StDev	2	4	5	7	4	4	5	6
M, H95, W95	Avg	25	22	25	22	26	23	25	23
	StDev	8	6	8	6	7	5	7	5

Table 103: Seat back angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	12	12	12	12	13	13	14	13
	StDev	3	3	3	4	2	3	2	3
F, H50, W50	Avg	13	13	13	13	12	13	12	12
	StDev	4	4	4	3	4	4	4	4
F, H5, W95	Avg	12	12	13	12	13	13	14	14
	StDev	3	3	3	3	2	2	5	5
M, H95, W5	Avg	15	14	15	14	13	12	13	13
	StDev	5	5	5	5	5	4	5	5
M, H50, W50	Avg	14	16	16	14	15	14	15	14
	StDev	5	5	5	5	3	2	3	3
M, H95, W95	Avg	18	15	17	15	19	17	19	16
	StDev	6	5	7	4	4	4	5	3

Table 104: Seat back angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	18	17	18	17	18	17	18	17
	StDev	2	2	2	2	3	2	3	2
F, H50, W50	Avg	18	18	19	19	19	19	19	18
	StDev	3	1	1	1	2	2	2	2
F, H5, W95	Avg	18	17	17	17	17	17	17	17
	StDev	2	2	2	2	2	2	2	2
M, H95, W5	Avg	18	18	18	18	17	17	17	17
	StDev	2	2	2	2	2	2	2	2
M, H50, W50	Avg	20	19	20	19	19	19	20	19
	StDev	2	1	1	2	1	2	1	2
M, H95, W95	Avg	19	17	19	17	19	17	19	17
	StDev	2	2	3	2	2	2	3	2

Table 105: Manikin correlated seat back angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	22	19	19	18
	StDev	3	4	3	3
F, H50, W50	Avg	20	20	21	20
	StDev	3	2	2	2
F, H5, W95	Avg	17	17	16	16
	StDev	1	1	0	1
M, H95, W5	Avg	19	19	22	22
	StDev	3	3	5	5
M, H50, W50	Avg	22	24	24	24
	StDev	5	4	4	4
M, H95, W95	Avg	22	19	21	19
	StDev	5	4	4	3

Table 106: Manikin correlated seat back angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	13	12
TM05	22	22
TM09	24	21
TM12	15	14
TM13	13	13
TM14	14	13
TM15	12	12
TM17	13	13
TM18	28	25
TM19	15	11
TM26	22	28
TM28	15	14
TM29	14	15
TM30	22	18

Table 107: Manikin correlated seat back angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	22	21	22	21	20	20	20	20
	StDev	2	2	2	2	0	0	1	0
F, H50, W50	Avg	22	21	21	21	20	21	21	21
	StDev	2	1	1	1	1	1	1	1
F, H5, W95	Avg	24	22	24	22	21	21	21	21
	StDev	6	2	5	3	1	1	1	1
M, H95, W5	Avg	22	22	22	22	22	22	22	22
	StDev	1	1	1	1	2	2	2	1
M, H50, W50	Avg	23	23	25	23	24	22	24	23
	StDev	3	2	3	2	4	2	4	2
M, H95, W95	Avg	23	22	24	22	22	21	23	21
	StDev	3	2	3	1	2	1	2	0

Table 108: Manikin correlated seat back angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	25	24	26	24	26	25	27	25
	StDev	5	5	6	5	5	5	5	6
F, H50, W50	Avg	27	27	26	24	28	27	28	27
	StDev	7	6	7	6	6	5	6	5
F, H5, W95	Avg	20	20	21	20	21	20	21	21
	StDev	2	2	2	2	2	3	3	3
M, H95, W5	Avg	27	26	26	26	29	28	28	27
	StDev	4	5	4	5	4	5	4	5
M, H50, W50	Avg	29	28	29	26	28	27	28	26
	StDev	3	6	7	10	5	6	6	8
M, H95, W95	Avg	32	27	32	28	33	29	32	29
	StDev	11	8	10	8	9	6	9	7

Table 109: Manikin correlated seat back angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	14	14	15	14	16	15	16	15
	StDev	4	5	4	5	3	3	3	4
F, H50, W50	Avg	15	16	15	15	15	15	14	14
	StDev	6	5	5	4	5	5	5	5
F, H5, W95	Avg	14	14	15	15	15	15	17	17
	StDev	4	4	4	4	3	3	7	7
M, H95, W5	Avg	18	17	18	17	16	14	16	16
	StDev	7	7	7	7	6	6	6	7
M, H50, W50	Avg	17	19	20	16	18	17	19	17
	StDev	6	7	6	7	3	2	4	4
M, H95, W95	Avg	22	18	21	18	24	21	24	20
	StDev	9	7	9	6	5	5	7	4

Table 110: Manikin correlated seat back angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	19	19	19	19	19	19	19	19
	StDev	3	2	3	3	4	3	3	3
F, H50, W50	Avg	19	20	21	21	21	21	21	20
	StDev	4	1	2	1	3	3	3	3
F, H5, W95	Avg	19	19	19	19	19	19	19	19
	StDev	3	3	3	3	3	3	3	3
M, H95, W5	Avg	20	19	20	19	18	19	19	18
	StDev	2	3	3	3	3	3	3	2
M, H50, W50	Avg	22	22	23	22	21	21	22	21
	StDev	2	2	2	3	2	2	2	2
M, H95, W95	Avg	21	19	21	18	21	19	21	18
	StDev	3	2	3	2	3	2	3	2

Table 111: Toebar to HJC horizontal distance in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	802	800	767	764
	StDev	48	47	41	37
F, H50, W50	Avg	829	837	815	815
	StDev	38	36	33	36
F, H5, W95	Avg	780	773	716	716
	StDev	49	37	26	27
M, H95, W5	Avg	895	899	845	861
	StDev	17	31	28	34
M, H50, W50	Avg	850	863	839	846
	StDev	18	23	23	23
M, H95, W95	Avg	924	932	878	891
	StDev	21	27	25	37

Table 112: Toebar to HJC horizontal distance in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	755	736
TM05	843	849
TM09	878	893
TM12	707	661
TM13	748	747
TM14	822	815
TM15	750	747
TM17	907	884
TM18	902	884
TM19	908	867
TM26	901	879
TM28	970	930
TM29	929	910
TM30	956	921

Table 113: Toebar to HJC horizontal distance in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	774	768	770	753	742	724	731	717
	StDev	49	63	52	74	29	54	45	53
F, H50, W50	Avg	813	820	757	812	776	790	776	785
	StDev	39	36	163	36	39	38	33	35
F, H5, W95	Avg	750	759	755	754	712	716	712	714
	StDev	64	67	59	67	37	35	33	36
M, H95, W5	Avg	896	907	887	900	854	862	844	853
	StDev	12	15	19	17	25	21	22	22
M, H50, W50	Avg	844	853	847	848	818	820	808	814
	StDev	28	28	26	28	30	24	29	28
M, H95, W95	Avg	888	903	882	901	859	870	851	865
	StDev	15	10	23	14	12	20	13	20

Table 114: Toebar to HJC horizontal distance in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	775	765	758	746	753	750	685	730
	StDev	40	59	40	58	39	38	159	40
F, H50, W50	Avg	847	846	796	815	795	802	764	773
	StDev	57	52	50	55	45	38	47	45
F, H5, W95	Avg	762	763	750	755	727	724	717	723
	StDev	57	58	61	57	52	53	50	48
M, H95, W5	Avg	923	926	893	904	875	880	849	861
	StDev	19	17	19	16	14	11	9	9
M, H50, W50	Avg	890	898	857	877	862	865	829	846
	StDev	44	39	38	35	36	34	35	31
M, H95, W95	Avg	942	947	924	925	900	898	883	883
	StDev	27	29	22	40	15	23	10	17

Table 115: Toebar to HJC horizontal distance in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	776	781	762	753	744	745	728	717
	StDev	48	48	51	60	39	41	36	57
F, H50, W50	Avg	821	829	786	802	795	804	760	776
	StDev	69	53	59	57	55	39	47	52
F, H5, W95	Avg	750	759	745	744	729	734	724	726
	StDev	45	44	51	52	39	37	37	35
M, H95, W5	Avg	883	902	860	878	865	876	840	853
	StDev	24	13	19	9	12	11	25	15
M, H50, W50	Avg	870	878	836	865	855	857	824	836
	StDev	35	33	25	26	25	22	37	28
M, H95, W95	Avg	927	926	904	908	881	871	859	861
	StDev	11	27	15	19	8	41	7	23

Table 116: Toebar to HJC horizontal distance in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	779	782	768	767	749	747	739	735
	StDev	35	31	33	33	32	32	32	32
F, H50, W50	Avg	824	839	818	827	809	810	797	807
	StDev	55	45	50	45	48	41	42	42
F, H5, W95	Avg	747	756	743	748	716	727	717	721
	StDev	34	31	29	33	28	33	32	34
M, H95, W5	Avg	890	902	880	889	851	858	840	845
	StDev	12	14	16	20	19	18	20	18
M, H50, W50	Avg	841	847	833	842	815	831	809	821
	StDev	22	20	24	12	32	21	24	14
M, H95, W95	Avg	900	910	891	883	860	873	848	856
	StDev	26	21	28	17	7	11	5	8

Table 117: Toebar to HJC vertical distance in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	91	94	193	195
	StDev	5	6	9	7
F, H50, W50	Avg	104	104	203	207
	StDev	26	25	24	26
F, H5, W95	Avg	119	109	206	209
	StDev	38	20	24	21
M, H95, W5	Avg	94	98	188	187
	StDev	5	22	7	7
M, H50, W50	Avg	98	100	197	197
	StDev	9	18	12	13
M, H95, W95	Avg	95	96	198	199
	StDev	20	21	14	16

Table 118: Toebar to HJC vertical distance in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	124	130
TM05	123	120
TM09	125	128
TM12	100	101
TM13	130	131
TM14	153	157
TM15	127	128
TM17	131	132
TM18	119	127
TM19	130	141
TM26	137	130
TM28	164	156
TM29	124	115
TM30	147	149

Table 119: Toebar to HJC vertical distance in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	123	123	124	124	223	224	225	226
	StDev	12	10	10	9	13	13	12	12
F, H50, W50	Avg	122	119	70	125	225	228	230	230
	StDev	14	13	169	15	15	14	15	16
F, H5, W95	Avg	127	126	128	127	226	228	227	229
	StDev	17	17	16	16	20	21	20	22
M, H95, W5	Avg	117	113	120	116	219	218	222	222
	StDev	5	5	5	6	7	6	6	7
M, H50, W50	Avg	106	105	111	110	201	200	203	203
	StDev	10	13	11	13	15	17	16	16
M, H95, W95	Avg	114	114	117	118	216	218	221	220
	StDev	23	22	23	23	27	25	27	27

Table 120: Toebar to HJC vertical distance in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	115	114	122	122	213	214	223	225
	StDev	7	8	7	7	7	5	8	7
F, H50, W50	Avg	117	117	129	124	218	219	227	223
	StDev	20	20	23	23	17	18	21	21
F, H5, W95	Avg	126	121	124	124	218	217	241	222
	StDev	22	25	24	23	27	26	56	26
M, H95, W5	Avg	115	113	129	127	209	210	223	222
	StDev	9	10	7	7	4	3	4	5
M, H50, W50	Avg	109	107	121	120	209	206	220	221
	StDev	13	13	11	11	14	12	13	11
M, H95, W95	Avg	112	113	122	126	211	213	219	221
	StDev	19	21	17	20	20	19	19	19

Table 121: Toebar to HJC vertical distance in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	120	117	129	129	219	221	230	231
	StDev	8	12	10	9	11	11	13	11
F, H50, W50	Avg	117	125	136	137	225	224	239	238
	StDev	24	16	20	21	18	20	19	19
F, H5, W95	Avg	126	126	133	130	226	226	229	231
	StDev	21	21	15	19	23	24	22	24
M, H95, W5	Avg	124	121	136	133	215	215	227	227
	StDev	7	9	6	6	3	3	2	2
M, H50, W50	Avg	116	113	129	128	213	213	229	228
	StDev	9	13	10	9	12	15	15	13
M, H95, W95	Avg	121	122	130	132	220	222	229	229
	StDev	20	22	20	20	25	29	25	25

Table 122: Toebar to HJC vertical distance in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	115	111	119	116	214	215	219	218
	StDev	11	19	10	15	13	15	13	14
F, H50, W50	Avg	120	120	124	122	219	223	227	228
	StDev	20	19	18	20	16	20	21	21
F, H5, W95	Avg	122	123	123	123	222	225	224	226
	StDev	17	19	17	18	21	23	23	23
M, H95, W5	Avg	124	122	131	126	219	220	225	224
	StDev	6	5	7	7	5	3	4	4
M, H50, W50	Avg	104	105	110	107	207	203	210	210
	StDev	12	12	12	10	15	15	16	16
M, H95, W95	Avg	121	122	122	124	221	221	223	221
	StDev	27	26	29	30	24	25	27	28

Table 123: Horizontal Offset from HJC to J826 H-point in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	6	10	2	3
	StDev	7	7	11	11
F, H50, W50	Avg	-11	-3	1	-2
	StDev	31	32	25	30
F, H5, W95	Avg	-57	-46	-56	-53
	StDev	12	13	17	18
M, H95, W5	Avg	-32	-24	-26	-23
	StDev	7	7	21	21
M, H50, W50	Avg	-41	-29	-28	-22
	StDev	31	30	22	22
M, H95, W95	Avg	-28	-25	-24	-21
	StDev	12	15	11	11

Table 124: Horizontal Offset from HJC to J826 H-point in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	-46	-63
TM05	-8	-20
TM09	22	3
TM12	-33	-77
TM13	-68	-67
TM14	-84	-91
TM15	-71	-73
TM17	-37	-57
TM18	-10	-45
TM19	-39	-74
TM26	-26	-19
TM28	-19	-51
TM29	-27	-42
TM30	-17	-53

Table 125: Horizontal Offset from HJC to J826 H-point in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	9	11	3	6	11	12	7	7
	StDev	9	9	9	10	5	5	6	6
F, H50, W50	Avg	0	7	-8	-3	2	4	-5	-4
	StDev	19	17	21	19	20	26	26	27
F, H5, W95	Avg	-43	-39	-46	-44	-41	-38	-42	-41
	StDev	14	12	13	10	18	16	17	17
M, H95, W5	Avg	-25	-19	-31	-26	-19	-16	-25	-23
	StDev	15	13	13	10	7	7	7	6
M, H50, W50	Avg	-28	-23	-33	-33	-24	-24	-31	-31
	StDev	21	20	22	19	28	29	27	31
M, H95, W95	Avg	-28	-23	-30	-27	-19	-15	-24	-21
	StDev	3	3	5	6	7	9	6	8

Table 126: Horizontal Offset from HJC to J826 H-point in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	3	6	-16	-16	15	15	-5	-8
	StDev	13	11	15	13	9	8	14	16
F, H50, W50	Avg	4	8	-27	-16	16	20	-11	-1
	StDev	31	31	34	31	26	25	27	20
F, H5, W95	Avg	-61	-53	-70	-67	-46	-45	-59	-53
	StDev	10	10	9	11	19	17	16	20
M, H95, W5	Avg	-18	-11	-46	-40	-6	-3	-32	-28
	StDev	12	13	13	16	11	13	10	12
M, H50, W50	Avg	-28	-19	-52	-53	-12	-8	-39	-39
	StDev	31	31	26	36	26	28	25	31
M, H95, W95	Avg	-12	-13	-30	-28	-3	-7	-22	-22
	StDev	21	16	23	17	15	7	16	11

Table 127: Horizontal Offset from HJC to J826 H-point in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-22	-17	-39	-40	-10	-7	-29	-29
	StDev	12	16	12	16	10	13	13	14
F, H50, W50	Avg	-30	-18	-55	-52	-24	-16	-55	-48
	StDev	37	26	33	39	29	32	31	34
F, H5, W95	Avg	-65	-60	-79	-74	-52	-48	-57	-57
	StDev	15	16	12	12	16	15	16	20
M, H95, W5	Avg	-47	-38	-70	-63	-26	-23	-49	-47
	StDev	13	15	14	15	9	8	6	9
M, H50, W50	Avg	-55	-40	-80	-73	-35	-34	-64	-60
	StDev	36	38	33	32	22	21	25	19
M, H95, W95	Avg	-25	-26	-48	-47	-13	-16	-32	-34
	StDev	19	16	24	18	15	13	12	8

Table 128: Horizontal Offset from HJC to J826 H-point in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-10	-5	-20	-17	-20	-17	-30	-29
	StDev	12	10	12	11	11	10	11	10
F, H50, W50	Avg	-17	-9	-27	-22	-19	-21	-39	-34
	StDev	32	31	26	27	28	36	34	36
F, H5, W95	Avg	-56	-49	-62	-55	-64	-64	-73	-71
	StDev	15	17	17	19	17	21	21	21
M, H95, W5	Avg	-43	-36	-55	-48	-59	-55	-70	-67
	StDev	12	10	11	10	4	4	5	4
M, H50, W50	Avg	-44	-39	-57	-59	-50	-44	-63	-58
	StDev	30	27	29	24	26	25	22	23
M, H95, W95	Avg	-47	-42	-56	-53	-55	-51	-68	-63
	StDev	7	7	7	8	7	8	7	9

Table 129: Vertical Offset from HJC to J826 H-point in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-7	-6	0	2
	StDev	5	4	10	8
F, H50, W50	Avg	2	1	6	9
	StDev	20	19	18	20
F, H5, W95	Avg	8	12	14	16
	StDev	25	22	26	25
M, H95, W5	Avg	-1	-6	-3	-5
	StDev	5	5	9	9
M, H50, W50	Avg	-8	-4	-2	-2
	StDev	8	11	12	13
M, H95, W95	Avg	0	-1	8	8
	StDev	24	24	17	17

Table 130: Vertical Offset from HJC to J826 H-point in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	12	18
TM05	13	11
TM09	14	17
TM12	-12	-11
TM13	14	15
TM14	50	54
TM15	15	17
TM17	17	19
TM18	8	16
TM19	18	30
TM26	28	23
TM28	52	43
TM29	8	2
TM30	44	48

Table 131: Vertical Offset from HJC to J826 H-point in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	13	14	15	15	19	19	22	22
	StDev	9	7	6	6	10	10	9	9
F, H50, W50	Avg	17	13	20	18	23	25	27	27
	StDev	15	15	15	16	16	15	16	17
F, H5, W95	Avg	22	21	23	22	24	24	24	24
	StDev	20	21	19	20	23	22	22	23
M, H95, W5	Avg	8	4	11	7	15	13	17	16
	StDev	5	5	5	6	7	6	6	7
M, H50, W50	Avg	2	2	9	7	3	2	5	4
	StDev	12	13	12	14	18	18	19	19
M, H95, W95	Avg	8	7	11	10	14	14	18	17
	StDev	21	21	22	22	25	23	25	25

Table 132: Vertical Offset from HJC to J826 H-point in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	4	3	10	11	4	4	13	14
	StDev	6	6	5	6	6	5	6	8
F, H50, W50	Avg	9	9	21	16	10	11	19	15
	StDev	21	19	23	23	18	18	22	22
F, H5, W95	Avg	16	12	14	15	9	7	16	12
	StDev	26	28	27	27	30	29	24	29
M, H95, W5	Avg	5	3	19	16	-1	-1	12	10
	StDev	8	10	7	7	3	3	5	5
M, H50, W50	Avg	5	3	16	16	5	3	16	17
	StDev	14	14	13	13	16	14	15	13
M, H95, W95	Avg	6	5	15	15	5	6	14	13
	StDev	18	21	18	20	19	18	20	19

Table 133: Vertical Offset from HJC to J826 H-point in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	9	8	19	18	9	10	20	20
	StDev	4	4	6	6	8	8	10	9
F, H50, W50	Avg	10	17	28	29	18	18	31	31
	StDev	24	16	20	21	17	20	18	19
F, H5, W95	Avg	17	17	24	21	17	16	20	21
	StDev	24	24	19	22	26	26	25	26
M, H95, W5	Avg	14	10	26	22	5	4	16	15
	StDev	6	7	6	6	2	2	4	4
M, H50, W50	Avg	12	7	24	22	9	9	25	24
	StDev	12	13	11	12	14	15	16	13
M, H95, W95	Avg	15	14	24	24	14	10	22	20
	StDev	19	21	20	20	24	27	24	26

Table 134: Vertical Offset from HJC to J826 H-point in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	10	10	14	13	20	21	24	24
	StDev	7	7	6	6	3	4	3	4
F, H50, W50	Avg	22	21	26	24	32	34	37	37
	StDev	24	23	23	25	22	24	25	26
F, H5, W95	Avg	16	16	17	17	24	27	26	28
	StDev	20	21	19	21	22	25	25	25
M, H95, W5	Avg	16	12	22	17	20	20	26	24
	StDev	5	5	6	7	5	5	5	5
M, H50, W50	Avg	17	18	23	19	29	26	34	32
	StDev	15	16	13	14	17	19	18	18
M, H95, W95	Avg	16	15	17	14	25	24	27	23
	StDev	26	25	27	26	23	24	25	26

Table 135: HJC-RecBot X in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-157	-152	-152	-151
	StDev	7	7	11	11
F, H50, W50	Avg	-173	-165	-153	-156
	StDev	31	32	25	30
F, H5, W95	Avg	-219	-209	-210	-207
	StDev	12	13	17	18
M, H95, W5	Avg	-195	-187	-181	-178
	StDev	7	7	21	21
M, H50, W50	Avg	-204	-192	-182	-176
	StDev	31	30	22	22
M, H95, W95	Avg	-190	-187	-179	-176
	StDev	12	15	11	11

Table 136: HJC-RecBot X in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	-221	-238
TM05	-183	-195
TM09	-153	-172
TM12	-208	-252
TM13	-243	-242
TM14	-258	-266
TM15	-246	-248
TM17	-212	-231
TM18	-185	-219
TM19	-213	-248
TM26	-201	-193
TM28	-194	-226
TM29	-202	-216
TM30	-192	-227

Table 137: HJC-RecBot X in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-131	-129	-136	-134	-126	-124	-130	-131
	StDev	8	9	9	10	5	6	6	6
F, H50, W50	Avg	-140	-133	-148	-143	-135	-134	-142	-141
	StDev	19	17	21	19	20	26	26	27
F, H5, W95	Avg	-183	-178	-186	-184	-178	-175	-180	-179
	StDev	14	12	13	10	18	16	17	17
M, H95, W5	Avg	-165	-159	-171	-165	-157	-153	-162	-160
	StDev	15	13	13	10	7	7	7	6
M, H50, W50	Avg	-168	-163	-173	-172	-162	-162	-168	-169
	StDev	21	20	22	19	28	29	27	31
M, H95, W95	Avg	-168	-162	-170	-167	-156	-153	-161	-158
	StDev	3	3	5	6	7	9	6	8

Table 138: HJC-RecBot X in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-171	-169	-191	-190	-159	-159	-178	-182
	StDev	13	11	15	13	9	8	14	16
F, H50, W50	Avg	-173	-169	-208	-196	-158	-153	-187	-176
	StDev	35	34	35	33	29	28	30	23
F, H5, W95	Avg	-236	-228	-244	-241	-219	-218	-232	-226
	StDev	10	10	9	11	19	17	16	20
M, H95, W5	Avg	-192	-184	-216	-207	-179	-174	-204	-198
	StDev	13	15	9	11	13	14	10	12
M, H50, W50	Avg	-202	-194	-227	-227	-186	-182	-212	-212
	StDev	31	31	26	36	26	28	25	31
M, H95, W95	Avg	-187	-188	-205	-203	-177	-180	-195	-196
	StDev	21	16	23	17	15	7	16	11

Table 139: HJC-RecBot X in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-196	-190	-214	-215	-184	-182	-202	-202
	StDev	13	18	12	16	11	13	12	14
F, H50, W50	Avg	-204	-191	-232	-228	-194	-184	-224	-215
	StDev	43	30	37	44	31	35	33	35
F, H5, W95	Avg	-240	-234	-254	-249	-225	-222	-231	-230
	StDev	15	16	12	12	16	15	16	20
M, H95, W5	Avg	-219	-209	-241	-233	-202	-196	-221	-217
	StDev	14	15	12	14	9	9	6	6
M, H50, W50	Avg	-229	-215	-254	-248	-209	-208	-238	-233
	StDev	36	38	33	32	22	21	25	19
M, H95, W95	Avg	-199	-201	-222	-222	-187	-189	-205	-208
	StDev	19	16	24	18	15	13	12	8

Table 140: HJC-RecBot X in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-184	-179	-194	-191	-173	-170	-183	-182
	StDev	12	10	12	11	11	10	11	10
F, H50, W50	Avg	-191	-183	-201	-196	-173	-174	-192	-187
	StDev	32	31	26	27	28	36	34	36
F, H5, W95	Avg	-230	-223	-236	-229	-217	-217	-226	-224
	StDev	15	17	17	19	17	21	21	21
M, H95, W5	Avg	-217	-209	-228	-222	-212	-208	-223	-220
	StDev	12	10	11	10	4	4	5	4
M, H50, W50	Avg	-218	-213	-231	-232	-204	-197	-216	-212
	StDev	30	27	29	24	26	25	22	23
M, H95, W95	Avg	-220	-215	-230	-227	-208	-204	-221	-216
	StDev	7	7	7	8	7	8	7	9

Table 141: HJC-RecBot Z in mm for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	152	153	155	156
	StDev	5	4	10	8
F, H50, W50	Avg	161	160	161	163
	StDev	20	19	18	20
F, H5, W95	Avg	167	171	169	171
	StDev	25	22	26	25
M, H95, W5	Avg	158	153	151	150
	StDev	5	5	9	9
M, H50, W50	Avg	151	155	152	152
	StDev	8	11	12	13
M, H95, W95	Avg	159	158	162	162
	StDev	24	24	17	17

Table 142: HJC-RecBot Z in mm for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	133	139
TM05	135	132
TM09	135	138
TM12	109	110
TM13	136	136
TM14	171	175
TM15	137	138
TM17	138	140
TM18	130	137
TM19	140	151
TM26	150	145
TM28	173	164
TM29	130	123
TM30	166	169

Table 143: HJC-RecBot Z in mm for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	149	148	150	149	151	152	154	154
	StDev	9	7	6	6	10	9	9	9
F, H50, W50	Avg	151	148	155	152	155	157	159	159
	StDev	15	15	15	16	16	15	16	17
F, H5, W95	Avg	157	156	158	156	156	156	156	156
	StDev	20	21	19	20	23	22	22	23
M, H95, W5	Avg	143	139	146	142	146	145	149	148
	StDev	5	5	5	6	7	6	6	7
M, H50, W50	Avg	137	137	144	142	135	134	137	136
	StDev	12	13	12	14	18	18	19	19
M, H95, W95	Avg	142	142	146	145	146	146	150	149
	StDev	21	21	22	22	25	23	25	25

Table 144: HJC-RecBot Z in mm for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	125	124	132	132	126	126	135	137
	StDev	6	6	5	6	6	5	6	8
F, H50, W50	Avg	138	138	151	147	139	140	150	148
	StDev	15	13	16	13	13	12	14	13
F, H5, W95	Avg	137	133	136	136	131	129	138	134
	StDev	26	28	27	27	30	29	24	29
M, H95, W5	Avg	125	123	138	135	121	120	132	130
	StDev	9	12	7	7	4	3	2	2
M, H50, W50	Avg	126	124	137	137	127	125	138	139
	StDev	14	14	13	13	16	14	15	13
M, H95, W95	Avg	127	126	137	136	127	128	136	135
	StDev	18	21	18	20	19	18	20	19

Table 145: HJC-RecBot Z in mm for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	131	131	141	140	131	131	141	141
	StDev	5	6	8	8	8	7	8	7
F, H50, W50	Avg	136	144	156	157	146	148	160	160
	StDev	26	10	16	15	13	13	15	13
F, H5, W95	Avg	138	138	145	142	139	139	142	143
	StDev	24	24	19	22	26	26	25	26
M, H95, W5	Avg	135	131	145	143	126	126	136	135
	StDev	7	9	7	7	2	2	2	1
M, H50, W50	Avg	133	128	145	144	132	131	147	146
	StDev	12	13	11	12	14	15	16	13
M, H95, W95	Avg	136	135	145	145	136	132	144	142
	StDev	19	21	20	20	24	27	24	26

Table 146: HJC-RecBot Z in mm for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	149	150	153	152	151	152	155	155
	StDev	7	7	6	6	3	4	3	4
F, H50, W50	Avg	161	161	165	163	163	165	168	169
	StDev	24	23	23	25	22	24	25	26
F, H5, W95	Avg	156	155	156	156	155	158	158	159
	StDev	20	21	19	21	22	25	25	25
M, H95, W5	Avg	155	152	161	156	151	151	157	155
	StDev	5	5	6	7	5	5	5	5
M, H50, W50	Avg	157	157	163	159	161	157	165	164
	StDev	15	16	13	14	17	19	18	18
M, H95, W95	Avg	156	155	157	154	156	155	158	154
	StDev	26	25	27	26	23	24	25	26

Table 147: Knee angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	94	110	91	102
	StDev	6	6	5	7
F, H50, W50	Avg	97	112	96	109
	StDev	5	8	5	5
F, H5, W95	Avg	95	109	88	102
	StDev	9	4	8	4
M, H95, W5	Avg	91	106	90	97
	StDev	6	5	6	5
M, H50, W50	Avg	93	107	93	104
	StDev	7	6	4	2
M, H95, W95	Avg	100	111	99	106
	StDev	3	3	4	6

Table 148: Knee angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	102	103
TM05	115	96
TM09	128	127
TM12	100	89
TM13	116	115
TM14	121	115
TM15	105	105
TM17	108	103
TM18	110	101
TM19	112	103
TM26	105	101
TM28	124	112
TM29	122	115
TM30	120	108

Table 149: Knee angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	89	102	87	103	85	99	86	98
	StDev	6	8	6	8	4	5	4	6
F, H50, W50	Avg	96	107	94	107	95	104	94	103
	StDev	8	5	9	6	7	4	5	4
F, H5, W95	Avg	89	105	90	106	88	102	88	101
	StDev	14	12	11	11	9	7	8	6
M, H95, W5	Avg	90	104	90	104	89	100	88	100
	StDev	5	3	6	2	6	1	5	1
M, H50, W50	Avg	89	103	90	101	86	98	85	98
	StDev	7	6	6	6	5	6	8	6
M, H95, W95	Avg	97	105	96	105	96	103	96	102
	StDev	8	6	8	6	6	4	6	4

Table 150: Knee angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	93	105	90	103	90	103	90	101
	StDev	8	6	4	7	6	5	5	6
F, H50, W50	Avg	98	112	92	110	95	83	91	106
	StDev	6	10	6	10	5	50	5	8
F, H5, W95	Avg	96	110	92	106	91	103	91	104
	StDev	10	12	14	11	10	9	11	9
M, H95, W5	Avg	92	109	90	106	91	102	87	101
	StDev	4	4	4	3	2	3	5	3
M, H50, W50	Avg	98	111	95	108	96	107	92	106
	StDev	7	5	6	4	6	5	8	4
M, H95, W95	Avg	103	113	103	112	101	106	99	104
	StDev	6	4	5	5	5	4	5	4

Table 151: Knee angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	91	107	90	105	90	103	92	101
	StDev	8	9	7	8	5	8	6	7
F, H50, W50	Avg	96	113	94	108	98	111	93	108
	StDev	9	11	7	12	5	6	6	9
F, H5, W95	Avg	93	107	91	104	91	105	93	105
	StDev	12	11	14	11	8	7	7	7
M, H95, W5	Avg	88	106	88	102	91	103	87	99
	StDev	4	2	2	1	4	4	6	4
M, H50, W50	Avg	97	111	91	108	97	108	93	105
	StDev	9	8	7	4	5	6	7	5
M, H95, W95	Avg	102	110	101	107	100	104	96	102
	StDev	4	4	5	7	4	5	4	6

Table 152: Knee angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	91	107	92	103	88	102	87	101
	StDev	7	6	5	7	7	6	7	6
F, H50, W50	Avg	96	112	97	110	98	109	96	110
	StDev	9	10	11	11	8	6	5	7
F, H5, W95	Avg	93	107	92	107	90	104	91	104
	StDev	9	9	8	9	9	8	10	8
M, H95, W5	Avg	92	106	91	105	90	101	89	100
	StDev	4	1	3	3	7	4	6	5
M, H50, W50	Avg	89	102	89	99	91	102	90	101
	StDev	9	5	7	7	7	5	5	5
M, H95, W95	Avg	98	108	98	107	97	104	95	102
	StDev	6	6	6	7	6	5	7	7

Table 153: Knee splay angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	17	15	28	25
	StDev	3	2	3	3
F, H50, W50	Avg	18	15	27	24
	StDev	3	2	3	2
F, H5, W95	Avg	21	17	31	26
	StDev	3	2	2	1
M, H95, W5	Avg	22	22	29	27
	StDev	3	4	3	3
M, H50, W50	Avg	21	24	29	26
	StDev	3	5	2	3
M, H95, W95	Avg	19	20	24	24
	StDev	3	3	3	2

Table 154: Knee splay angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	**Standard**
TM04	19	20
TM05	16	26
TM09	15	15
TM12	15	16
TM13	19	19
TM14	19	20
TM15	18	18
TM17	22	23
TM18	29	27
TM19	27	26
TM26	25	25
TM28	24	25
TM29	22	26
TM30	21	24

Table 155: Knee splay angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	22	19	23	19	33	28	33	29
	StDev	3	2	4	2	2	2	2	2
F, H50, W50	Avg	20	17	20	17	30	26	30	26
	StDev	3	2	4	2	3	1	3	2
F, H5, W95	Avg	23	18	23	18	33	27	33	27
	StDev	3	1	2	1	4	2	4	2
M, H95, W5	Avg	24	24	24	25	29	27	30	27
	StDev	5	5	4	4	3	3	2	2
M, H50, W50	Avg	23	21	22	23	30	27	31	27
	StDev	5	4	2	4	1	2	2	2
M, H95, W95	Avg	20	22	21	23	25	25	26	25
	StDev	4	2	4	3	5	4	5	4

Table 156: Knee splay angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	22	18	21	19	31	27	33	29
	StDev	4	2	2	2	2	2	2	2
F, H50, W50	Avg	18	16	21	17	28	20	31	26
	StDev	3	3	4	2	3	10	4	3
F, H5, W95	Avg	21	17	22	18	32	26	33	27
	StDev	1	2	1	2	2	2	4	2
M, H95, W5	Avg	23	23	25	23	28	26	30	27
	StDev	4	4	3	4	4	4	4	3
M, H50, W50	Avg	21	23	22	23	30	26	31	28
	StDev	3	4	3	3	2	2	3	3
M, H95, W95	Avg	19	22	20	22	24	24	25	25
	StDev	5	4	4	3	3	3	4	3

Table 157: Knee splay angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	22	19	24	20	30	26	31	28
	StDev	5	4	6	4	4	4	4	4
F, H50, W50	Avg	19	17	21	18	28	25	31	27
	StDev	3	2	4	3	3	2	4	3
F, H5, W95	Avg	22	18	23	18	33	27	32	27
	StDev	1	2	2	1	2	2	3	2
M, H95, W5	Avg	23	23	24	24	28	26	31	27
	StDev	5	5	3	4	4	3	3	3
M, H50, W50	Avg	23	22	24	25	29	27	32	29
	StDev	3	4	3	4	2	3	4	3
M, H95, W95	Avg	20	23	21	24	25	25	26	26
	StDev	6	3	4	2	4	4	4	4

Table 158: Knee splay angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	21	18	21	19	32	28	34	28
	StDev	3	3	2	2	3	2	3	2
F, H50, W50	Avg	19	16	20	17	29	25	30	26
	StDev	3	2	3	2	3	2	3	2
F, H5, W95	Avg	21	18	22	19	33	27	33	27
	StDev	1	1	3	1	1	2	2	2
M, H95, W5	Avg	24	24	25	24	29	27	30	27
	StDev	5	4	4	4	3	2	3	2
M, H50, W50	Avg	22	23	22	23	31	27	30	28
	StDev	3	4	4	4	3	3	2	3
M, H95, W95	Avg	21	23	22	23	26	26	27	26
	StDev	5	3	6	4	5	4	5	4

Table 159: Shoe angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	53	---	44
	StDev	---	2	---	7
F, H50, W50	Avg	---	52	---	44
	StDev	---	7	---	4
F, H5, W95	Avg	---	52	---	44
	StDev	---	7	---	6
M, H95, W5	Avg	---	49	---	46
	StDev	---	8	---	11
M, H50, W50	Avg	---	48	---	41
	StDev	---	4	---	5
M, H95, W95	Avg	---	52	---	48
	StDev	---	7	---	7

Table 160: Shoe angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	50	47
TM05	47	49
TM09	58	54
TM12	44	39
TM13	67	66
TM14	53	43
TM15	42	45
TM17	36	38
TM18	65	59
TM19	46	49
TM26	46	41
TM28	43	47
TM29	58	59
TM30	61	56

Table 161: Shoe angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	46	---	36	---	38	---	38
	StDev	---	8	---	19	---	9	---	8
F, H50, W50	Avg	---	49	---	51	---	40	---	42
	StDev	---	3	---	5	---	3	---	3
F, H5, W95	Avg	---	50	---	51	---	42	---	42
	StDev	---	7	---	8	---	6	---	7
M, H95, W5	Avg	---	42	---	43	---	40	---	41
	StDev	---	8	---	10	---	8	---	9
M, H50, W50	Avg	---	45	---	44	---	38	---	39
	StDev	---	4	---	5	---	6	---	6
M, H95, W95	Avg	---	50	---	51	---	47	---	46
	StDev	---	5	---	5	---	6	---	6

Table 162: Shoe angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	50	---	49	---	42	---	42
	StDev	---	4	---	4	---	6	---	5
F, H50, W50	Avg	---	48	---	48	---	34	---	45
	StDev	---	3	---	2	---	20	---	4
F, H5, W95	Avg	---	51	---	49	---	43	---	44
	StDev	---	10	---	10	---	7	---	7
M, H95, W5	Avg	---	47	---	49	---	40	---	40
	StDev	---	12	---	9	---	11	---	11
M, H50, W50	Avg	---	47	---	46	---	41	---	41
	StDev	---	4	---	7	---	7	---	6
M, H95, W95	Avg	---	52	---	52	---	46	---	46
	StDev	---	6	---	6	---	6	---	4

Table 163: Shoe angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	48	---	50	---	43	---	42
	StDev	---	5	---	5	---	6	---	6
F, H50, W50	Avg	---	49	---	49	---	44	---	44
	StDev	---	5	---	5	---	2	---	4
F, H5, W95	Avg	---	49	---	47	---	44	---	44
	StDev	---	11	---	10	---	6	---	8
M, H95, W5	Avg	---	48	---	48	---	41	---	41
	StDev	---	9	---	9	---	10	---	10
M, H50, W50	Avg	---	48	---	49	---	41	---	41
	StDev	---	5	---	6	---	5	---	5
M, H95, W95	Avg	---	49	---	50	---	46	---	46
	StDev	---	6	---	7	---	7	---	5

Table 164: Shoe angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	52	---	49	---	44	---	43
	StDev	---	4	---	5	---	6	---	6
F, H50, W50	Avg	---	49	---	48	---	44	---	45
	StDev	---	4	---	5	---	4	---	5
F, H5, W95	Avg	---	53	---	51	---	43	---	43
	StDev	---	8	---	9	---	7	---	7
M, H95, W5	Avg	---	46	---	46	---	41	---	42
	StDev	---	11	---	12	---	9	---	9
M, H50, W50	Avg	---	45	---	40	---	41	---	41
	StDev	---	5	---	17	---	4	---	4
M, H95, W95	Avg	---	55	---	53	---	48	---	46
	StDev	---	8	---	7	---	6	---	5

Table 165: Elbow angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	93	---	89
	StDev	---	17	---	13
F, H50, W50	Avg	---	106	---	106
	StDev	---	16	---	13
F, H5, W95	Avg	---	101	---	91
	StDev	---	8	---	9
M, H95, W5	Avg	---	136	---	131
	StDev	---	12	---	16
M, H50, W50	Avg	---	119	---	116
	StDev	---	10	---	14
M, H95, W95	Avg	---	129	---	121
	StDev	---	21	---	16

Table 166: Elbow angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	94	73
TM05	108	85
TM09	126	126
TM12	110	113
TM13	116	117
TM14	108	111
TM15	104	98
TM17	134	133
TM18	131	29
TM19	140	133
TM26	118	122
TM28	110	110
TM29	119	124
TM30	153	154

Table 167: Elbow angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	95	---	98	---	92	---	94
	StDev	---	15	---	14	---	7	---	6
F, H50, W50	Avg	---	108	---	108	---	106	---	108
	StDev	---	16	---	12	---	10	---	10
F, H5, W95	Avg	---	107	---	109	---	100	---	100
	StDev	---	8	---	11	---	9	---	10
M, H95, W5	Avg	---	141	---	142	---	139	---	139
	StDev	---	9	---	7	---	10	---	8
M, H50, W50	Avg	---	117	---	120	---	113	---	111
	StDev	---	16	---	15	---	13	---	11
M, H95, W95	Avg	---	128	---	128	---	121	---	122
	StDev	---	18	---	16	---	20	---	21

Table 168: Elbow angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	85	---	88	---	84	---	87
	StDev	---	18	---	17	---	16	---	14
F, H50, W50	Avg	---	111	---	106	---	89	---	104
	StDev	---	19	---	19	---	41	---	15
F, H5, W95	Avg	---	98	---	98	---	95	---	98
	StDev	---	9	---	8	---	10	---	7
M, H95, W5	Avg	---	131	---	134	---	129	---	128
	StDev	---	8	---	8	---	9	---	11
M, H50, W50	Avg	---	120	---	120	---	117	---	119
	StDev	---	15	---	12	---	14	---	14
M, H95, W95	Avg	---	124	---	125	---	119	---	119
	StDev	---	17	---	19	---	18	---	21

Table 169: Elbow angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	86	---	88	---	85	---	85
	StDev	---	16	---	16	---	11	---	13
F, H50, W50	Avg	---	103	---	108	---	101	---	107
	StDev	---	15	---	14	---	13	---	14
F, H5, W95	Avg	---	104	---	108	---	105	---	108
	StDev	---	13	---	8	---	13	---	10
M, H95, W5	Avg	---	130	---	132	---	128	---	126
	StDev	---	4	---	4	---	4	---	4
M, H50, W50	Avg	---	116	---	122	---	113	---	117
	StDev	---	12	---	16	---	6	---	7
M, H95, W95	Avg	---	122	---	122	---	116	---	117
	StDev	---	19	---	20	---	19	---	20

Table 170: Elbow angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	86	---	86	---	84	---	87
	StDev	---	14	---	14	---	9	---	8
F, H50, W50	Avg	---	109	---	111	---	108	---	106
	StDev	---	18	---	20	---	16	---	15
F, H5, W95	Avg	---	101	---	99	---	98	---	96
	StDev	---	13	---	15	---	14	---	12
M, H95, W5	Avg	---	137	---	136	---	132	---	132
	StDev	---	11	---	9	---	15	---	15
M, H50, W50	Avg	---	114	---	119	---	110	---	112
	StDev	---	15	---	17	---	13	---	12
M, H95, W95	Avg	---	121	---	113	---	118	---	107
	StDev	---	20	---	16	---	23	---	11

Table 171: Arm splay angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	---	16	---	16
	StDev	---	5	---	5
F, H50, W50	Avg	---	19	---	21
	StDev	---	7	---	5
F, H5, W95	Avg	---	30	---	31
	StDev	---	4	---	4
M, H95, W5	Avg	---	35	---	30
	StDev	---	7	---	8
M, H50, W50	Avg	---	23	---	26
	StDev	---	7	---	7
M, H95, W95	Avg	---	35	---	32
	StDev	---	15	---	11

Table 172: Arm splay angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	**Standard**
TM04	18	13
TM05	20	18
TM09	27	26
TM12	39	43
TM13	34	31
TM14	33	34
TM15	59	33
TM17	36	35
TM18	42	35
TM19	35	35
TM26	45	38
TM28	26	23
TM29	22	26
TM30	53	51

Table 173: Arm splay angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	16	---	14	---	16	---	16
	StDev	---	3	---	8	---	4	---	4
F, H50, W50	Avg	---	21	---	19	---	20	---	21
	StDev	---	9	---	5	---	3	---	4
F, H5, W95	Avg	---	32	---	32	---	31	---	31
	StDev	---	4	---	4	---	4	---	3
M, H95, W5	Avg	---	31	---	30	---	33	---	33
	StDev	---	4	---	5	---	6	---	6
M, H50, W50	Avg	---	24	---	24	---	24	---	22
	StDev	---	8	---	8	---	6	---	6
M, H95, W95	Avg	---	34	---	32	---	30	---	30
	StDev	---	9	---	9	---	11	---	11

Table 174: Arm splay angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	16	---	17	---	17	---	17
	StDev	---	4	---	6	---	5	---	4
F, H50, W50	Avg	---	22	---	21	---	18	---	21
	StDev	---	6	---	6	---	9	---	5
F, H5, W95	Avg	---	30	---	31	---	32	---	33
	StDev	---	5	---	6	---	7	---	5
M, H95, W5	Avg	---	33	---	35	---	32	---	32
	StDev	---	7	---	8	---	6	---	8
M, H50, W50	Avg	---	26	---	25	---	26	---	26
	StDev	---	9	---	6	---	6	---	7
M, H95, W95	Avg	---	33	---	31	---	32	---	28
	StDev	---	10	---	12	---	9	---	11

Table 175: Arm splay angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	17	---	15	---	17	---	17
	StDev	---	6	---	3	---	5	---	3
F, H50, W50	Avg	---	21	---	21	---	19	---	22
	StDev	---	4	---	6	---	4	---	5
F, H5, W95	Avg	---	34	---	34	---	33	---	34
	StDev	---	6	---	5	---	6	---	5
M, H95, W5	Avg	---	34	---	33	---	31	---	31
	StDev	---	4	---	5	---	7	---	5
M, H50, W50	Avg	---	25	---	26	---	23	---	25
	StDev	---	9	---	10	---	4	---	5
M, H95, W95	Avg	---	32	---	31	---	28	---	29
	StDev	---	13	---	13	---	11	---	8

Table 176: Arm splay angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	---	18	---	16	---	16	---	18
	StDev	---	7	---	6	---	5	---	8
F, H50, W50	Avg	---	19	---	21	---	21	---	22
	StDev	---	4	---	5	---	6	---	4
F, H5, W95	Avg	---	31	---	32	---	31	---	31
	StDev	---	6	---	6	---	6	---	6
M, H95, W5	Avg	---	34	---	32	---	32	---	31
	StDev	---	7	---	9	---	8	---	5
M, H50, W50	Avg	---	23	---	27	---	23	---	22
	StDev	---	6	---	12	---	7	---	5
M, H95, W95	Avg	---	32	---	27	---	31	---	24
	StDev	---	12	---	9	---	15	---	5

Table 177: Body recline angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	17	15	15	15
	StDev	5	6	4	5
F, H50, W50	Avg	17	17	18	17
	StDev	4	3	3	2
F, H5, W95	Avg	18	19	19	18
	StDev	2	2	2	3
M, H95, W5	Avg	16	15	17	17
	StDev	2	2	2	1
M, H50, W50	Avg	18	19	19	19
	StDev	5	2	5	4
M, H95, W95	Avg	15	14	14	12
	StDev	8	6	7	4

Table 178: Body recline angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	21	21
TM05	23	26
TM09	22	20
TM12	18	21
TM13	21	21
TM14	17	19
TM15	21	20
TM17	14	17
TM18	19	22
TM19	15	17
TM26	15	22
TM28	8	10
TM29	12	16
TM30	22	21

Table 179: Body recline angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	21	21	23	22	21	21	23	22
	StDev	4	4	4	4	3	3	3	3
F, H50, W50	Avg	21	20	22	22	21	21	23	23
	StDev	3	2	2	1	2	1	2	1
F, H5, W95	Avg	24	23	25	24	24	24	23	24
	StDev	6	2	6	3	3	3	4	4
M, H95, W5	Avg	21	20	22	21	21	21	22	21
	StDev	2	2	2	2	3	3	3	2
M, H50, W50	Avg	20	20	23	22	22	21	24	23
	StDev	6	4	5	4	6	4	6	4
M, H95, W95	Avg	19	17	20	19	19	17	21	18
	StDev	5	4	5	4	4	4	4	4

Table 180: Body recline angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	15	14	21	19	16	16	21	20
	StDev	6	6	5	5	5	6	4	5
F, H50, W50	Avg	16	16	20	18	16	15	21	19
	StDev	5	4	5	4	5	4	4	3
F, H5, W95	Avg	17	16	17	18	17	16	20	19
	StDev	3	3	3	3	3	2	4	3
M, H95, W5	Avg	13	13	16	17	14	14	18	17
	StDev	1	2	1	3	2	2	2	3
M, H50, W50	Avg	18	16	21	20	18	16	21	20
	StDev	6	4	4	6	5	5	5	5
M, H95, W95	Avg	15	12	18	14	16	13	19	15
	StDev	10	8	9	7	9	7	8	7

Table 181: Body recline angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	14	13	18	17	16	15	20	18
	StDev	6	7	6	7	4	5	3	6
F, H50, W50	Avg	15	13	20	19	15	15	20	19
	StDev	5	4	3	3	5	4	3	3
F, H5, W95	Avg	18	18	21	22	19	19	22	22
	StDev	3	2	5	4	3	4	7	7
M, H95, W5	Avg	15	15	18	19	14	13	17	17
	StDev	3	2	2	3	3	3	3	3
M, H50, W50	Avg	16	17	22	20	16	15	23	21
	StDev	4	3	5	3	4	2	5	3
M, H95, W95	Avg	16	13	18	16	17	14	21	17
	StDev	9	7	8	6	7	6	7	6

Table 182: Body recline angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	16	15	17	16	17	15	18	17
	StDev	4	5	4	5	4	4	4	4
F, H50, W50	Avg	19	18	20	20	20	20	21	21
	StDev	3	3	3	2	2	2	2	1
F, H5, W95	Avg	20	20	19	19	21	20	20	20
	StDev	5	5	5	5	4	3	4	4
M, H95, W5	Avg	19	17	21	19	18	18	20	19
	StDev	2	2	3	2	2	2	2	2
M, H50, W50	Avg	19	20	22	22	20	18	21	20
	StDev	3	2	3	3	4	4	3	3
M, H95, W95	Avg	18	15	19	14	18	16	19	14
	StDev	7	5	7	4	6	5	7	4

Table 183: Openness angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	214	217	220	221
	StDev	5	4	5	4
F, H50, W50	Avg	212	217	221	221
	StDev	10	10	8	7
F, H5, W95	Avg	233	239	239	243
	StDev	13	13	13	13
M, H95, W5	Avg	191	195	200	200
	StDev	7	6	7	7
M, H50, W50	Avg	207	214	217	219
	StDev	7	7	6	6
M, H95, W95	Avg	206	209	212	212
	StDev	9	7	7	4

Table 184: Openness angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	**Standard**
TM04	228	223
TM05	224	225
TM09	233	227
TM12	261	251
TM13	230	230
TM14	242	244
TM15	237	237
TM17	210	207
TM18	203	199
TM19	200	194
TM26	207	213
TM28	213	210
TM29	214	213
TM30	226	217

Table 185: Openness angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	218	220	221	223	225	226	229	228
	StDev	5	5	6	4	3	4	3	3
F, H50, W50	Avg	217	218	218	221	225	223	226	225
	StDev	10	10	11	9	8	8	8	7
F, H5, W95	Avg	237	242	238	242	243	245	244	247
	StDev	16	14	15	13	12	13	14	11
M, H95, W5	Avg	198	199	200	201	205	205	207	208
	StDev	7	5	7	5	5	5	8	6
M, H50, W50	Avg	209	214	213	217	217	220	220	221
	StDev	8	7	7	5	8	6	9	6
M, H95, W95	Avg	210	211	211	213	216	213	219	216
	StDev	8	7	7	7	7	7	8	8

Table 186: Openness angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	213	214	220	222	220	221	230	229
	StDev	7	6	6	8	6	5	5	6
F, H50, W50	Avg	208	212	213	216	215	216	222	223
	StDev	8	8	7	7	7	5	6	6
F, H5, W95	Avg	231	237	233	237	239	238	238	243
	StDev	10	11	10	8	11	12	14	11
M, H95, W5	Avg	190	191	194	196	197	197	201	201
	StDev	4	5	7	3	4	2	6	7
M, H50, W50	Avg	208	211	212	216	216	215	220	222
	StDev	6	6	5	7	6	6	5	7
M, H95, W95	Avg	205	205	208	206	211	208	213	211
	StDev	8	5	8	4	8	4	7	3

Table 187: Openness angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	212	215	220	222	219	221	228	228
	StDev	6	5	7	4	7	5	5	4
F, H50, W50	Avg	206	212	214	217	210	216	221	224
	StDev	12	7	7	7	15	7	7	6
F, H5, W95	Avg	234	238	233	241	242	245	245	247
	StDev	10	10	12	8	11	10	11	10
M, H95, W5	Avg	193	197	197	200	198	204	201	203
	StDev	5	6	4	6	4	9	5	6
M, H50, W50	Avg	208	213	213	219	214	217	223	224
	StDev	6	6	5	6	5	4	5	5
M, H95, W95	Avg	209	209	210	211	214	212	218	215
	StDev	8	7	9	7	8	6	8	8

Table 188: Openness angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	214	217	218	219	222	223	227	227
	StDev	4	4	4	3	4	5	3	4
F, H50, W50	Avg	214	217	217	220	224	224	224	226
	StDev	10	9	8	8	8	8	8	8
F, H5, W95	Avg	235	240	236	241	245	244	243	246
	StDev	10	11	10	13	14	12	10	10
M, H95, W5	Avg	199	198	203	203	203	205	206	207
	StDev	7	3	8	6	4	8	6	6
M, H50, W50	Avg	208	214	212	217	218	219	220	223
	StDev	5	4	4	6	5	6	5	6
M, H95, W95	Avg	210	211	210	210	215	213	216	213
	StDev	9	9	10	8	8	8	11	8

Table 189: Pelvis angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	83	87	91	92
	StDev	3	2	2	1
F, H50, W50	Avg	83	87	91	92
	StDev	3	5	3	4
F, H5, W95	Avg	94	99	102	103
	StDev	4	5	3	4
M, H95, W5	Avg	74	78	82	83
	StDev	3	2	3	3
M, H50, W50	Avg	76	80	86	87
	StDev	5	6	4	4
M, H95, W95	Avg	81	85	88	89
	StDev	3	4	3	4

Table 190: Pelvis angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	91	85
TM05	92	89
TM09	100	96
TM12	102	91
TM13	107	106
TM14	101	99
TM15	101	102
TM17	85	83
TM18	86	79
TM19	87	80
TM26	87	85
TM28	92	85
TM29	90	85
TM30	97	92

Table 191: Pelvis angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	84	86	85	87	92	93	93	94
	StDev	1	2	1	2	2	2	2	2
F, H50, W50	Avg	84	86	84	86	92	91	92	92
	StDev	4	3	4	5	3	4	4	4
F, H5, W95	Avg	94	97	95	98	102	103	103	103
	StDev	3	4	3	3	4	4	4	5
M, H95, W5	Avg	77	79	77	80	83	84	84	85
	StDev	2	2	2	2	1	2	2	1
M, H50, W50	Avg	77	80	77	80	84	85	84	85
	StDev	5	5	5	5	4	5	5	5
M, H95, W95	Avg	81	84	82	85	88	89	89	89
	StDev	2	3	2	3	4	4	4	4

Table 192: Pelvis angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	85	87	86	89	92	94	95	96
	StDev	4	2	3	3	2	2	2	2
F, H50, W50	Avg	84	87	85	89	91	92	93	95
	StDev	5	6	3	6	4	4	3	2
F, H5, W95	Avg	97	99	95	97	101	102	102	103
	StDev	4	6	6	7	4	5	5	5
M, H95, W5	Avg	78	81	78	81	84	85	84	85
	StDev	2	1	2	2	1	1	1	1
M, H50, W50	Avg	79	84	80	84	87	88	88	90
	StDev	4	4	5	5	5	4	5	4
M, H95, W95	Avg	82	86	84	86	88	89	89	89
	StDev	2	2	2	2	2	2	3	3

Table 193: Pelvis angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	85	89	88	90	92	93	95	95
	StDev	3	3	4	4	3	2	3	2
F, H50, W50	Avg	82	89	85	88	92	94	93	95
	StDev	8	5	3	6	4	5	4	4
F, H5, W95	Avg	96	98	95	97	103	104	104	104
	StDev	5	7	6	7	4	5	5	6
M, H95, W5	Avg	77	81	78	81	84	85	84	84
	StDev	3	2	2	2	2	2	1	1
M, H50, W50	Avg	81	84	80	86	88	89	89	90
	StDev	5	4	4	3	3	3	4	3
M, H95, W95	Avg	83	86	84	86	89	89	89	90
	StDev	2	3	2	3	3	3	3	4

Table 194: Pelvis angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	85	89	86	89	93	95	95	96
	StDev	2	1	2	2	1	2	2	1
F, H50, W50	Avg	84	87	85	88	93	93	92	94
	StDev	5	6	4	5	3	4	3	4
F, H5, W95	Avg	95	99	96	100	104	104	104	105
	StDev	5	6	5	6	5	5	5	5
M, H95, W5	Avg	78	81	79	82	84	85	84	85
	StDev	3	2	3	2	1	2	2	2
M, H50, W50	Avg	77	80	78	80	86	88	86	88
	StDev	6	4	5	4	5	4	4	3
M, H95, W95	Avg	83	86	82	85	88	90	87	89
	StDev	3	5	2	3	3	4	2	3

Table 195: Thorax angle in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	41	39	39	39
	StDev	5	5	6	5
F, H50, W50	Avg	39	40	40	39
	StDev	9	8	8	7
F, H5, W95	Avg	48	50	47	50
	StDev	14	13	13	12
M, H95, W5	Avg	27	27	27	27
	StDev	5	5	4	5
M, H50, W50	Avg	41	43	41	42
	StDev	6	5	6	7
M, H95, W95	Avg	36	35	34	33
	StDev	8	5	8	5

Table 196: Thorax angle in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	47	48
TM05	42	46
TM09	44	41
TM12	69	70
TM13	33	34
TM14	51	55
TM15	46	45
TM17	35	34
TM18	27	30
TM19	23	24
TM26	31	39
TM28	31	34
TM29	34	38
TM30	39	36

Table 197: Thorax angle in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	43	43	46	46	43	43	46	45
	StDev	4	5	5	3	4	5	3	4
F, H50, W50	Avg	43	42	44	45	43	42	44	44
	StDev	7	8	8	6	8	7	8	6
F, H5, W95	Avg	52	53	53	55	50	53	51	54
	StDev	15	14	15	14	14	14	15	13
M, H95, W5	Avg	32	29	33	32	31	32	33	34
	StDev	5	4	5	4	5	5	7	5
M, H50, W50	Avg	43	44	46	47	44	45	46	46
	StDev	8	6	6	5	8	6	9	7
M, H95, W95	Avg	39	37	39	38	38	35	40	37
	StDev	7	6	7	6	5	4	6	6

Table 198: Thorax angle in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	38	37	44	43	38	38	45	43
	StDev	6	6	6	6	7	5	5	6
F, H50, W50	Avg	37	37	40	39	36	35	41	40
	StDev	7	6	7	7	8	6	7	7
F, H5, W95	Avg	44	47	48	50	45	47	46	50
	StDev	12	16	14	14	14	13	15	13
M, H95, W5	Avg	24	22	27	25	24	24	28	27
	StDev	4	6	5	4	4	4	6	6
M, H50, W50	Avg	38	38	42	43	40	38	42	43
	StDev	6	7	6	8	6	8	7	8
M, H95, W95	Avg	32	29	34	31	33	30	35	33
	StDev	9	5	8	5	8	4	6	3

Table 199: Thorax angle in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	37	36	43	42	37	38	43	43
	StDev	7	7	5	5	6	5	5	4
F, H50, W50	Avg	37	36	41	41	36	35	42	41
	StDev	9	8	7	6	8	9	7	7
F, H5, W95	Avg	47	50	50	54	49	51	52	53
	StDev	13	13	17	14	13	13	14	14
M, H95, W5	Avg	27	26	31	30	25	28	28	29
	StDev	4	4	5	4	4	7	4	5
M, H50, W50	Avg	37	40	43	43	36	38	43	44
	StDev	4	6	4	5	5	5	5	6
M, H95, W95	Avg	36	33	36	35	35	34	39	36
	StDev	8	6	8	5	7	5	6	5

Table 200: Thorax angle in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	39	38	42	41	39	38	42	42
	StDev	5	4	4	4	4	5	3	4
F, H50, W50	Avg	40	40	43	42	41	41	42	42
	StDev	6	7	6	5	7	7	7	7
F, H5, W95	Avg	49	51	50	51	51	50	49	51
	StDev	13	12	12	13	14	14	12	12
M, H95, W5	Avg	31	28	34	32	29	31	32	31
	StDev	4	3	7	6	3	7	5	6
M, H50, W50	Avg	41	44	44	47	42	42	44	45
	StDev	4	5	4	5	5	6	4	6
M, H95, W95	Avg	37	35	38	35	37	34	38	34
	StDev	7	6	9	6	6	5	9	6

Table 201: Total lumbar curvature in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-5	3	4	7
	StDev	6	11	9	12
F, H50, W50	Avg	-12	-9	-4	-4
	StDev	6	8	5	7
F, H5, W95	Avg	-1	5	5	8
	StDev	8	7	8	8
M, H95, W5	Avg	-9	-4	0	2
	StDev	9	7	9	9
M, H50, W50	Avg	-10	-9	-2	-1
	StDev	6	10	7	9
M, H95, W95	Avg	-4	0	3	5
	StDev	8	7	8	8

Table 202: Total lumbar curvature in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	7	-1
TM05	5	6
TM09	7	2
TM12	-9	-21
TM13	9	11
TM14	3	5
TM15	9	8
TM17	0	7
TM18	11	3
TM19	3	-10
TM26	1	-8
TM28	4	4
TM29	8	10
TM30	28	1

Table 203: Total lumbar curvature in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	3	5	5	7	10	12	13	13
	StDev	10	11	12	12	12	11	11	11
F, H50, W50	Avg	-10	-7	-9	-6	0	-1	-1	0
	StDev	6	7	6	6	5	6	6	7
F, H5, W95	Avg	2	4	3	7	8	11	9	12
	StDev	12	10	11	10	10	10	11	10
M, H95, W5	Avg	-6	-1	-4	1	4	5	5	7
	StDev	8	8	9	7	7	7	9	6
M, H50, W50	Avg	-8	-6	-9	-5	-3	0	-1	2
	StDev	5	7	7	7	7	7	6	6
M, H95, W95	Avg	-2	-1	-1	1	6	4	8	6
	StDev	8	9	8	7	8	8	9	9

Table 204: Total lumbar curvature in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-5	-2	0	2	3	3	10	10
	StDev	9	10	10	10	8	7	8	8
F, H50, W50	Avg	-15	-12	-11	-8	-8	-6	-3	0
	StDev	8	10	6	7	6	7	6	4
F, H5, W95	Avg	-5	-3	-7	-3	-2	-2	3	1
	StDev	10	16	16	17	11	12	10	14
M, H95, W5	Avg	-8	-3	-6	-4	-2	0	1	3
	StDev	8	6	9	4	8	7	8	7
M, H50, W50	Avg	-14	-8	-9	-6	-7	-3	-1	1
	StDev	9	11	10	11	12	12	12	11
M, H95, W95	Avg	-6	-3	-3	-2	1	1	3	3
	StDev	6	6	6	6	7	6	6	6

Table 205: Total lumbar curvature in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-4	0	3	5	3	5	10	12
	StDev	10	10	12	12	7	7	8	8
F, H50, W50	Avg	-15	-10	-9	-6	-5	-5	-2	1
	StDev	14	10	5	8	7	9	7	8
F, H5, W95	Avg	-1	2	3	4	5	7	10	11
	StDev	11	11	11	15	12	10	15	14
M, H95, W5	Avg	-8	-2	-4	0	3	3	2	4
	StDev	8	8	8	7	6	9	9	7
M, H50, W50	Avg	-10	-3	-4	-1	-3	2	3	4
	StDev	7	7	8	9	10	8	10	10
M, H95, W95	Avg	-1	0	-1	0	4	4	6	6
	StDev	9	7	8	7	8	8	6	8

Table 206: Total lumbar curvature in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-1	3	3	5	7	8	11	13
	StDev	10	11	10	11	11	10	9	11
F, H50, W50	Avg	-11	-7	-8	-5	0	0	0	1
	StDev	8	7	5	8	5	6	5	7
F, H5, W95	Avg	0	5	1	5	11	10	9	12
	StDev	11	10	10	8	11	10	10	10
M, H95, W5	Avg	-4	0	-2	3	2	7	5	8
	StDev	9	7	8	7	6	9	7	7
M, H50, W50	Avg	-9	-7	-8	-3	-3	0	0	3
	StDev	6	8	9	8	9	7	8	8
M, H95, W95	Avg	0	0	0	0	5	5	6	4
	StDev	10	9	11	9	8	9	11	11

Table 207: TSLA in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	7	7	6	6
	StDev	10	8	7	10
F, H50, W50	Avg	5	5	5	4
	StDev	4	3	5	5
F, H5, W95	Avg	2	4	1	3
	StDev	6	6	5	6
M, H95, W5	Avg	8	9	8	9
	StDev	2	2	3	2
M, H50, W50	Avg	6	4	5	4
	StDev	5	3	6	6
M, H95, W95	Avg	4	3	3	3
	StDev	8	6	9	8

Table 208: TSLA in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	16	15
TM05	4	9
TM09	0	-1
TM12	6	5
TM13	4	5
TM14	-6	-3
TM15	6	5
TM17	4	7
TM18	10	11
TM19	8	10
TM26	-2	3
TM28	0	3
TM29	6	8
TM30	9	6

Table 209: TSLA in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	9	9	10	10	8	9	10	10
	StDev	6	6	6	7	5	7	7	6
F, H50, W50	Avg	7	6	8	9	9	8	8	8
	StDev	4	5	4	5	5	6	5	6
F, H5, W95	Avg	5	5	6	7	4	6	4	7
	StDev	7	7	8	8	6	6	7	7
M, H95, W5	Avg	9	10	10	11	10	11	12	12
	StDev	3	2	3	2	4	4	4	4
M, H50, W50	Avg	5	7	7	8	6	8	8	8
	StDev	8	6	5	5	5	6	7	6
M, H95, W95	Avg	5	3	6	5	5	3	7	4
	StDev	6	7	7	6	6	6	7	6

Table 210: TSLA in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	1	1	4	4	1	0	5	5
	StDev	5	6	4	5	6	6	5	5
F, H50, W50	Avg	0	1	4	3	0	1	4	4
	StDev	3	4	3	4	4	4	4	6
F, H5, W95	Avg	-5	-5	-4	-3	-6	-6	-4	-3
	StDev	1	2	3	4	2	2	3	2
M, H95, W5	Avg	4	5	6	5	4	4	6	7
	StDev	2	3	2	3	1	1	1	2
M, H50, W50	Avg	-1	0	4	2	0	1	4	3
	StDev	5	6	6	6	5	5	6	4
M, H95, W95	Avg	-1	-1	1	0	1	0	2	1
	StDev	9	6	8	5	8	6	6	5

Table 211: TSLA in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	1	2	6	5	1	2	6	7
	StDev	7	8	5	7	6	8	5	7
F, H50, W50	Avg	1	1	5	6	1	1	5	5
	StDev	4	6	4	6	4	3	4	4
F, H5, W95	Avg	0	2	3	5	0	1	5	6
	StDev	3	3	5	5	5	5	10	10
M, H95, W5	Avg	5	7	8	9	6	7	7	8
	StDev	3	3	3	3	2	3	2	3
M, H50, W50	Avg	1	4	6	6	1	3	6	6
	StDev	5	6	6	5	4	5	6	4
M, H95, W95	Avg	3	2	3	2	3	3	5	4
	StDev	9	7	8	7	9	7	7	7

Table 212: TSLA in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	5	5	8	7	4	4	7	8
	StDev	6	7	8	7	6	6	7	7
F, H50, W50	Avg	6	6	8	7	7	8	8	7
	StDev	5	5	5	5	6	5	6	6
F, H5, W95	Avg	2	4	3	5	3	4	3	5
	StDev	7	7	7	9	7	6	7	7
M, H95, W5	Avg	9	9	10	12	9	12	11	12
	StDev	3	3	4	4	2	4	3	3
M, H50, W50	Avg	4	7	7	9	5	5	6	7
	StDev	6	4	6	5	5	6	5	5
M, H95, W95	Avg	5	3	4	1	4	3	5	1
	StDev	8	8	9	7	7	7	10	7

Table 213: LSLA in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	27	21	27	23
	StDev	13	11	9	12
F, H50, W50	Avg	34	33	33	34
	StDev	11	9	9	8
F, H5, W95	Avg	47	47	49	48
	StDev	14	13	15	15
M, H95, W5	Avg	31	27	38	34
	StDev	10	12	10	10
M, H50, W50	Avg	41	44	48	45
	StDev	13	14	10	13
M, H95, W95	Avg	33	27	33	24
	StDev	14	13	10	10

Table 214: LSLA in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	28	34
TM05	47	48
TM09	39	37
TM12	31	36
TM13	42	41
TM14	64	65
TM15	41	44
TM17	33	37
TM18	49	55
TM19	29	33
TM26	39	46
TM28	40	42
TM29	20	28
TM30	40	44

Table 215: LSLA in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	38	37	39	38	39	35	39	39
	StDev	7	6	7	5	4	8	6	7
F, H50, W50	Avg	40	38	42	40	40	40	44	42
	StDev	4	5	6	5	7	8	7	8
F, H5, W95	Avg	59	57	59	57	58	56	57	56
	StDev	13	13	12	12	11	11	10	11
M, H95, W5	Avg	46	41	46	42	48	45	47	45
	StDev	9	8	7	7	6	7	7	10
M, H50, W50	Avg	47	44	50	47	50	47	52	51
	StDev	10	10	7	9	9	11	9	10
M, H95, W95	Avg	44	43	45	42	47	43	48	44
	StDev	11	11	7	8	12	10	10	10

Table 216: LSLA in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	37	33	40	39	40	37	45	41
	StDev	9	10	10	11	9	10	9	12
F, H50, W50	Avg	37	36	40	36	38	36	42	37
	StDev	12	10	10	8	11	12	8	4
F, H5, W95	Avg	52	52	50	48	52	49	54	46
	StDev	18	16	14	14	15	15	13	14
M, H95, W5	Avg	34	29	40	44	40	39	46	44
	StDev	8	11	10	14	11	11	11	16
M, H50, W50	Avg	50	50	52	50	52	50	55	53
	StDev	9	10	8	12	8	9	10	13
M, H95, W95	Avg	43	32	47	38	44	36	48	40
	StDev	16	14	14	13	14	13	13	12

Table 217: LSLA in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	30	28	36	35	36	32	40	35
	StDev	7	10	8	9	7	8	7	9
F, H50, W50	Avg	33	29	38	35	32	33	39	37
	StDev	12	6	6	11	15	13	8	8
F, H5, W95	Avg	47	46	51	49	51	50	53	53
	StDev	15	15	12	12	15	14	17	17
M, H95, W5	Avg	35	32	43	41	34	23	40	39
	StDev	12	14	10	11	15	15	17	20
M, H50, W50	Avg	46	44	54	48	46	45	56	51
	StDev	14	13	13	13	12	13	13	10
M, H95, W95	Avg	35	30	43	37	41	34	47	39
	StDev	14	12	10	9	13	14	12	13

Table 218: LSLA in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	30	26	28	27	29	31	31	24
	StDev	11	11	12	11	10	10	11	7
F, H50, W50	Avg	38	36	37	37	39	38	41	39
	StDev	9	9	7	8	5	7	5	6
F, H5, W95	Avg	50	48	48	45	50	50	51	49
	StDev	12	13	12	13	12	14	14	15
M, H95, W5	Avg	42	38	44	37	40	31	41	34
	StDev	8	9	7	8	11	13	10	11
M, H50, W50	Avg	47	44	49	48	47	44	51	47
	StDev	16	16	16	15	14	14	15	12
M, H95, W95	Avg	42	39	45	38	45	39	45	37
	StDev	16	15	15	15	15	11	15	14

Table 219: PLA in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	48	44	40	39
	StDev	4	5	5	6
F, H50, W50	Avg	51	47	43	42
	StDev	6	6	5	5
F, H5, W95	Avg	35	31	28	26
	StDev	3	4	3	4
M, H95, W5	Avg	51	46	42	42
	StDev	5	4	5	5
M, H50, W50	Avg	49	48	40	39
	StDev	3	6	5	5
M, H95, W95	Avg	47	43	40	38
	StDev	2	3	3	5

Table 220: PLA in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	39	45
TM05	35	38
TM09	40	44
TM12	26	37
TM13	24	25
TM14	33	35
TM15	27	26
TM17	35	37
TM18	39	46
TM19	39	46
TM26	44	46
TM28	34	41
TM29	34	39
TM30	36	42

Table 221: PLA in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	47	45	46	44	39	38	38	38
	StDev	6	6	5	7	6	7	6	7
F, H50, W50	Avg	51	48	51	48	41	43	43	42
	StDev	8	6	7	7	5	6	6	5
F, H5, W95	Avg	35	33	35	32	27	27	26	26
	StDev	2	3	2	1	3	4	3	4
M, H95, W5	Avg	49	45	48	45	41	41	41	40
	StDev	5	4	5	4	4	5	5	4
M, H50, W50	Avg	48	46	49	46	42	41	42	40
	StDev	5	6	4	5	4	4	4	4
M, H95, W95	Avg	47	44	46	44	39	39	39	38
	StDev	3	2	3	2	2	2	2	2

Table 222: PLA in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
F, H5, W5	Avg	46	44	45	42	39	38	36	35
	StDev	2	4	3	3	4	5	3	4
F, H50, W50	Avg	53	49	52	47	46	44	43	41
	StDev	3	5	3	4	4	4	3	1
F, H5, W95	Avg	33	31	34	32	28	27	27	26
	StDev	4	6	5	6	3	3	3	3
M, H95, W5	Avg	47	42	46	43	40	38	40	38
	StDev	5	4	5	4	3	4	4	4
M, H50, W50	Avg	46	42	46	42	40	37	38	36
	StDev	3	6	4	6	4	5	4	5
M, H95, W95	Avg	45	42	44	41	39	38	39	38
	StDev	4	3	4	3	2	3	2	3

Table 223: PLA in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	46	43	44	41	39	38	37	36
	StDev	4	5	4	5	6	6	5	6
F, H50, W50	Avg	55	48	51	49	44	43	45	41
	StDev	8	3	3	5	4	4	8	3
F, H5, W95	Avg	33	32	34	32	26	25	26	25
	StDev	4	6	5	6	3	4	4	5
M, H95, W5	Avg	47	43	46	43	39	38	40	39
	StDev	6	4	5	4	4	5	4	4
M, H50, W50	Avg	45	41	46	40	38	36	37	36
	StDev	3	6	4	5	4	6	4	5
M, H95, W95	Avg	44	41	44	42	38	38	38	38
	StDev	2	3	3	3	2	3	1	2

Table 224: PLA in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	46	43	45	43	38	37	36	36
	StDev	5	5	4	6	6	7	6	6
F, H50, W50	Avg	51	47	50	47	41	41	42	40
	StDev	7	6	6	6	6	5	6	5
F, H5, W95	Avg	34	31	34	30	25	25	25	25
	StDev	4	5	4	5	4	4	4	4
M, H95, W5	Avg	47	44	47	43	41	40	40	39
	StDev	6	5	5	5	4	4	5	4
M, H50, W50	Avg	48	47	48	45	41	38	39	37
	StDev	4	4	5	4	5	5	5	4
M, H95, W95	Avg	45	42	44	42	39	37	39	38
	StDev	1	1	2	2	2	2	2	3

Table 225: Head tilt in degrees for seat A (Tan LH).

		Sedan		Van	
		Lumbar Off		Lumbar Off	
		Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	1	-1	0	1
	StDev	11	5	11	10
F, H50, W50	Avg	-3	-4	-4	-3
	StDev	4	8	9	9
F, H5, W95	Avg	0	0	4	1
	StDev	7	11	10	10
M, H95, W5	Avg	1	0	-2	0
	StDev	7	9	8	10
M, H50, W50	Avg	7	4	5	4
	StDev	8	5	9	7
M, H95, W95	Avg	1	0	6	-2
	StDev	11	6	10	7

Table 226: Head tilt in degrees for extra BMW.

	Sedan	
	Lumbar On	
	Driver	
	Extra	Standard
TM04	-11	-22
TM05	-7	-5
TM09	-18	-16
TM12	-4	-1
TM13	4	-2
TM14	15	8
TM15	11	6
TM17	-3	0
TM18	3	-2
TM19	-20	-11
TM26	3	-4
TM28	4	2
TM29	6	0
TM30	-2	13

Table 227: Head tilt in degrees for seat B (Town & Country).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-2	0	-2	-3	-4	-6	-5	-3
	StDev	7	11	10	8	8	10	9	10
F, H50, W50	Avg	-3	-4	-3	-4	-4	-4	-4	-4
	StDev	4	8	4	8	8	8	8	8
F, H5, W95	Avg	0	0	0	0	0	0	0	0
	StDev	7	11	7	11	11	11	11	11
M, H95, W5	Avg	1	0	1	0	0	0	0	0
	StDev	7	9	7	9	9	9	9	9
M, H50, W50	Avg	7	4	7	4	4	4	4	4
	StDev	8	5	8	5	5	5	5	5
M, H95, W95	Avg	1	0	1	0	0	0	0	0
	StDev	11	6	11	6	6	6	6	6

Table 228: Head tilt in degrees for seat C-F (BMW, thorax support fully forward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-4	-3	-2	-2	-5	-4	-5	-3
	StDev	6	10	9	6	6	8	6	10
F, H50, W50	Avg	-4	-4	-4	-4	-4	-4	-4	-4
	StDev	9	9	9	9	9	9	9	9
F, H5, W95	Avg	0	0	0	0	0	0	0	0
	StDev	11	11	11	11	11	11	11	11
M, H95, W5	Avg	-2	-2	-2	-2	-2	-2	-2	-2
	StDev	7	7	7	7	7	7	7	7
M, H50, W50	Avg	4	4	4	4	4	4	4	4
	StDev	5	5	5	5	5	5	5	5
M, H95, W95	Avg	0	0	0	0	0	0	0	0
	StDev	6	6	6	6	6	6	6	6

Table 229: Head tilt in degrees for seat C-R (BMW, thorax support fully rearward).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	-5	-4	-5	-5	0	-2	-3	-1
	StDev	10	10	10	13	13	8	7	9
F, H50, W50	Avg	-4	-4	-4	-4	-4	-4	-4	-4
	StDev	9	9	9	9	9	9	9	9
F, H5, W95	Avg	0	0	0	0	0	0	0	0
	StDev	11	11	11	11	11	11	11	11
M, H95, W5	Avg	-2	-2	-2	-2	-2	-2	-2	-2
	StDev	7	7	7	7	7	7	7	7
M, H50, W50	Avg	4	4	4	4	4	4	4	4
	StDev	5	5	5	5	5	5	5	5
M, H95, W95	Avg	0	0	0	0	0	0	0	0
	StDev	6	6	6	6	6	6	6	6

Table 230: Head tilt in degrees for seat D (Gray LH).

		Sedan				Van			
		Lumbar Off		Lumbar On		Lumbar Off		Lumbar On	
		Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver
F, H5, W5	Avg	1	0	-2	0	-2	1	-2	-3
	StDev	10	7	9	13	9	10	10	8
F, H50, W50	Avg	-4	-4	-4	-4	-4	-4	-4	-4
	StDev	8	8	8	8	8	8	8	8
F, H5, W95	Avg	0	0	0	0	0	0	0	0
	StDev	11	11	11	11	11	11	11	11
M, H95, W5	Avg	0	0	0	0	0	0	0	0
	StDev	9	9	9	9	9	9	9	9
M, H50, W50	Avg	4	4	4	4	4	4	4	4
	StDev	5	5	5	5	5	5	5	5
M, H95, W95	Avg	0	0	0	0	0	0	0	0
	StDev	6	6	6	6	6	6	6	6

REFERENCES

1) Andersson, B. J. G., Ortengren, R., Nachemson, A., Elfstrom, G., "Lumbar Disc Pressure and Myoelectric Back Muscle Activity During Sitting; IV. Studies on a Car Driver's Seat," Scandinavian Journal of Rehabilitation Medicine, Vol. 6, pp. 128-133, 1974.

2) Andersson, G. B. J., Ortengren, R., Nachemson, A., "Intradiskal Pressure, Intra-abdominal Pressure and Myoelectric Back Muscle Activity Related to Posture and Loading," *Clinical Orthopaedics and Related Research*, No 129, pp. 156-164, 1977.

3) Lateral aspect of the ankle. [Online Image] Available http://www.bartleby.com/107/illus441.html, August 24, 2000. Reprinted with permission.

4) ASPECT manual – program documentation, 1999.

5) ASPECT Interim Report, Task 1: Foundational Activities.

6) Bell, A. L., Pederson, D. R., Brand, R. A., "A Comparison of Several Hip Center Location Prediction Models," *Journal of Biomechanics*, Vol. 23, No. 6, pp. 617-621, 1990.

7) Bogard, H., "Additional Methods to Characterize Lumbar Supports Using the ASPECT Manikin," Thesis for the Bachelor of Science Degree, Michigan State University, 2000.

8) Bony Framework of the Thorax, Anterior View [Online Image] Available http://www.britannica.com/bcom/eb/article/single_image/0,5716,1383+bin%5Fid,00.html , August 14, 2000.

9) Boughner, R. L., "A Model of Average Adult Male Human Skeletal and Leg Muscle Geometry and Hamstring Length for Automotive Seat Designers," Thesis for the Master of Science Degree, Michigan State University, 1991.

10) Brodeur, R. R., Cui, Y., Reynolds, H. M., "Locating the Pelvis in the Seated Automobile Driver," *Society of Automotive Engineers Technical Paper*, No. 960481, 1996.

11) Bush, N. J., "Two-Dimensional Drafting Template and Three-Dimensional Computer Model Representing the Average Adult Male in Automotive Seated Postures," Thesis for the Master of Science Degree, Michigan State University, 1992.

12)Bush, T. R., Gregg, S. J., Hubbard, R. P., "Measuring and Modeling Support Forces of People to Assist in the Development of the ASPECT Manikin Weighting," *Society of Automotive Engineers Technical Paper*, No. 990961, 1999.

13)Bush, T. R., Hubbard, R., Reinecke, S., "An Evaluation of Postural Motions, chair Motions, and Contact in Four Office Seats," *Human Factors and Ergonomics Society*, 1999.

14)Bush, T. R., "Posture and Force Measures of Mid-Sized Men in Seated Positions," Thesis for Doctoral Degree, Michigan State University, 2000.

15)Bush, T. R., Gutowski, P. E., Hubbard, R. "Alternative Method for Estimationing Hip Joint Center," Submitted for publication.

16)Calais-Germain, B., Anatomy of Movement, Eastland Press, Seattle, pp.2-245, 1993.

17)Chaffin, D. B., Andersson, G. B., Occupational Biomechanics, John Wiley & Sons, New York, NY, 1991.

18)Clement, C. D., Anatomy: A Regional Atlas of the Human Body, Urban & Schwarzenberg, Baltimore, 1981.

19)Cohen, D., "An Objective Measure of Seat Comfort," *Aviation, Space, and Environmental Medicine*, Vol. 69, No. 4, pp. 410-414, 1998.

20)Corlett, E. N., "Pain, Posture and Performance," Stress, Work Design, and Productivity, John Wiley & Sons Ltd., New York, pp. 27-42, 1981.

21)Drummond, D. S., Narechania, R. G., Rosenthal, A. N., Breed, A. L., Lange, T. A., Drummond, D. K., "A Study of Pressure Distributions Measured During Balanced and Unbalanced Sitting," Journal of Bone and Joint Surgery, Vol. 64-A, No. 7, pp.1034-1039, 1982.

22)Dwyer, A. P., "Backache and its Prevention," *Clinical Orthopaedics and Related Research*, No. 222, pp. 35-43, 1987.

23)Ekern, D. F., "Two-Dimensional Kinetic Modeling of Human Posture in Automotive Seats," Thesis for the Master of Science Degree, Michigan State University, 1998.

24)Ekern, D. F., Gedraitis, C. J., Hubbard, R. P., Bush, N. J., "Kinetic Computer Modeling of Human Posture in Automotive Seats," *Society of Automotive Engineers Technical Paper*, No. 970592, 1997.

25) The elbow joint. [Online Image] Available http://www.bartleby.com/107/illus330.html, August 24, 2000. Reprinted with permission.

26) The femur. [Online Image] Available http://www.bartleby.com/107/illus252.html, August 24, 2000. Reprinted with permission.

27) Flannagan, C. A. C., Manary, M. A., Schneider, L. W., Reed, M. P., "An Improved Seating Accommodation Model with Application to Different User Populations," *Society of Automotive Engineers Technical Paper*, No. 980651, 1998.

28) Frost, B. L., III, "A Three-Dimensional Computer Model of Human Back Contours for Automotive Seat Design," Thesis for the Master of Science Degree, Michigan State University, 1999.

29) Gedraitis, M. S., "Experimental Determination of a Spinal Linkage Model for the Seated Human Torso," Thesis for the Master of Science Degree, Michigan State University, 1997.

30) Gregg, S. J., "Weighting of ASPECT Manikin Determined by Two-Dimensional Kinetic Modeling," Thesis for the Bachelor of Science Degree, Michigan State University, 1998.

31) Haas, W. A., "Geometric Model and Spinal Motions of the Average Male in Seated Postures," Thesis for the Master of Science Degree, Michigan State University, 1989.

32) Hosea, T. M., Simon, S. R., Delatizky, J., Wong, M. A., Hsieh, C.C., "Myoelectric Analysis of the Paraspinal Musculature in Relation to Automobile Driving," *Spine*, Vol. 11, No. 9, pp. 928-936, 1986.

33) Hubbard, R. P., "Seat with Biomechanical Articulation," U.S Patent #5,597,203, January 28, 1997.

34) Hubbard, R., Gedraitis, M., Bush, T., "Simulation of Torso Posture and Motion in Seating," *Society of Automotive Engineers Technical Paper*, No. 981304, 1998.

35) Hubbard, R., C. Gedraitis, "Initial Measurements and Interpretations of Seat Factors for the ASPECT Program," *Society of Automotive Engineers Technical Paper*, No. 1999-01-0958, 1999.

36)Hubbard, R. P., Haas, W. A., Boughner, R. L., Canole, R. A., Bush, N. J., "New Biomechanical Models for Automobile Seat Design," *Society of Automotive Engineers Technical Paper*, No. 930110, 1993.

37)Hubbard, R., Gedraitis, C., "Biomechanically Articulated Chair Concept and Prototypes," *Society of Automotive Engineers Technical Paper*, No. 970591, 1997.

38)Hubbard, R. P., Bush, T. R., Work Plan for Research and Development of JOHN Modules in RAMSIS, 1997.

39)Hur, Y. S., Park, S. J., "Evaluation of Comfort Properties with Covering Textiles of Car Seats," *Society of Automotive Engineers Technical Paper*, No. 980654. 1998.

40)Jack [Online] Available http://www.transom.com/products/jack-, September 6, 2000.

41)J826 manual – Society of Automotive Engineers Technical Standard, July 1995.

42)Image of JOHN model in seat, courtesy of Johnson Controls, Inc.

43)Kayis, B., Hoang, K., "Static Three-Dimensional Modeling of Prolonged Seated Posture," *Applied Ergonomics*, Vol. 30, pp. 255-262, 1999.

44)Kelsey, J. L., Hardy, R. J., "Driving of Motor Vehicles as a Risk Factor for Acute Herniated Lumbar intervertebral Disc," *American Journal of Epidemiology*, Vol. 102, No. 1, pp. 63-73, 1975.

45)Kelsey, J. L., Githens, P. B., O-Conner, T., Weil, U., Calogero, J. A., Holford, T. R., White, A. A., Walter, S. D., Ostfeld, A. M., Southwick, W. O., "Acute Prolapsed Lumbar Intervertebral Disc: An Epidemiologic Study with Special Reference to Driving Automobiles and Cigarette Smoking," *Spine*, Vol. 9, No. 6, pp. 608-613, 1984.

46)Frontal view of the right knee joint. [Online Image] Available http://www.bartleby.com/107/illus347.html, August 24, 2000. Reprinted with permission.

47)Lueder, R. K., "Seat Comfort: A Review of the Construct in the Office Environment," *Human Factors*, Vol. 25, No. 6, pp. 701-711, 1983.

48)Lueder, R., Noro, K., Hard Facts About Soft Machines: The Ergonomics of Seating, Taylor & Francis, Bristol, PA, pp. 147-215, 1994.

49) Marchinda, D. M., Seidel, G. K., Dijkers, M., Soutas-Little, R. W., "Hip Joint Center Location from Palpable Bony Landmarks – A Cadaver Study," *Journal of Biomechanics*, Vol. 28, No. 8, pp. 995-998, 1995.

50) McNally, C., "Experimental Comparison of Amount of Lumbar Prominence to Seated Posture in Automobile Seats," Thesis for the Bachelor of Science Degree, Michigan State University, 1998.

51) MDHMS [Online] Available http://www.boeing.com/assocproducts/hms/back/, September 6, 2000.

52) "1988 Anthropometric Survey of U. S. Army Personnel: Summary Statistics Interim Report," United States Army Natick Research, Natick, Massachusetts, 01760-5000, AD-A209 600.

53) Park, S. J., Kim, C. B., "The Evaluation of Seating Comfort by Objective Measures," *Society of Automotive Engineers Technical Paper*, No. 970595, 1997.

54) Side view of the pelvis. [Online Image] Available http://www.bartleby.com/107/illus237.html, August 24, 2000. Reprinted with permission.

55) Qualisys User Manual CAB 1000, version 1.0, 1994.

56) RAMSIS, [Online] Available http://www.tecmath.de/html/english/index.html, September 6, 2000.

57) TecMath RContour program documentation, 1998.

58) Reed, M. P., Lee, N. S., Saito, M., Kakishima, Y., Schneider, L. W., "An Investigation of Driver Discomfort and related Seat Design Factors in extended-Duration Driving," *Society of Automotive Engineers Technical Paper*, No. 901171, 1991.

59) Reed, M. P., Schneider, L. W., Eby, B. A. H., "Some Effects of Lumbar Support Contour on Driver Selected Posture," *Society of Automotive Engineers Technical Paper*, No. 950141, 1995.

60) Reed, M. P., Schneider, L. W., "Lumbar Support in Auto Seats: Conclusions from a Study of Preferred Driving Posture," *Society of Automotive Engineers Technical Paper*, No. 960478, 1996.

61) Reynolds, H. M., Snow, C. C., Young, J. W., "Spatial Geometry of the Human Pelvis," AAC-119-81-5, 1981.

62) Side view of the ribcage. [Online Image] Available http://www.bartleby.com/107/illus114.html, August 24, 2000. Reprinted with permission.

63) Communication with Ron Roe of Anthrodynamics, May 30, 1999.

64) SAE Standard J826, "Devices for use in Defining and Measuring Vehicle Seating Accommodation," *Society of Automotive Engineers*, 1995.

65) Safework [Online] Available http://www.safework.com/saf-4Dnav/release.html, September 6, 2000.

66) Schneider, L. W., Anderson, C. K., Olson, P. L., "Driver Anthropometry and vehicle Design Characteristics Related to Seat Positions Selected Under Driving and Non-Driving Conditions," *Society of Automotive Engineers Technical Paper*, No. 790384, 1980.

67) Schneider, L. W., Robbins, D. H., Pflug, M. A., Snyder, R. G., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Volume 1," *U. S. Dept. of Transportation*, DOT-HS-806-715, 1985.

68) Schneider, L. W., Robbins, D. H., Pflug, M. A., Snyder, R. G., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Volume 2," *U. S. Dept. of Transportation*, DOT-HS-806-716, 1985.

69) Schneider, L. W., Robbins, D. H., Pflug, M. A., Snyder, R. G., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Volume 3," *U. S. Dept. of Transportation*, DOT-HS-806-717, 1985.

70) Seymour, M. B., "The Ergonomics of Seating – Posture and Chair Adjustment," *Nursing Times*, Vol. 91, No. 9, pp. 35-37, 1995.

71) Shen, W., Vertiz, A. M., "Redefining Seat Comfort," *Society of Automotive Engineers Technical Paper*, No. 970597, 1997.

72) SigmaStat Program Documentation, 1997.

73) The vertebral column. [Online Image] Available http://www.britannica.com/bcom/eb/article/single_image/0,5716,1378+bin%5Fid,00.html, August 14, 2000.

74) Wachsler, R. A., Learner, D. B., "An Analysis of Some Factors Influencing Seat Comfort," Ergonomics, Vol. 3, pp. 315-320, 1960.

75) White, A. A. III, Panjabi, M. M., Clinical Biomechanics of the Spine, J.B. Lippincott Co., Philadelphia, PA, pp. 44-84, 1978.

76) The wrist joint. [Online Image] Available http://www.bartleby.com/107/illus335.html, August 24, 2000. Reprinted with permission.

77) Zacharkow, D. Wheelchair Posture and Pressure Sores, C. C. Thomas, Springfield, IL, pp. 6-57, 1984.

78) Zacharkow, D. The Healthy Lower Back: Laying the Foundation Through Proper Lifting, Sitting and Exercise, C. C. Thomas, Springfield, IL, pp. 56, 1984.

79) Zacharkow, D., Posture: Sitting, Standing, Chair Design and Exercise, C. C. Thomas, Springfield, IL, pp. 74-202, 1988.