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Measurement of Older and Younger Drivers' Selected Seat Position within their Personal Vehicles to Influence Recommended Practices for Meeting Safety Needs of Drivers

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MEASUREMENT OF OLDER AND YOUNGER DRIVERS' SELECTED SEAT POSITION WITHIN THEIR PERSONAL VEHICLES TO INFLUENCE RECOMMENDED PRACTICES FOR MEETING SAFETY NEEDS OF DRIVERS

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ABSTRACT

The objective of this research was to measure and understand the preferred seat position and posture of older drivers and younger drivers within their personal vehicles to influence recommended practices for meeting the safety needs of all drivers.

Currently, the United States is experiencing an ageing population, whereby in 2020 nearly 40 million people over the age of 65 will be licensed drivers. In addition, crash reports show that older drivers are over represented in vehicle fatality statistics, once adjusted for vehicle miles traveled. The increased fatality rate of older drivers has been attributed to a combination of increased fragility of older drivers and their selected seat position. Educational programs, such as CarFit©, have been established to teach older drivers about safe seating guidelines in an effort to reduce the over representation of older drivers in crash statistics.

The research for this dissertation was conducted to collect data from older drivers over the age of 60 and younger drivers between the ages of 30 to 39. Data were collected within the driver's personal vehicle to obtain a natural and accurate driver selected seat position. Each driver was measured twice. The first set measures were obtained right after the driver's arrival to the study site in the seat position the driver had selected. The second set of measures were taken after each driver was educated on CarFit© safe seating guidelines.

The results of this dissertation show that the addition of an age term to the SAE J4004 recommended practice model for predicting driver selected seat position of any driver is a

statistically significant contribution to the model thereby, improving the fit of the model and the accuracy of the predicted seat position model. In addition, age was shown as predictor variable for the CarFit© line of sight above the steering wheel measure, whereby older drivers were 5 times more likely than younger drivers to meet the CarFit© guideline of a 76 mm (3 in) line of sight above the steering wheel. Last, stature was shown as a predictor variable for the likelihood of meeting the CarFit© criteria, where tall-statured individuals were less likely to meet the backset, top of head to ceiling, and top of leg to bottom of steering wheel measurements and more likely to meet the line of sight above the steering wheel measurement.

DEDICATION

I dedicate this to my loving wife Addie McConomy, my precious daughter Miriam, and my wonderful son William. Without their love and support, none of this would have been possible.

DISCLAIMER

This dissertation was part of a larger study titled "Comparing Driving Evaluations of Healthy Individuals to Those with Mild Cognitive Impairment or Lower Extremity Impairment" funded by the National Highway Traffic Safety Administration. This particular research explored driving behaviors of older drivers with different medical conditions.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof. If trade names, manufacturers' names, or specific products are mentioned, it is because they are considered essential to the object of the publication and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

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Last, this dissertation would not have been possible without National Highway Traffic Safety Administration, TransAnalytics, LLC., and Greenville Health System’s Roger C. Peace Rehabilitation Hospital generous contributions of equipment, funding, and facilities.

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TABLE OF CONTENTS

Page

Table of Contents (Continued)

Page

Table of Contents (Continued)

Table of Contents (Continued)

Page

Table of Contents (Continued)

LIST OF TABLES

Table Page

List of Tables (Continued)

Table Page

List of Tables (Continued)

Table Page

List of Tables (Continued)

Table Page

List of Tables (Continued)

Table Page

List of Tables (Continued)

Table Page

List of Tables (Continued)

Table Page

LIST OF FIGURES

List of Figures (Continued)

Figure Page

List of Figures (Continued)

Figure Page

List of Figures (Continued)

Figure | Page

List of Figures (Continued)

Figure Page

Figure Page

Figure Page

List of Figures (Continued)

Figure Page

List of Figures (Continued)

Figure Page

Figure Page

NOTATION

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled
Difference	Difference between the calculated and measured BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point

IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center
L7	Steering Wheel Torso Clearance
L11	Wheel Center to Heel Point
L17	H-point Travel
L53	H-point to Accelerator Heel Point
NASS	National Automotive Sampling System
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NHES	National Health Examination Survey
NHTSA	National Highway Traffic Safety Administration
NPTS	Nationwide Personal transportation Survey
OEM	Original Equipment Manufacturer
PA	Pan Angle
RC	Relative Contribution
RCP	Roger C. Peace Rehabilitation Hospital
SAE	Society of Automotive Engineers
SAE J4004	Calculated BOFRP to H-point as described in SAE J4004 recommended practice
SgRP	Seating Reference Point
SUV	Sport Utility Vehicle
SWR	Strength to Weight Ratio
US	United States
VIN	Vehicle Identification Number
W9	Steering Wheel Outside Diameter
WA	Steering Column Angle
WD	Steering Wheel Outside Diameter
WX	Wheel Center to Heel Point
WZ	Wheel Center to Heel Pont

CHAPTER ONE

INTRODUCTION

1.1 Objective

The objective of this research is to measure and understand the preferred seat position and posture[1] of older drivers and younger drivers within their personal vehicles to influence recommended practices for meeting the increased safety needs of drivers. It is important to note that the data collection for the older participants was funded by a larger NHTSA study titled *Comparing Driving Evaluations of Healthy Individuals to Those with Mild Cognitive Impairment or Lower Extremity Impairment* contract number DTNH22-07-D-00049.

The five major tasks to complete the objective of this dissertation are as follows:

- Compare the measured seat position of older drivers to the measured seat position of younger drivers to discern whether differences exist between the two groups.
- Compare the driver selected seat position of older and younger drivers to the theoretical values calculated from the Society of Automotive Engineers' recommended practices to assess the accuracy of their model.
- Compare posture measurements of older drivers' and younger drivers' selected seat positions to the recommended seating guidelines written in the CarFit© education program.

[1] For the purpose of this dissertation, measures of posture refer to dimensions that include the participant, such as measurement from the vehicle floor to the eye. These measurements are not to be mistaken as measurements that indicate good or bad posture or level of comfort.

- Propose improvements to SAE's recommended practices in order to accommodate the needs of the older driver.
- Quantify older drivers' and younger drivers' ability to demonstrate the seat adjustments available within their personal vehicle.

Each of these tasks is represented by a distinct hypothesis and explained in the gap analyses in Chapter Two.

1.2 Motivation and Background

General aging of the population in the United States (US) and other developed countries is occurring at unprecedented rates. With life expectancy at an all-time high of nearly 78 years (Centers for Disease Control and Prevention, 2007) and the first Baby Boomers turning 60 years of age in 2006, resulting in 16.8 million Baby Boomers turning 60 in 2010 (U.S. Census Bureau, 2014), the older population in the US is growing rapidly. As reported by the Administration of Aging (2010), the US has an aging population whereby in the year 2020, 22% of the US population will be over the age of 60; 16% of the population will be over the age of 65; and 2% of the population will be over the age of 85.

As a result of the aging Baby Boomer generation and the fact that individuals in general are living longer and healthier lives, we can expect many older drivers on US roadways over the next several decades. Census projections estimate that by 2020 nearly 40 million people over the age of 65 will be licensed drivers (U.S. Census Bureau, 2000). According to recent estimates, by the year 2030, 25% of drivers will be age 65 or older and will be relying on the private automobile to meet their daily mobility needs (Zegeer et al., 2010).

As physical and cognitive functions typically diminish with normal aging, older individuals may experience changes in their vision, cognition, and physical functioning that may have a direct effect on their ability to drive safely (American Automobile Association, 2006). According to the American Automobile Association (AAA), 90% of drivers age 65 and older suffer from various health issues that may impact their safety while driving (White, 2013). The decline in health issues related to vision, cognition, and physical functionality has been shown to correspond to an increased number of driving errors, thereby contributing the overrepresentation of older drivers in fatal crash statistics (Zegeer et al., 2010).

It is estimated that there are 20 decisions made each mile, and there is approximately half a second to avoid a crash (American Automobile Association, 2006). If there is a decline in the ability to respond to a possible crash situation, then the risk of crash will increase. "The 2002 study by Lyman, Ferguson, Braver, and Williams reported that drivers 65 and older account for more than one-half of the total increase in fatal crashes and approximately 40% of crash involvements" (as cited in Yoganandan, Pintar, Stemper, Gennarelli, & Weigelt, 2007, p. 228). As the mean age of the US population continues to increase, it is expected that the older population's crash involvement will also increase. In fact, by 2030 drivers over the age of 65 are expected to account for 25% of all fatal crashes, which is double the number of older drivers' fatal crashes in 2011 (Insurance

Institute for Highway Safety, 2001; National Highway Traffic Safety Administration, 2011c). There is a disproportionately higher rate of poor outcomes with older drivers, due in part to chest and head injuries (Bauzá, LaMorte, Burke, & Hirsch, 2008). The first and foremost explanation of the higher fatality rate for older drivers is that older drivers are more fragile than younger drivers (Li, Braver, & Chen, 2003). For example, as osteoporosis increases with age, resulting in a decreased fracture toughness of the bones, minor crashes with an older driver can result in severe upper extremity injuries, discussed further in section 1.9 (Wang, Kosinski, Schwartzberg, & Shanklin, 2003; Yoganandan et al., 2007).

The gradual onset of many medical and physical conditions, such as those described above, may adversely affect critical driving tasks (i.e., left turns, merges, lane changes etc.). Yet older adults are sometimes unaware of how the process of aging or disease can influence their abilities needed to drive, thereby affecting their safety (Eby & Molnar, 2009). An additional challenge of ensuring safe mobility is that a large majority of aging adult drivers have not received any formal training about safe operating procedures since the time of their initial licensure (Wang et al., 2003). The first drivers education class in the US was offered in 1934; however, drivers education did not have a nationwide impact on the public education system until 1965 (Peatman, 2011; Stack, 1966).

To help older drivers remain safely mobile and to decrease injuries and/or fatalities during a vehicle crash, an optimal position of the driver's seat should be used by the driver. This would allow drivers to gain the ideal position in their vehicle to maintain a clear view of the road and the vehicle's dashboard use of the full range of the pedals without over extension of their arms and legs, adequate reach within the interior, and space for the vehicle's safety equipment to function properly. Proper "fit" within a vehicle can enable older drivers to utilize their visual scanning ability, strength, and range of motion to their maximum potential.

1.3 Overview of the Research

The literature review that follows consists of section 1.4, which identifies older drivers in the United States (US) and explains why they are important to study. Section 1.5 provides a brief summary of the automotive seat history. The National Health and Nutrition Examination and Survey data with the relevant literature discussing the stature growth rate of the U.S. population is presented in section 1.6. Section 1.7 reviews the current recommended design practices and regulations written by the Society of Automotive Engineers (SAE). Next, the research that has contributed to the current state-of-the-art on driver selected seat position is reviewed in section 1.8. Section 1.9 highlights potential injury and fatalities that could result if the driver were to sit in an unsafe position. Section 1.10 discusses the CarFit© educational program that is used as a part of the research methods for the three studies presented in Chapters Three through Five.

The gap analyses with the research questions and the associated hypotheses are listed in Chapter Two. Chapter Three, a pilot study to identify older drivers' selected seat position within their own vehicle; Chapter Four, a study to capture drivers' selected seat position of younger adults; and Chapter Five, a study of drivers' selected seat position of older adults in a clinical setting, describe the methods used for this dissertation. Chapter Six provides an analysis of driver selected seat position. Chapter Seven presents improved driver selected seat position model. Chapter Eight presents an evaluation of CarFit© criteria compliance and the ability to demonstrate seat adjustments. Conclusions of the research and the future work are provided in Chapter Nine.

1.4 Older Drivers

As mentioned above, by the year 2020, 22% of the US population will be over the age of 60 (Administration of Aging, 2010). Within the US, this is known as the age wave and is attributed mostly to the Baby Boomer generation turning 60 years of age, and increased life expectancy. The Baby Boomer generation is the generation of people that were born in the post-World War II era (1946-1964). There were 76 million Baby Boomers born in the US, which resulted in an unprecedented average population growth of 1.7% per year for 19 years (Werner, 2011).

The population numbers for the Baby Boomers are substantial enough that, when plotted in comparison to the rest of the population, they represent the peak value in a histogram categorized by age. When this plot is displayed over multiple decades, the Baby Boomers appear to make a wave effect; whereby, with each decade the Baby Boomer's peak progress through the histogram. The age wave effect, coined by Ken Dychtwald (Dychtwald, 1990), can be seen in the area plots in Figure 1.

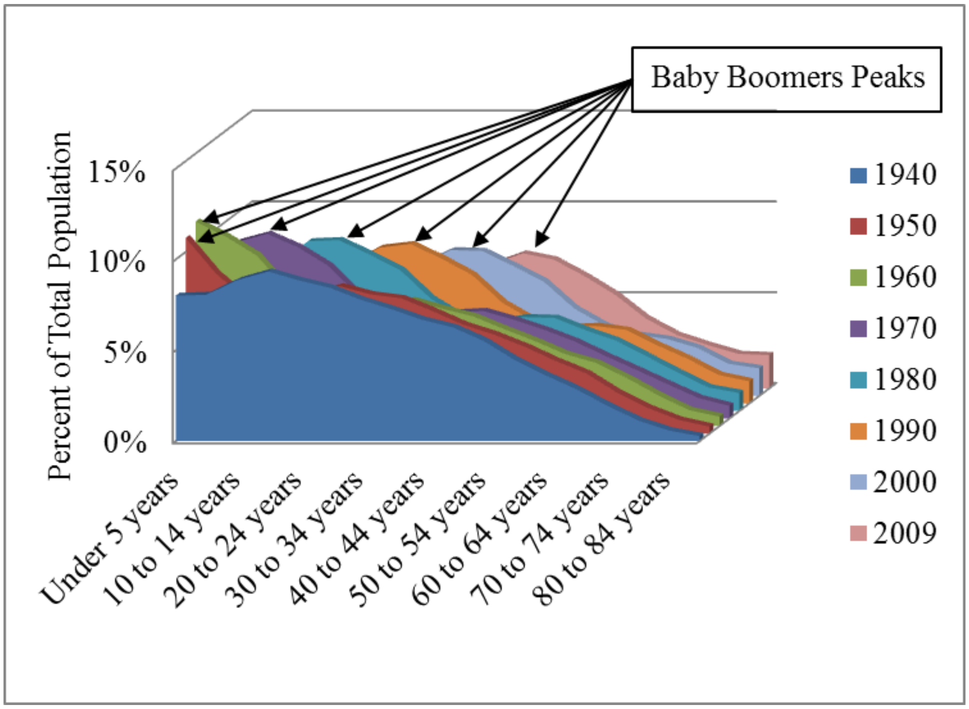

Figure 1. Age wave effect (U.S. Census Bureau, 1900 - 2012).

Similarly, as the population's mean age increases, the number of senior citizen drivers also continues to grow. Figure 2 shows the percentage of total population in comparison to the percentage of total licensed drivers that are over the age of 60. The trend in Figure 2 shows that not only is the 60 and over population growing as a whole, but also a larger percentage of older adults plan to maintain a driving license. It may be worth noting that it is unknown how many of the licensed individuals drive on a regular basis or if they simply maintain the license.

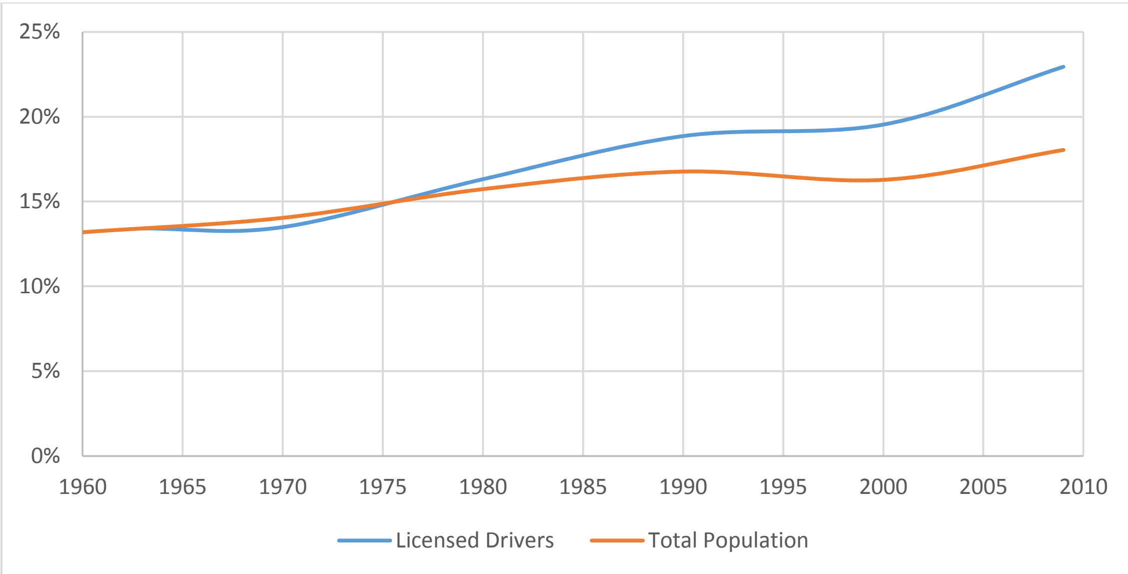

Figure 2. Percentage of licensed drivers and total population 60 and over (Federal Highway Administration, 2011; U.S. Census Bureau, 1900 - 2012).

The United States has become a mobile society, and driving is the preferred means of transportation. According to the Federal Transit Administration (2011), less than 4% of the US population use public transportation for their daily commutes. The lack of public transportation in the US requires older drivers to continue driving. In addition, driving may be the only means of transportation for those who live in rural and suburban parts of the country. Thus, many older adult drivers, who want to keep both a sense of independence and continued mobility, rely on the private automobile to carry out necessary activities of daily living: everyday chores, volunteer work, social and recreational activities, as well as commutes to work (Stutts, 1998).

Motor vehicle injuries are the second leading cause (after falls) of injury-related deaths for individuals 65 and older (Centers for Disease Control and Prevention, 2010). When compared to other drivers, older drivers show a significantly higher fatality rate per mile driven than all middle age drivers (ages 35 to 64) (Insurance Institute for Highway Safety, 2011; Wang et al., 2003). In 2011 the fatality rate for drivers 85 and older was on average 6.8 times higher than the rate for drivers 30 to 64 (Insurance Institute for Highway Safety, 2011). The Insurance Institute for Highway Safety (2011) reports that the frequency of a fatal accident for the senior citizen population is significantly higher than the majority of the younger population age brackets as seen in Figure 3.

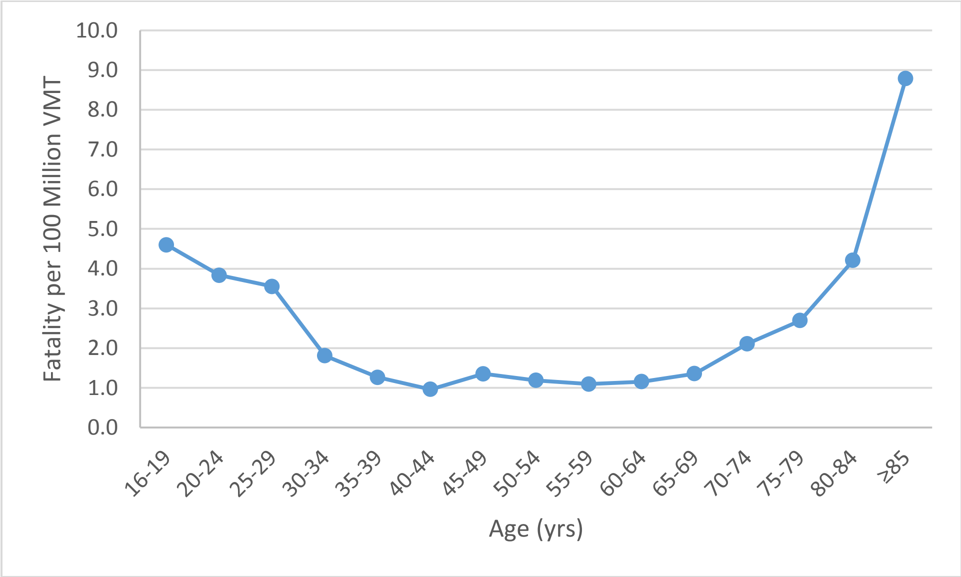

Figure 3. Fatality crash rate per 100 million vehicle miles traveled by driver age (Insurance Institute for Highway Safety, 2011).

In 1998, Cerrelli examined the 1996 Fatality Analysis Reporting System (FARS) data and assessed that drivers ages 70-74 have a fatal crash rate twice that of the 30-39 age group. In addition, Cerrelli found that the oldest age group (85+) had a fatal crash rate that was eight times as great as the 30-39 age group (Cerrelli, 1998). Furthermore, the increased fatality rate of older drivers has been a result of the increased fragility of the older driver, rather than any unsafe practices or age effects (Bayam, Liebowitz, & Agresti, 2005).

In 2003, authors Li et al. used the FARS, General Estimates System (GES) and Nationwide Personal Transportation Survey (NPTS) to estimate older driver fragility. The authors used a relative contribution formula (RC) and a series of ratios to estimate the risk of a driver's death once a crash has occurred. First, the authors found the driver death per involvement ratio (DDI) and the driver involvement per vehicle mile traveled ratio (DIT) for each age bracket.

$$DDI = \frac{driver\ deaths}{drivers\ involved\ in\ crash} \qquad \text{Equation 1}$$

$$DIT = \frac{drivers\ involved\ in\ crash}{vehicle\ mile\ traveled} \qquad \text{Equation 2}$$

Then a death rate ratio (DRR) was computed to estimate the risk of death once a crash has occurred.

$$DRR = \frac{driver\ deaths_1/vehicle\ mile\ traveled_1}{driver\ deaths_2/vehicle\ mile\ traveled_2} \qquad \text{Equation 3}$$

The subscript 1 is the target age group and subscript 2 is the reference age group. The referenced age group used by Li et al. (2003) was 30 to 59 years of age.

$$RC_i = \frac{|\ln(ratio_i)|}{\sum_{i=1}^{2}|\ln(ratio_i)|} \times 100\% \qquad \text{Equation 4}$$

Where, RC_i is the relative contribution of the targeted age group, and the term $ratio_i$ is defined below as a ratio between a target age group and a reference group.

$$ratio_1 = \frac{DDI(Target\ Age)}{DDI(30\ to\ 59\ years\ of\ age)} \qquad \text{Equation 5}$$

$$ratio_2 = \frac{DIT(Target\ Age)}{DIT(30\ to\ 59\ years\ of\ age)} \qquad \text{Equation 6}$$

The likelihood of a fatality occurring, given that there is a crash, can be estimated by using the aforementioned formulae. For example, if the DRR is greater than 1, the population is overrepresented in fatal crashes. If RC is greater than 50%, then the population is more likely to result in a fatality, given that a crash has occurred. Table 1 provides a synopsis of the DRR and the RC statistics.

Table 1

Description of Death Rate Ratio and Relative Contribution to Explain Fragility

	RC > 50%	RC < 50%
DRR > 1	Overrepresented and fatality likely	Overrepresented but fatality unlikely
DRR < 1	Underrepresented and fatality likely	Underrepresented but fatality unlikely

Note. DDR = Death Rate Ratio; RC = Relative Contribution.

Li et al. (2003) examined the fragility for both age and gender, as well as for age and impact points (frontal, side, and rear impact). For all cases, fragility increased with age. In particular, the authors found that men, ages 70-74, had a RC of 87% and a DDR of 2.2;

meanwhile, women, ages 60-64, had a RC of 97% and a DDR of 1.8. In comparison to younger drivers, ages 16-19, the DDR was 4.1 for males and 3.9 for females, which indicates that there is an over involvement of younger driver deaths; however, the RC for drivers ages 16-19 was 5% for males and 2% for females. The low RC for the 16-19 age group indicates that the younger driver death rates were related to the excessive crash involvement rather than the crash itself. The research by Li et al. (2003) provides a methodology for examining crash data and assessing the over representation of a population and the likelihood that a death would occur, given that a crash has occurred.

Considering that older drivers are overrepresented in crash data per vehicle mile traveled and that a crash involving an older driver is more likely to result in a fatality, the rapidly growing, older driver population and their selected seat position for driving is of great interest.

1.5 Evolution of the Automotive Seat

Since the first automobile in 1896 [Benz Patent-Motorwagen], the automotive seat has evolved from a stationary carriage bench seat shown in Figure 4, to the first United States' patented adjustable seat shown below in Figure 5, to a modern seat in a luxury sedan that may have as many as 22 seat adjustments.

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Figure 4. 1896 Benz Patent-Motorwagen.

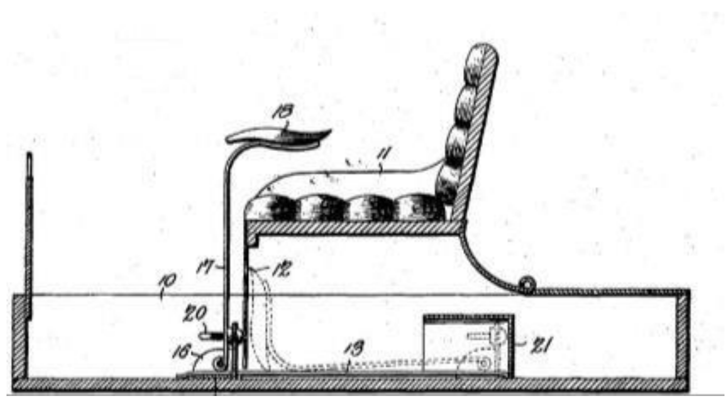


Figure 5. First seat patented as an adjustable vehicle seat (Smith, 1903).

Automotive seats have changed considerably since the Benz Patent-Motorwagen (1896); however, what may be less obvious is how the automotive seating has changed throughout decades of development and construction. Table 2 gives a historical summary of automotive seating. For instance, shortly after seats became adjustable, the Society of Automotive Engineers (SAE) published the recommended practice regarding the location of the driver’s eye (SAE International, 2010b), and after the first seat belt laws were passed, SAE published recommended practices about driver reach (SAE International, 2007).

Table 2

Automotive Seat Related Timeline

Year	Milestone	Number
1886	Benz & Co. was awarded a German patent, signifying the first automobile.	DMPA 37435
1903	Thomas Smith was awarded the first US patent for an adjustable vehicle seat.	USPTO 741,077
1914	The Maxwell “25” was the first car to advertise two-way adjustable seating.	
1921	Hudson Motor Car Company had the first car to implement an adjustable bench seat.	
1946	Buick had the first car to have two-way power seats.	
1953	Lincoln Motor Company was the first car to have four-way power seats.	
1957	Ford introduced the “seat-o-matic” in the Thunderbird as a seat position memory system.	
1965	SAE published a recommended practice to determine the drivers’ eye location.	SAE J941
1968	Federal seatbelt law required all new vehicles to have seatbelts installed.	FMVSS 208
1968	First federal head restraint law was passed.	FMVSS 202
1973	SAE published a recommended practice to describe and measure the driver’s field of view.	SAE J1050
1976	SAE published recommended practice to standardize the driver’s reach.	SAE J287
1984	The state of New York passed the first seatbelt law requiring front seat occupants to wear their seatbelt.	NY TV Law § 33-1229-c
1985	SAE published the recommended practice to determine the accelerator heel point for Class B vehicles.	SAE J1516
1985	SAE published the recommended practice to determine driver selected seat position for Class B vehicles.	SAE J1517
1985	SAE published the recommended practice to determine driver and passenger head position.	SAE J1052
1995	Maine passed a seatbelt law requiring all passengers to	MRS Title 29-A

	wear their seatbelt, leaving New Hampshire to be the last state without an adult seat belt law.	§2081
1998	Federal law required airbags to be installed in all new cars.	FMVSS 208
2004	SAE published procedures to use a new H-point machine.	SAE J4002
2005	SAE published a recommended practice to benchmark vehicle seats using the new H-point machine.	SAE J4003
2008	SAE published a recommended practice utilizing a new seat accommodation model.	SAE J4004

Note. DPMA = Deustshes Patent- und Markenamt (German Patent and Trade Mark Office); FMVSS = Federal Motor Vehicle Safety Standard; MRS = Maine Revised Statues; NY TV = New York Traffic and Vehicle; SAE = Society of Automotive Engineers; USPTO = United States Patent and Trademark Office.

Today, the most basic driver seat contains at least four ways seat adjustments: fore/aft seat track adjustment and forward/rearward tilt of the seat back. As a result of past research (discussed later in Section 1.8), automakers place the seat on an incline track to accommodate a broader range of stature. See Figure 6.

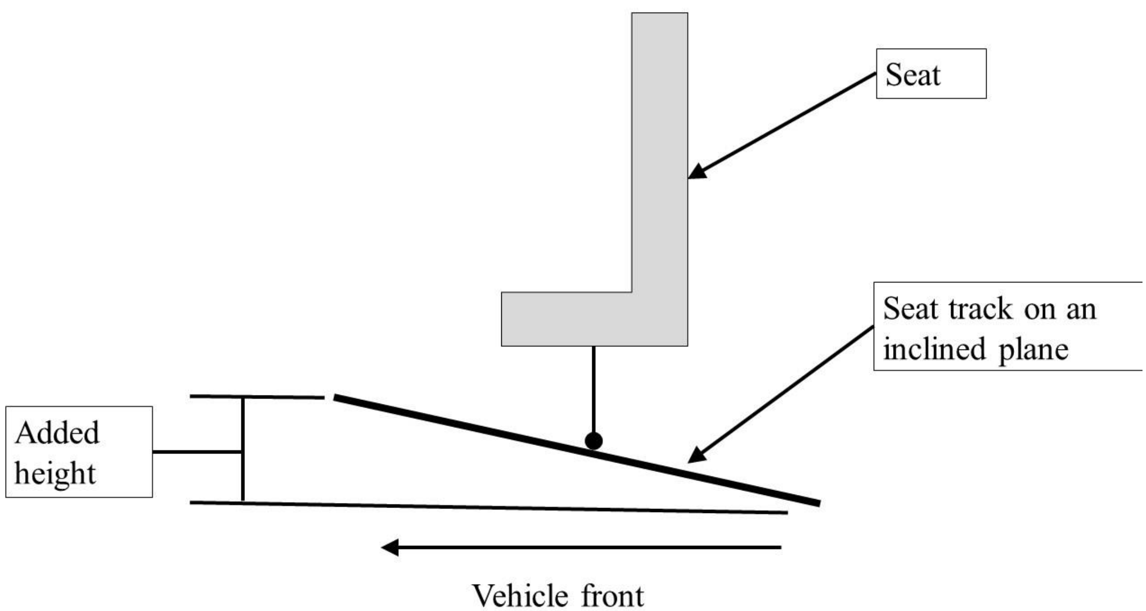


Figure 6. A seat track on an incline plane explanation.

The incline plane allows a shorter person, who might naturally sit more forward in the vehicle and require a higher seating position, to obtain the desired height without including a designated seat height adjustor to make the accommodations. Though the concept seems trivial, the idea that a shorter person would need to sit more forward and upward is based on decades of research.

Driver selected position research began with the work from Hammond and Roe (1972). Although this study was focused primarily on driver reach, Hammond and Roe reported a gender difference in driver selected seat position. Hammond and Roe's data provided a foundation for other researchers, such as Philippart, Roe, Arnold, and Kuechenmeister (1984). Philippart et al.'s work (described in more detail in Section 1.8) resulted in the J1517 SAE recommended practice for driver selected seat position and remains influential in the more recent J4004 SAE recommended practice.

Typically, a modestly equipped vehicle would have a driver seat with at least six ways of adjustment, and a moderately equipped vehicle would have a driver seat with eight ways of adjustment as shown in Figure 7. As mentioned before, luxury vehicles are very likely to have 22 ways of seat adjustment. See Table 3 for a comparison of the adjustments. Each additional option tends to compound the driver's selection of a proper seat position by adding a greater level of control, thus requiring a driver to be more knowledgeable of the adjustments that provide safe, optimal seat positioning.

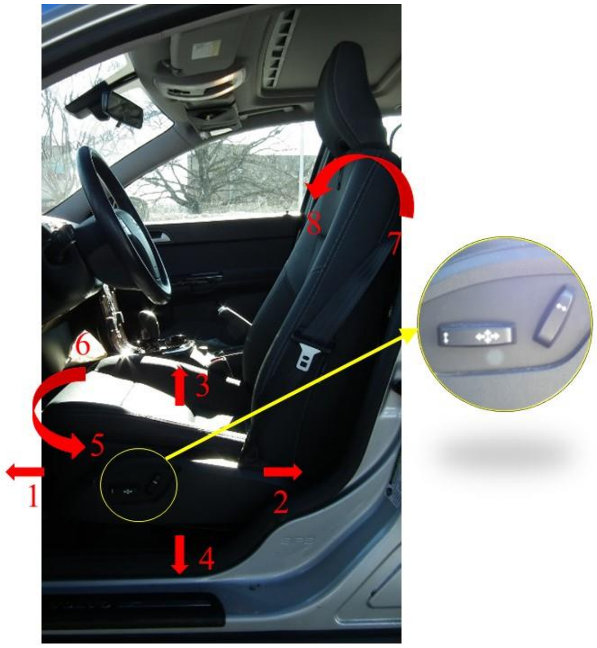


Figure 7. Modern sedan with eight-way seat adjustment.

Table 3

Common Seat Adjustment Arrangements

Seat Adjustment	4-way	6-way	8-way	22-way
Fore/aft seat track	X	X	X	X
Seat back angle	X	X	X	X
Upward/rearward seat height		X	X	X
Front seat base angle			X	X
Rear seat base angle				X
Seat belt height				X
Upper seat back contour				X
Lumbar depth				X
Lumbar height				X
Side bolsters				X
Seat base length				X

1.6 National Health Surveys

In 1956, the US passed the National Health Survey Act and began their first large-scale public health survey called the National Health Examination Survey (NHES). The data collection focused on

- interviews with the sample persons;
- clinical tests, measurements, and physical tests on the sample persons; and
- places where the sample persons seek medical care.

The purpose of the first NHES, conducted from 1960 to 1962, was to investigate chronic illnesses of adults. The sample size for the first NHES was n=6,672 with an age range of 18-79 years of age. There were two more NHES conducted: one from 1963 to 1965 and another from 1966 to 1970. The last two NHES focused on children (Centers for Disease Control and Prevention, 2011). See Table 4 for further details.

In 1970, the National Center for Health Statistics (NCHS) added nutritional information to its survey, and the title changed to the National Health and Nutrition Examination Survey (NHANES). The first NHANES data capture then took place from 1971 to 1975. The sample size of NHANES I survey was n=23,808 and the age range was from 1 to 74 years of age. Finally, in 1999 the NHANES became a continuous project, and the data sets are now published in two year increments with approximately 7,000 randomly selected US residents (Centers for Disease Control and Prevention, 2011).

Table 4

A Summary of the NHES and NHANES (Centers for Disease Control and Prevention, 2011; Ogden, Fryar, Carroll, & Flegal, 2004; Stoudt, Damon, McFarland, & Roberts, 1965)

Survey	Dates	Sample Size	Ages	Mean Male Stature (cm)	Mean Female Stature (cm)
NHES I	1960 – 1962	6,672	18 – 79 years	173.4	160.2
NHES II	1963 – 1965	7,119	6 – 11 years	Not Applicable	Not Applicable
NHES III	1966 – 1970	6,768	12 – 17 years	Not Applicable	Not Applicable
NHANES I	1971 – 1975	23,808	1 – 74 years	175.1	161.6
NHANES II	1976 – 1980	20,322	6 mo. – 74 years	175.4	161.8
NHANES III	1988 – 1994	33,994	2 mo. +	175.4	161.8
NHANES 1999	1999 – 2000	9,965	All Ages	175.8	162.0
NHANES 2001	2001 – 2002	11,039	All Ages		
NHANES 2003	2003 – 2004	10,122	All Ages		
NHANES 2005	2005 – 2006	10,348	All Ages		
NHANES 2007	2007 – 2008	10,149	All Ages		
NHANES 2009	2009 – 2010	10,537	All Ages		

Note. NHES = National Health Examination Survey; NHANES = National Health and Nutrition Examination Survey.

The NHANES data sets have been used extensively in research to establish non-military based anthropometric data. In particular, these data sets are used to define the population percentiles used in most research. For instance, Philippart et al. (1984) used the NHES I report written by Stoudt et al. (1965) to define the stature percentiles for their population in driver selected seat positions (Philippart et al. (1984) work described below). Philippart et al. (1984) used a mean stature of 173.2 cm (68.2 in) for males and 160.0 cm (63.0 in) for females to define their 50^{th} percentile; whereas, according to the NHANES II collected in 1976 to 1980, the data set closest to Philippart et al.'s work, the mean stature of the time was actually 175.5 cm (69.1 in) for males and 161.8 cm (63.7 in) for females – a difference of 2.3 cm (0.9 in) and 1.8 cm (0.7 in), respectively. Later, Flannagan, Schneider, and Manary (1996) discovered a 5 cm (2.0 in) error in Philippart et al.'s seat model, which could be partially explained by the difference in population stature.

In 1978, Stoudt performed a literature review of studies that examined the stature of a variety of populations, including the US civilian, US military, Western Europe, Apache Indians, and the Xingu Indians. Stoudt's purpose was to determine if people are getting bigger and present this information to automakers in order to aid designers to accommodate the target marketing population. Based on the review of the literature, Stout found that the US population increases in stature by an average of 1 cm (0.39 inch) per decade. The growth rate is explained primarily by improvements in environmental factors, such as better nutrition and medical care. Populations that have had little change to their environment, such as the Xingu Indians of the Amazon Basin of Brazil, have experienced no significant change to stature (Stoudt, 1978).

Schneider, Robbins, Pflug, and Snyder (1983) examined anthropometric data specifically related to motor vehicle occupants. The purpose of this research was to develop specifications for an anthropometric dummy. During the research, Schneider et al. (1983) found that the growth rate was 1 cm (0.39 in) every other decade, rather than the 1 cm every decade that Stoudt (1978) indicated. In other words, the significance of this research showed that the growth rate previously indicated was half the rate of the new findings (Schneider et al., 1983).

Then most recently, Ogden et al. (2004) used the NHES I, II, and II, as well as the NHANES I, NHANES II, NHANES III, and NHANES 1999-2000 to examine the trends of mean height, weight, and body mass index. The findings for Ogden et al.'s work showed that over a period of 40 years the average weight for the sampled US population increased by more than 10.8 kg (24 lbs). Meanwhile, average stature increased by 2.5 cm (1 in), and the body mass index increased by 3. Ogden et al.'s (2004) findings are more in line with Schneider et al.'s 1983 findings, rather than Stoudt's (1978); albeit, Ogden et al. report an average growth of 0.63 cm (0.25 in) per decade, which is 13% greater than the findings of Schneider et al. These growth rate findings of the three aforementioned studies show that standards based on population percentiles will eventually become obsolete. Table 5 summarizes the US growth rate findings determined by Stoudt (1978), Schneider et al. (1983), and Ogden et al. (2004).

Table 5

The US Growth Rate as Determined by Stoudt (1978), Schneider et al. (1983), and Ogden et al. (2004)

Referenced Paper	Growth Rate (cm/decade)	Growth Rate (in/decade)
Stoudt (1978)	1	0.39
Schneider et al. (1983)	0.5	0.20
Ogden et al. (2004)	0.63	0.25

Though the growth rate of the population has been found to be increasing each decade, the population growth rate is confounded by the individual's stature changes with increasing age. The age effects on stature have been studied quite extensively. Studies almost unanimously agree that there are stature changes with age, and the rate differs between gender; however, the age which the stature decline begins and the magnitude of stature loss differs between studies. In general, the age at which stature begins to decrease occurs somewhere between the age of 25 and 40 (Borkan, Hults, & Glynn, 1983; Chandler & Bock, 1991; Friedlaender et al., 1977; Noppa, Andersson, Bengtsson, Bruce, & Isaksson, 1980). The magnitude of stature loss with age for males has been stated to range from 1.3 cm to 6.0 cm and from and 3.12 cm to 6.6 cm for females (Chandler & Bock, 1991; Gsell, 1967; Hertzog, Garn, & Hempy, 1969). Over the course of a 28 year mixed-longitudinal study in which 1,785 females and 1,544 males were measured every three years, Chandler and Bock (1991) have shown that males can expect a loss of 6.0 cm in stature by the age of 80; whereas, females can expect a 6.6 cm loss of stature. The rate at which the loss of stature occurs is 0.4 cm/year for males and 0.3 cm/year for females (Dey, Rothenberg, Sundh, Bosaeus, & Steen, 1999). Chandler and Bock (1991) have shown that females lose more total stature than males with age; however, Dey et al. (1999) have shown that males experience a greater rate of stature loss. Büchi (1950) explains that this discrepancy is accounted for by the fact that females begin to decline in stature earlier than males (as cited in Chandler & Bock, 1991). The change of an individual's stature as age increases demonstrates how age can influence a standard, such as the SAE J1517 and SAE J4004 recommended practices (see below) which do not account for these age effects.

1.7 Recommended Practices and Standards

The Society of Automotive Engineers (SAE) publishes a number of recommended practices for automotive engineers. These recommended practices are not legally mandated for an Original Equipment Manufacturer (OEM) like a Federal Motor Vehicle Safety Standard (FMVSS). Nonetheless, they provide the OEMs a foundation of practices to provide uniformity across product lines.

The recommended practices below are published by the SAE and were selected for this review because they are all associated with seat positioning. The first recommended practice (SAE J182) describes the coordinate system that the SAE uses to take vehicle measures. The next recommended practices (SAE J1100 and SAE J2732) define the measurements for seat positions. The remaining recommended practices describe the driver's selected seat position, and how to take the measurement of this position.

Vehicle reference system.

The SAE J182 recommended practice is used to describe an origin and coordinate system within the vehicle. The SAE J182 practice defines three planes and the directionality of the associated axes. The Zero Y Plane is the vertical plane that passes through the longitudinal centerline. The Zero X Plane a vertical plane that is normal to the Zero Y Plane and is selected such that its position avoids the use of negative numbers in measurements. Finally, the Zero Z Plane is the horizontal plane, and the location is selected so that vertical measures are all positive upward for all loaded conditions (SAE International, 2005).

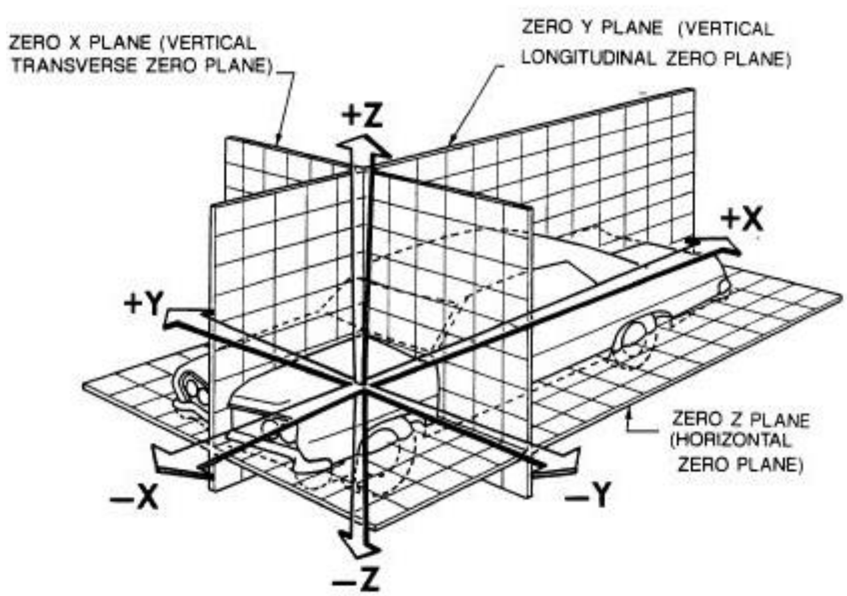


Figure 8. SAE three-dimensional reference system (SAE International, 2005).

Measurements and definitions.

The SAE J1100 standard is used to identify vehicle dimensions and layout procedures for measuring vehicle information in a computer aided design (CAD) environment. Because the SAE J1100 standard establishes dimensional references, the standard also defines many "hard points" designers use for design purposes. The SAE J1100 standard begins with the general definitions of motor vehicle classes and vehicle loads, then moves to defining the general vehicle reference points, then to specific reference points for H-point devices, and then to foot-related reference points. While the SAE J1100 provides a good foundation for vehicle dimensions, each section of the standard is not covered fully. Therefore, the SAE J2732 standard was written to expand upon interior measures specifically related to the seat itself and seat measures that interact with the H-Point Machine (HPM) and H-point Machine II (HPM-II) (SAE International, 2008b). Table 6 defines the most relevant definitions from the J1100 and J2732 standards related to seating elements within this study, and Figure 9 illustrates these definitions.

Table 6

Pertinent Definitions from SAE J1100 and J2732 (SAE International, 2008b, 2009)

Term	Definition	SAE Standard
Accelerator heel point (AHP)	The heel of shoe location on the floor at the depressed floor covering, when the bottom of shoe is in contact with the undepressed accelerator pedal and the ankle angle is at 87 degrees	J1100
Ball of foot (BOF)	A point on the lateral centerline of the shoe 203 mm from the heel of shoe	J1100
Cushion angle	Angle of the cushion line from the horizontal with the HPM loaded in the seat with the seat at design attitude	J2732
Cushion line	Line from the H-point through the C1 divot point	J2732
H-point	A point on the HPM, HPM-II or the HPD located at the pivot center of the back pan and cushion pan assemblies, on the lateral centerline of the device	J1100
Torso angle	Angle measured between a vertical line through the H-point and the torso (back) line	J2732
Torso (back) line	Line from the H-point through the sliding thoracic pivot (B1 divot point)	J2732
Seating reference point (SgRP)	SgRP is a specific and unique H-point established by the manufacturer as the design seat reference point for a given designated seating position which establishes the rearmost designated seating position	J1100

Note. SAE = Society of Automotive Engineers.

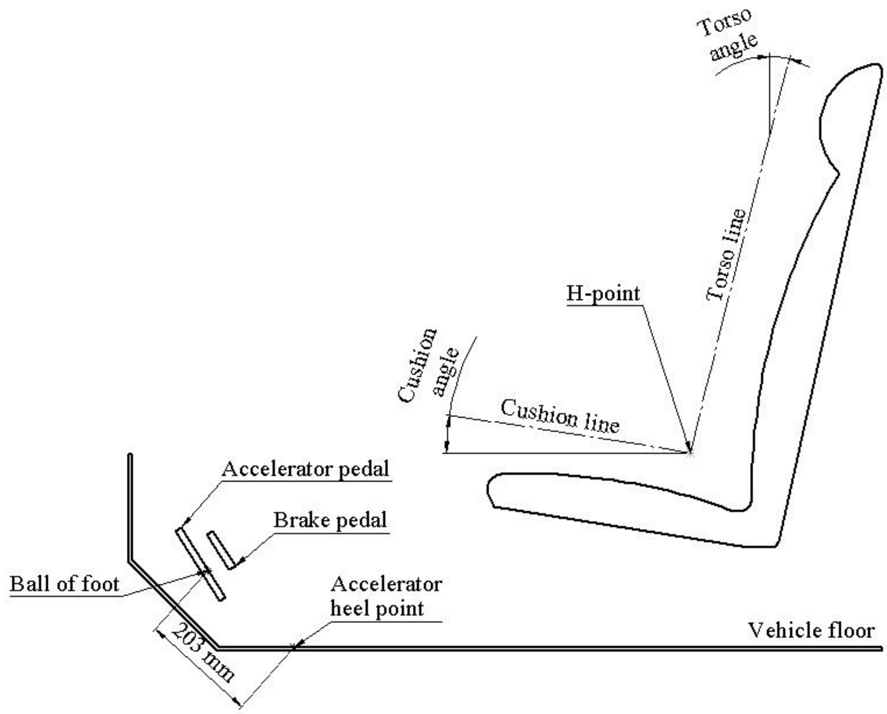


Figure 9. Pertinent definitions from SAE J1100 and J2732.

H-point Machine (HPM).

The SAE J826 standard describes two devices that can be used to measure the interior cabin space of a vehicle (SAE International, 2008a). The two mechanisms are the H-point template, and an H-point machine (HPM). The H-point template is the two dimensional "cutout" used to capture measurement. See Figure 10.

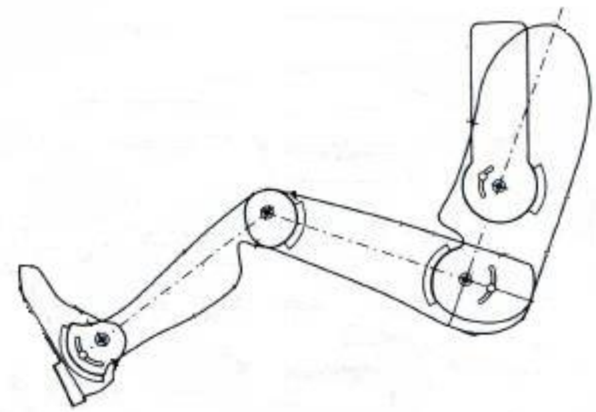


Figure 10. SAE J826 H-point template (SAE International, 2008a).

The HPM is a weighted manikin equipped with scales to capture the desired measurements from the machine itself, or taken directly from the provided reference points. The contours of both devices reflect the 50th percentile adult male driver; measurement values were taken from Geoffrey (1961) and the Centers for Disease Control and Prevention (1959-1962) studies (SAE International, 2008a). However, the leg segments can be adjusted to accommodate the 10th and 95th percentiles with some adjustments. See Figure 11.

Figure 11. SAE J826 H-point machine (SAE International, 2008a).

In 2002 the SAE updated the H-point Machine (HPM) in the SAE J826 recommended practice and created the H-point Machine-II (HPM-II), thus producing the SAE J4002 recommended practices (SAE International, 2010a). The SAE J4002 first highlights the changes between SAE J4002 and SAE J826, and then address that the two standards will coexist for a period of time, at which point the SAE J826 will be withdrawn. The SAE J4002 states that this period of time would be at least 10 years; however, as of November of 2008, SAE J826 was revised for at least another five years (SAE International, 2008a). The changes made from SAE J826 to SAE J4002 were primarily enhancements in the machine itself. For instance, the HPM-II now has separate components for the leg, shoe, and cushion pan. In addition, the HPM-II allows for measurements such as the thigh angle and cushion angle to be captured simultaneously (SAE International, 2010a). As far as the content, the main difference between the two standards is that the ball of the foot (BOF) no longer has to be placed on the pedal. This change eliminates the Pedal

Reference Point, and thereby creates the term Ball of Foot Reference Point (BOFRP). Last, accelerator heal point (AHP) to BOF was changed from 200 mm to 203 mm (SAE International, 2010a). The HPM-II is shown below in Figure 12.

Figure 12. SAE J4002 H-point machine II (SAE International, 2010a).

SAE J1517: Driver Selected Seat Position for Class B Vehicles – Seat Track Length and SgRP.

Initially, the SAE recommended practice J1517 was used to assess the driver selected seat position of passenger vehicles, heavy trucks, and buses; however, the SAE recommended practice J4004 now governs passenger vehicles. The purpose of this recommended practice is to describe a driver's selected seat position parallel to the Zero Y Plane or in the body's sagittal plane (SAE International, 2011).

The J1517 practice began from the research performed by Philippart et al. (1984); Sanders (1983); and Shaw and Sanders (1984). The standard defines how to calculate the fore/aft H-point location, given H-point height and the target stature percentile for three different male/female driver population ratios.

SAE J4004: Positioning the H-point Design Tool – Seating Reference Point and Seat Track Length.

The SAE J4004 recommended practice provides methodology to determine the reference points and seat track accommodations of the driver (SAE International, 2008c). Primarily, the SAE J4004 provides methods to find the SgRP for a fixed seat and fore/aft adjustable seats, with and without independent height adjustment. Each method of SgRP location begins by plotting the SgRP using the following equation (SAE International, 2008c).

$$SgRP_x = 913.7 + 0.672316(H30) - 0.0019553(H30)^2 \quad \text{Equation 7}$$

Where,

H30 is the vertical height of the H-point above the vehicle floor.

For a fixed seat, there is only one SgRP available, and the calculated values should be the same as the measured value. For a seat that has fore/aft adjustment but no independent height adjustment, the H-point can only travel along a line, and the SgRP is the intersection between the SgRP curve and the H-point line. For a seat that has fore/aft adjustment as well as vertical height adjustment, the preferred method is to take the H-point line to be 20 mm above the lowest position, and the SgRP is the intersection between the SgRP curve and the H-point line.

SAE J4004 also describes how to establish and set the seat track length. First, the H-point reference position (X_{ref}) is to be established using the equation below.

$$X_{ref} = 718 - 0.24(H30) + 0.41(L6) - 18.2t \qquad \text{Equation 8}$$

Where,

H30 is the vertical height of the H-point above the vehicle floor.

L6 is the BOFRP to steering wheel center, and

t is the transmission type (1 if manual and 0 is automatic)

The SAE J4004 then provides Table 7 to find the track length and the desired level of population accommodation.

Table 7

Seat Track Length for Desired Accommodation Levels (SAE International, 2008c)

Desired accommodation (%)	Population percentile accommodation ranges (%)	Front of H-point travel path from H-point X-reference (mm)	Rear of H-point travel path from H-point X-reference (mm)	Total seat track length (mm)
98	1 to 99	-135	145	280
97.5	1.3 to 98.8	-131	140	271
95	2.5 to 97.5	-116	124	240
90	5 to 95	-100	106	206
80	10 to 90	-79	83	162

Last, SAE J4004 specifies a seat position prediction model in the appendix that is used to describe the selected seat position of any individual. Since stature is normally distributed within gender and the equation is linear with stature, the stature term in the equation was deemed adequate enough to discern gender differences and therefore a gender specific equation was deemed unnecessary.

$$X = 16.8 + 0.433(stature) - 0.24(H30) - 2.19(A27) + 0.41(L6) - 18.2t \quad \text{Equation 9}$$

Where,

Stature is the standing height of the individual in millimeters.

H30 is the vertical height of the H-point above the vehicle floor.

A27 is the cushion angle.

L6 is the BOFRP to steering wheel center, and

t is the transmission type (1 if manual and 0 is automatic).

1.8 Driver Selected Seat Position

In 1954, Edwin Pickard of Ford Motor Company published a paper discussing the use of "Oscar" in seat design. Oscar was a manikin made from flat sheets of plastic with the possibility to lock the joints into a desired position and apply weights so that Oscar would have the proper weight distribution of a person while seated. Oscar's dimensions were taken from two anthropometric studies (the Armored Medical Research Laboratory and the Office of the Surgeon General), represented the 80^{th} percentile male, and had a stature of 177 cm (69.5 in) and a weight of 74.8 kg (165 lbs.). Pickard points out that Oscar could be used in all phases of the design process, such as the designation of the occupant space at the beginning of the design phase, during test and measurement of seat prototypes, and at the validation of the final seat design. Oscar represented a paradigm shift in seat design. Pickard states that until Oscar was invented seats were designed around the opinions of top management. Once Oscar became available, automotive engineers began to design seats for the vehicle's intended user (Pickard, 1954).

Later, Matthaei brought to the public's attention the deficiencies of the Ford's automotive seating dummy, Oscar. Matthaei stated that Oscar represented an average male, and by using Oscar as a benchmark of automotive drivers, the automotive industry excluded portions of the population; namely, Oscar excluded the female population. However, Oscar's dimensions were also based on anthropometric data from the US Army's Armored Medical Research Laboratory (Pickard, 1954). The use of military data provided a large sample size of participants, but the participants were all young, fit, healthy males. As a result, Oscar was determined to have the "average" American stature of 177 cm (69.5 in) and weight of 74.8 kg (165 lbs.). Matthaei (1954) stated that 53% of the population was 5.1 cm (2 in) shorter than Oscar, and 10% of the population was 2.5 cm (1 in) taller than Oscar.

At the time of the Matthaei (1954) study, vehicles were constructed with a fore/aft adjustable seat on an inclined plane; however, with Oscar as the average male, the seats would be designed lower and further back than necessary. Matthaei (1954) created a multi-adjustable seat and conducted a survey about the most comfortable driving position. The multi-adjustable seat was capable of adjusting the front and rear of the seat base up 3.8 cm (1.5 in) and 4.4 cm (1.75 in), respectively. The adjustment of the front and rear of the seat base could then provide a ± 7 degree from the normal seat base angle. Matthaei (1954) found that the driver's preference had a greater impact on the selected seat position rather than physical dimensions collected, that the most drivers' preferred seat angle was 15 degrees above horizontal, and that 75% of the drivers positioned the seat higher than the allowable position of a seat on just an inclined plane.

At the time of Matthaei's publication in 1954, Lincolns were the only vehicles that were implementing vertical seat height adjustment into the vehicles. See Table 2 above. Matthaei was making a case that vehicles of the future should include six-way adjustment of the seat to accommodate the population properly. Although Matthaei does state that stature and weight measures of the driver alone do not indicate a driver's selected seat position, Matthaei found that participants of similar stature and weight would adjust their seats to different locations, and he concluded that personal preferences would have the greatest bearing on the individual's seat position.

Matthaei does not provide any further information regarding stature and weight not being an indicator of driver selected seat position. However, by adding vertical height and seat base adjustments to the seat, Matthaei made several leaps in seat design, and what may have appeared to be similar drivers selecting a different seat location probably was a trend that needed further investigation.

Much of the initial occupant packaging research began with the control reach study performed by Hammond and Roe in 1972. Hammond and Roe (1972) noted that the ability for a driver to reach forward controls, such as the steering wheel and gearshift, would affect the driver's choices regarding the selected seat position as well as the vehicle's restraint systems. The purpose of the study was to quantify the ability of an individual to reach the forward controls with a hand and foot reach test (Hammond & Roe, 1972).

To begin the control reach study, Hammond and Roe first established nine measurements to define the workspace. See Table 8. However, with the factorial experimental design that they selected, the resulting test conditions became overwhelmingly large; therefore, the researchers paired down the conditions by creating the General package factor (G). This factor space variable incorporated the nine workspace variables into a single regression equation.

$$G = -0.171(zHX) + 0.171(zHZ) - 0.073(zBA) + 0.029(zHT) + 0.132(zWD) + 0.169(zWA) - 0.162(zWX) + 0.177(zWZ) - 0.011(zPA) \quad \text{Equation 10}$$

Where each of the variables represents the z-score of the of the variable listed in Table 8. The G factor is still used today to characterize the driver's seating configuration; however, the equation has been drastically changed to include only two variables: the H-point height (H30) and the center of steering wheel height (H17) (SAE International, 2007).

Hammond and Roe (1972) sought to limit the manipulations further by selecting three values of G: Fixture I (G=-1.4), Fixture II (G=0), and Fixture III (G=1.5). Fixture I was selected to represent a lower ride height vehicle such as a sports car. Fixture II was selected to represent a typical sedan, and Fixture III was selected to represent a heavy truck.

Table 8

Nine Measurements Hammond and Roe Used to Define the Workspace (Hammond & Roe, 1972)

Package Variable	Referenced SAE Dimension	Measurement Name
HX	L53	H-point to accelerator heel point
HZ	H30	H-point to accelerator heel point
BA	A40	Back angle
	A42	Hip angle
HT	L17	H-point travel
WD	W9	Steering wheel outside diameter
WA	A17	Steering column angle
	L7	Steering wheel torso clearance
	H13	Steering wheel thigh clearance
WX	L11	Wheel center to heel point
WZ	H17	Wheel center to heel point
PA	A27	Pan angle

Note. SAE = Society of Automotive Engineers

Hammond and Roe (1972) found that female participants sat more forward than male participants; however, as the seat height increased with the change between the three fixtures, the authors found the seat track difference between the gender to be less. For instance, the average seat track difference for Fixture I was 4.6 cm (1.8 in); for Fixture II the difference was 3.0 cm (1.2 in); and the difference for the highest arrangement, Fixture

III, was 1.5 cm (0.6 in). In addition, Hammond and Roe found that the range of seat track travel differed. Table 9 below provides a summary of the gender differences for each test fixture.

Table 9

Seat Position Difference in Control Reach Study (Hammond & Roe, 1972)

Fixture	Difference in Average Seat Track	Magnitude of Seat Track Range	
		Male	Female
I	4.6 cm (1.8 in)	14.2 cm (5.6 in)	13.5 cm (5.3 in)
II	3.0 cm (1.2 in)	12.7 cm (5.0 in)	14.7 cm (5.8 in)
III	1.5 cm (0.6 in)	10.9 cm (4.3 in)	13.2 cm (5.2 in)

In 2009 the Society of Automotive Engineers (SAE) reaffirmed the recommended practice publication J1517 for Driver Selected Seat Position (SAE International, 2011) which provides the suggested fore/aft seat position based upon the vertical H-point measure (H30). The J1517 was written primarily from the work of Philippart et al. (1984). In summary, Philppart et al. took two measurements and used regression techniques to fit the data to a second order polynomial for the 2.5, 5, 10, 50, 90, 95, and 97.5-percentile person.

$$x_i = C_{0_i} + C_{1_i}z - C_{2_i}z^2 \qquad \text{Equation 11}$$

Where,

z = H30 (mm)

x_i = longitudinal distance from ball of foot location

C = represents the coefficients of the term indicted by its subscript

i = indexes the percentile seat position (2.5, 5, 10, 50, 90, 95, 97.5)

Later, Flannagan et al. (1996) sought to improve the J1517 seat position model. According to Flannagan et al., using the J1517 recommended practices will result in the seat position error of 60 mm or more. They found that seat position is not solely dependent on the H30 measure, and in fact, the mere presence of a clutch pedal will result in a more forward seat position compared to the seat position of a vehicle without a clutch pedal. Therefore, based on the Flannagan et al. (1996) study, the seat position model should include, at minimum, the H30 measure, seat cushion angle, and transmission type.

$$x_i = C_{0_i} + C_{h_i}h + C_{p_i}p + C_{t_i}t \qquad \text{Equation 12}$$

Where,

h = H30 (mm)

p = seat-cushion angle (deg)

t = transmission type (0=automatic, 1=manual)

C = the coefficients of the term is indicated by its subscript

i = indexes the percentile seat position (2.5, 5, 10, 50, 90, 95, 97.5).

More recently, Kolich (2000) measured selected seat position within a specific vehicle market segment. The aim of the study was to tailor seat accommodations to anthropometric characteristics of marketing demographics. Kolich's experiment used the J826 H-point manikin (SAE International, 2008a) to position the seats from three vehicles within the same market segments. Twelve participants adjusted the seat to "comfortable" positions, and then Kolich measured the new seat location according to J826. From the collected data, Kolich provides a statistical account of the participants' seat positioning. Findings suggest that most often the full seat track length is not used, and the maximum rearward seat track position is a limiting value.

1.9 Events That Have Increased Risk for Occupants Positioned Outside of Safe Seating Guidelines

Improper seat position selection noticeably affects the driver's capacity to see the roadway and reach the vehicle's controls, such as the steering wheel, accelerator pedal, brake pedal, clutch pedal, and gear selector lever. Improper seat position selection also affects one's safety during a crash event. For example, sitting too close to the steering wheel during a crash will cause airbags to strike the driver, rather than the driver being protected by the safety system. The following data reveal potential hazards that drivers may experience during crash events. Upper extremity injuries or fatalities that may occur during such events can be minimized by selecting an accommodating seat position.

Airbag deployment.

According to the Insurance Institute for Highway Safety (2013a), airbags have saved approximately 28,000 people from 1990 to 2009; however, there are 290 cases in which the airbag itself has caused a fatality. NHTSA (2008a) reports that 104 counts of the airbag fatalities are drivers over 16 years of age. From the first NHTSA report in 2001 to the most recent in 2008, there has been a 37% increase of the total driver fatalities caused specifically by the airbag. In addition, 47% of the total driver fatalities were individuals over the age of 60, and 45% of the total driver fatalities were individuals who had a stature less than 163 cm (64 in) (National Highway Traffic Safety Administration, 2008a). The Insurance Institute for Highway Safety (IIHS) states that the majority of the older population fatalities caused by airbags results from a combination of the older population sitting too close to the steering wheel and the increased fragility of the older age group (Insurance Institute for Highway Safety, 2013a). Figure 13 shows the fatality rate by age of drivers involved in crashes where an airbag deployed.

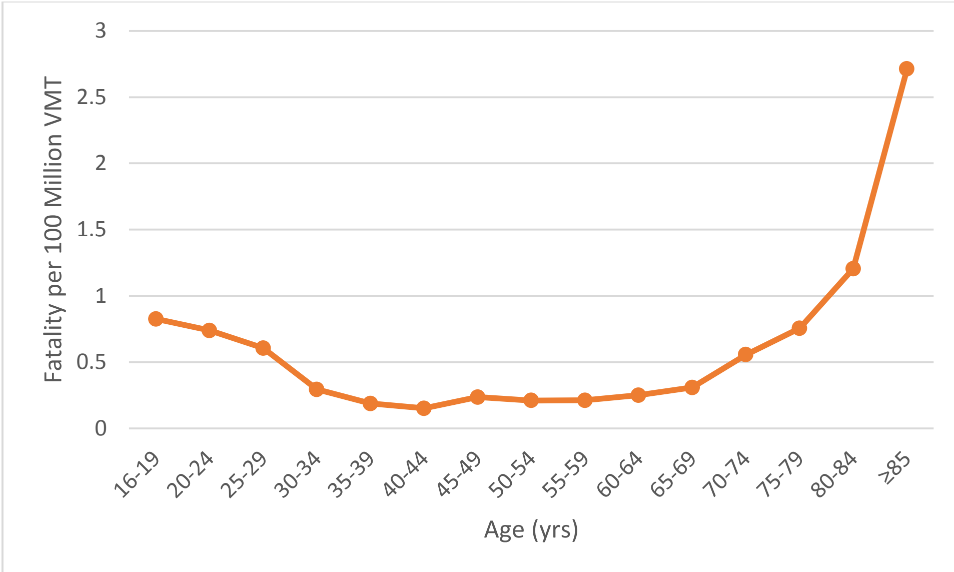


Figure 13. Driver fatality rate per 100 million vehicle miles traveled where the airbag(s) deployed (Insurance Institute for Highway Safety, 2011; National Highway Traffic Safety Administration, 2012).

In addition to fatalities, airbags have been documented to cause severe upper extremity injuries (Conroy et al., 2007; Jernigan & Duma, 2003; Jernigan, Rath, & Duma, 2005). Although these injuries are not as grim in nature as a fatality, the frequency of these injuries is far greater, and the implications are likely to result in long-term disability (Conroy et al., 2007). Using the National Automotive Sampling System (NASS) database, Jernigan et al. (2005) found 2,413,347 front seat occupants were exposed to an airbag deployment from 1993 to 2000. From the database, the authors were able to refine the query and identify 88,324 front seat occupants who suffered an upper extremity injury: amputations, avulsions, burns, dislocations, fractures, and lacerations. Table 10 summarizes the findings of Jernigan et al. (2005), stating that the three major sources of upper extremity injury result from the airbag, instrument panel, and steering wheel. Specifically, the authors identify the airbag as the greatest source of upper extremity injury, accounting for 28% of the 88,324 upper extremity injuries (Jernigan et al., 2005).

Table 10

Number of Upper Extremity Injuries from 1993 to 2000 in the NASS Database (Jernigan et al., 2005).

Cause of Injury	Total	Percentage
Upper extremity injuries	88,324	
Airbag	24,455	28%
Instrument panel	17,843	20%
Steering wheel	15,718	18%
Other	30,308	34%

In a biomechanics survey on aging occupants and airbag technology, authors Yoganandan et al. (2007) state that injuries at the inception of the airbag were mainly because of the occupant sitting too close to the steering wheel and the aggressive nature of airbag deployment. Since then, automakers have retuned the airbag to deploy less aggressively than the original designs; however, even with the redesigned airbags, fatalities and injuries still occur from airbag deployment.

With regards to age, Yoganandan et al. (2007) reported older drivers are more likely to sustain rib fractures during an airbag deployment, which coincides with the idea that bone loss occurs along with age. The bone fracture toughness of an individual 80 years of age is approximately 55% less than an individual that is 27 years of age. This means that older adults have half the bone strength of the younger population, supporting the concept that older drivers are more fragile than younger drivers; therefore, an airbag deployment for a driver that is sitting too close to the steering wheel is more devastating to the older driver (Yoganandan et al., 2007).

Whiplash and head restraint.

Neck sprains and strains, more commonly called whiplash, represent the most common insurance claim (Insurance Institute for Highway Safety, 2013b). In 2007 whiplash claims represented 25% of all insurance claim payout for crash injuries, for a total of $8.8 billion (Insurance Institute for Highway Safety, 2013b). Whiplash injuries are likely to occur from a rear-end crash. Occupants that have a smaller backset measurement (the horizontal distance from the back of the head to front of the head restraint) are less likely to have a whiplash injury occur in a rear-end crash event (Eriksson, 2005; Farmer, Wells, & Werner, 1999; Jonsson, Stenlund, & Bjornstig, 2008; Kolich, 2010).

According to the NHTSA, there has been an average of 1.8 million rear-end collisions each year (National Highway Traffic Safety Administration, 1994, 1995, 1996, 1997, 1998, 1999, 2000b, 2001b, 2002, 2003, 2004, 2005, 2006, 2007, 2008c, 2009, 2010, 2011b). Figure 14 shows the rear-end collision injuries as a percentage of the total number of vehicle collision injuries. On average, rear-end collisions represent 29% of all vehicle-related injuries.

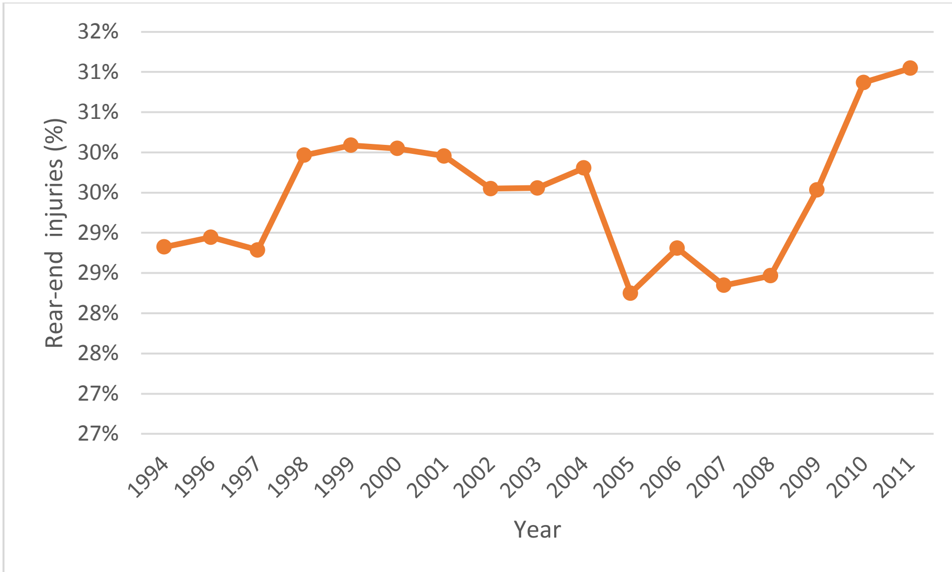


Figure 14. Percent of rear-end collision injuries from 1994 to 2011(National Highway Traffic Safety Administration, 1994, 1995, 1996, 1997, 1998, 1999, 2000b, 2001b, 2002, 2003, 2004, 2005, 2006, 2007, 2008c, 2009, 2010, 2011b).

In a mathematical dynamic model, Eriksson (2005) simulated rear-end collision for three car models and 132 different head positions in order to assess the head restraint influence on whiplash injuries. To do so, Eriksson varied the head-to-head-restraint height from 0 to 10 cm and backset from 0 to 11 cm. See Figure 15.

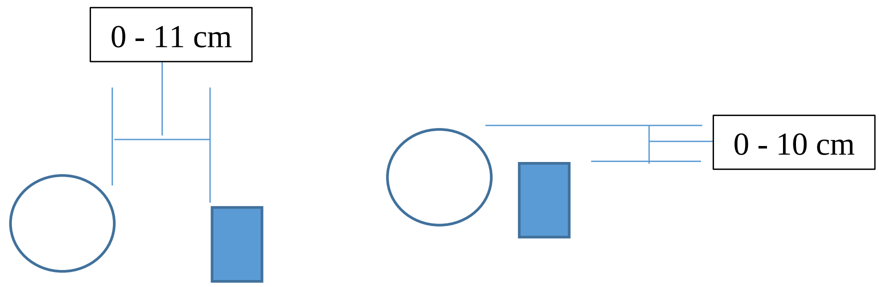


Figure 15. The head restraint to vehicle occupant's head dimensions that Eriksson (2005) varied. Left is the backset measurement. Right is the head-to-head-restraint measurement.

The finding showed that the backset dimension had the greater influence on whiplash injuries and that the probability of incurring a neck injury was reduced by 0.1 for every 2.5 cm of reduced backset (Eriksson, 2005).

In efforts to reduce the number of neck injuries from vehicle crashes, in 2004 NHTSA revised the head restraint regulation FMVSS 202 to include a measurement of backset as well as increase the obtainable height above the seating reference point (SgRP). The original standard, passed on January 1, 1969, stated that the head restraint must be at least 700 mm above the SgRP; that the width is to be 170 mm at 635 mm above SgRP; and that the restraint deflect no more than 100 mm with a 372 Nm moment applied through the seat back about the SgRP. In addition, the head reference line was to be limited to rearward angular displacement of 45 degrees with reference to the torso during a forward acceleration of 8g (National Highway Traffic Safety Administration, 2000a). The new regulation FMVSS 202aS states that the head restraint must have a minimum height of 800 mm above the SgRP and have a maximum backset measure of 55 mm (National

Highway Traffic Safety Administration, 2011a). The angular displacement requirement of the head remained the same; however, the sled test was modified such that the maximum backset measure of 55 mm was required to pass the test (National Highway Traffic Safety Administration, 2000a).

Head space for a rollover event.

A rollover event is defined as any event where the vehicle rotates onto the vehicle's side or roof at any time during the crash event (Insurance Institute for Highway Safety, 2013c). Though the total frequency of a rollover event is few (approximately 3% of all crashes), the fatality rate for these events is, on average, 29% of all fatalities (Insurance Institute for Highway Safety, 2013c; National Highway Traffic Safety Administration, 2012). Figure 16 shows the fatality rate of driver stratified by age as reported on FARS.

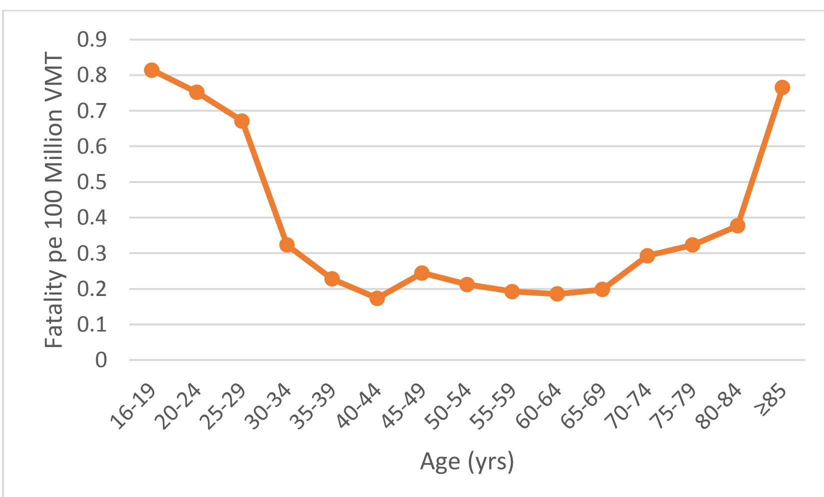


Figure 16. Driver fatality per 100 million vehicle miles traveled where the vehicle rolled over categorized by age (Insurance Institute for Highway Safety, 2011; National Highway Traffic Safety Administration, 2012).

The roof strength to weight ratio (SWR) or the roof supports are critical to protecting occupants during a rollover event. To test the SWR, the IIHS uses a plate to press on the vehicle's roof to crush it a total 12.7 cm (5 in), using a slowly increasing force. See Figure 17. During the crush, the load cells attached to the plate measure the peak force used to accomplish the 12.7 cm (5 in) of crush. Then the following equation is used to calculate the SWR:

$$SWR = \frac{Force\ used\ in\ test}{Weight\ of\ vehicle} \qquad \text{Equation 13}$$

Federal regulation states that vehicles made prior to 2013 were required to have a 1.5 SWR or higher; however, vehicles manufactured in 2013 or later are required to have a SWR of 3 or higher (National Highway Traffic Safety Administration, 2008b). IIHS also provides a rating of *good*, *acceptable*, *marginal*, or *poor*. In order to get the highest IIHS rating of *good*, the vehicle must obtain a SWR value of at least 4 (Insurance Institute for Highway Safety, 2013d). As with the previous two events, maintaining proper space to allow the vehicle designs to do their job during a crash is imperative. In the case of a rollover event, maintaining proper headspace will allow the vehicle to absorb a significant portion of the energy from the rollover impact before the occupant experiences an intrusion into the occupant's space.

Figure 17. IIHS Roof Crush Test (Insurance Institute for Highway Safety, 2013d).

1.10 CarFit©: An Educational Program for Older Drivers

The potential for serious injury or a fatality from vehicle impacts could be influenced by the selected seating position of a driver. The dangers of a driver sitting out of position in a vehicle are highlighted above in section 1.9. Maintaining correct seat positioning for drivers has the potential to provide added safety during the driving process. Given that the older population is increasing, and at the same time, this population is driving more than ever before, strategies for improving safety for aging road users continue to be a priority. Designed to help older persons remain safely mobile, CarFit© is an educational program to help older drivers learn about safe seating positions.

CarFit© was originally designed by the American Society on Aging (ASA) in 2001 (CarFit©, 2012). In 2004, ASA collaborated with the American Association of Retired Persons (AARP), the American Occupational Therapy Association (AOTA), and American Automobile Association (AAA) to disperse CarFit© materials and training around the country (CarFit©, 2012). The CarFit© program provides a quick yet comprehensive check to determine how well older adults “fit” in their car. The organizers of CarFit© provide guidelines to allow older drivers to gain the optimal position in their vehicle and to allow them to utilize their strength, range of motion, and visual (such as scanning the environments) abilities to their fullest potential. Some examples of these guidelines and safety rationale include the following:

- Steering wheel position must allow at least 5.1 cm (2 in) of space between the top of the driver's thighs and the bottom of the steering wheel. This will allow unimpeded leg movement, particularly the right leg movement between the pedals. Measurement is shown below in Figure 18.

Figure 18. Measurement of the space between the upper thigh and the bottom of the steering wheel.

- Head restraint should be positioned to allow only 5.1 cm (2 in) between the back of the person's head and the center of the head restraint. This position will decrease the risk for neck injuries in the event of a collision. Measurement is shown below in Figure 19.

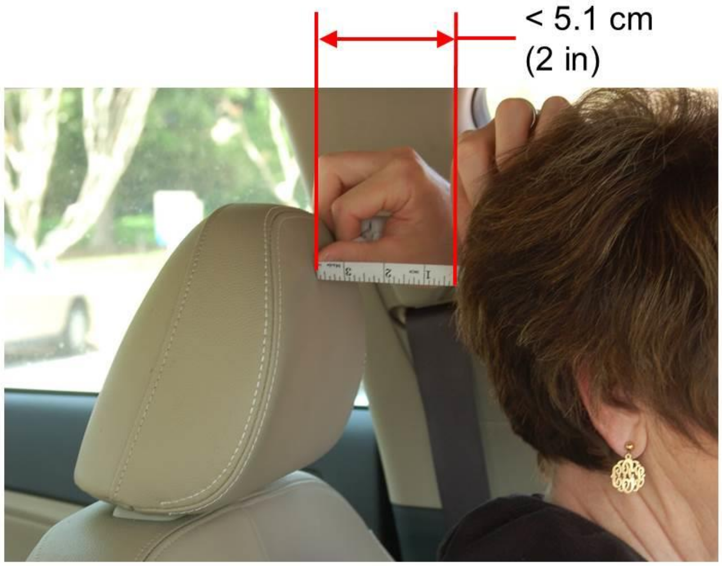


Figure 19. Horizontal distance from the back of the head to the front of the head restraint.

- Drivers need to sit at least 25.4 cm (10 in) back from the steering wheel/airbag. This decreases the risk of harm from airbag activation. The 25.4 cm (10 in) distance is a general guideline recommended by NHTSA and includes a safety margin. It was calculated by allowing 5.1-7.6 cm (2-3 in) for the size of the "risk zone" just beyond the airbag cover, plus 12.7 cm (5 in) for the distance occupants may move forward in a crash (even if belted) while the airbags are inflating, plus

5.1-7.6 cm (2-3 in) to give a margin of safety. Measurement is shown below in Figure 20.

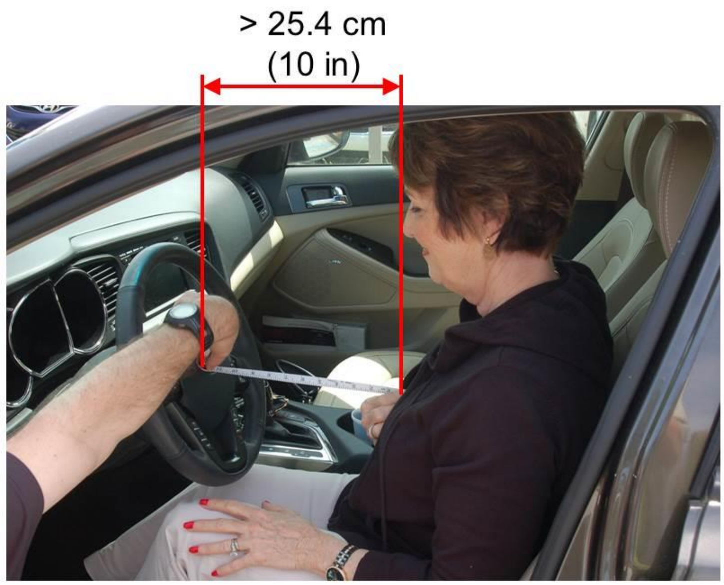


Figure 20. Distance the driver sits away from the center of the steering wheel.

- A minimum distance of 7.6 cm (3 in) above the top of the steering wheel is required for a good, straight line of vision for safety and for adequate view of the road ahead. Measurement is shown below in Figure 21.

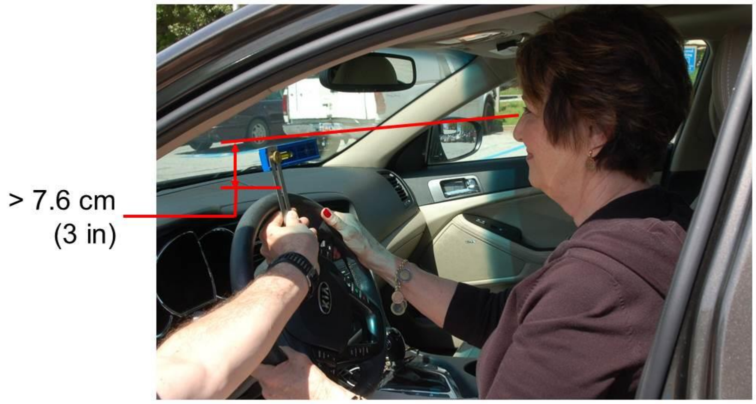


Figure 21. Measurement of straight-line vision above the steering wheel.

- A minimum distance of 10.2 cm (4 in) from the top of the head to the vehicle ceiling is required to provide adequate space for the roof to collapse in case of a rollover event. Measurement is shown below in Figure 22.

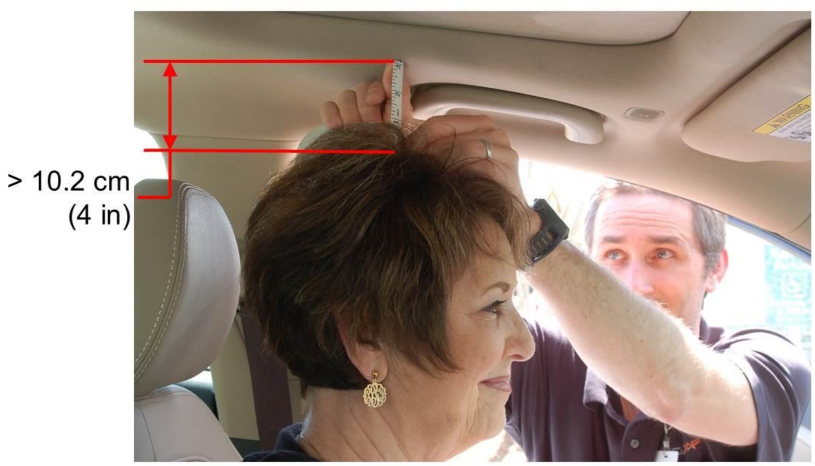


Figure 22. Measurement of the top of the head to the ceiling of the vehicle.

- Drivers should not have to extend their leg fully or use their toes to press on the gas and brake pedals and push them through their full range. If a driver has to extend his or her leg fully, it can be tiring and cause fatigue in the leg muscles (CarFit©, 2012).

CHAPTER TWO

GAP ANALYSES

2.1 Introduction

Several studies in the past have influenced industry standards as well as recommended practices for how seat positioning systems should be designed to accommodate an individual's preferred seat position. Some of the studies predate existing safety equipment such as airbags, yet remain influential in the fore/aft seat position. This chapter discusses the gaps found in the existing literature and states research questions and hypotheses that will address the absent research.

2.2 Gap One: Self-regulation of seat position.

As identified earlier, aging has an impact on an individual's driving behavior. Many medical and physical issues associated with aging, such as bone loss, decreased range of motion and degradation of vision, have a gradual onset, and older drivers are often unaware of the full extent that such issues influence their driving safety (Eby & Molnar, 2009). However, it is well-known that some older drivers self-regulate their driving behaviors by driving at slower speeds, driving during low traffic times of the day, and, ultimately, deciding on driving cessation (Baldock, Mathias, McLean, & Berndt, 2006; Eby & Molnar, 2009; Marottoli et al., 1997).

The current state-of-the-art does not address if older drivers are self-regulating their own seat position. Therefore, it is unknown whether or not older drivers are placing themselves in jeopardy by selecting a seat position that places them in harm's way during events such as an airbag deployment, being too close to the ceiling in the event of a vehicle roll-over, or being too far from the head restraint to protect from whiplash during a rear-end collision.

Research question 1.

Does the selected seat position from the older driver population differ significantly from the SAE J4004 recommended practice such that there is a need for adjustment to the practice?

Hypothesis 1.

This research hypothesizes that older drivers prefer a more forward driving position in the vehicle as compared to the SAE J4004 recommended practice. This is because older drivers are over represented in crash fatality statistics, specifically airbag related fatalities, which suggests that older drivers sit more forward than the SAE J4004 recommended practice predicts.

Research question 2.

Does the selected seat position from the younger driver population differ significantly from the SAE J4004 recommended practice such that there is a need for adjustment to the practice?

Hypothesis 2.

This research hypothesizes that the driving positon of younger drivers will not differ significantly in the vehicle as compared to the SAE J4004 recommended practice. This is because the SAE J4004 recommended practice is based on prior research data collected from a younger population sample.

Research question 3.

Does the selected seat position of the older driver population differ significantly from the selected seat position of a population of younger drivers, such that older drivers should be represented differently?

Hypothesis 3.

This research hypothesizes that the older driver population will differ significantly from the younger population by sitting more vertical, forward, and upright than younger drivers sit. This is because if older drivers differ from the SAE J4004 recommended practice as expected in Hypothesis 1, and younger drivers do not differ from the SAE J4004 recommended practice as expected in Hypothesis 2, then older drivers' selected seat position must also differ from younger drivers' selected seat position.

2.3 Gap Two: Description of older driver selected seat position.

There have been studies that have had significant impact on measuring driver selected seat position, and as a result, have influenced the development and reaffirmation of SAE recommended practices J1517 and J4004 (Flannagan, Manary, Schneider, & Reed, 1998; Flannagan et al., 1996; Philippart, Kuechenmeister, Ferrara, & Arnold, 1985; Philippart et al., 1984; Reed, 2013; Schneider, Olsen, Anderson, & Post, 1979). From these studies, three primary regressions have resulted, as discussed above in section 1.8. However, it is suggested that the older driver population will sit in a more assertive position than their younger counter parts. In addition, the growth rate of the population has caused a change in the percentiles that these regressions use to define the curves. Therefore, the regressions used in the literature potentially exclude the largest growing population in the US, and therefore a separate set of equations is needed to accommodate older drivers.

Research question 4.

Can the selected seat position of older drivers be accurately explained with a mathematical model?

Hypothesis 4.

It is the hypothesis of this investigator that an improved linear regression to include gender and age variables will provide a more accurate model to predict seat track position of older drivers. This is because of the stature changes that are associated with ageing and the fact that stature is normally distributed for both males and females.

2.4 Gap Three: Drivers positioned outside of safe seating guidelines.

CarFit© has developed an educational program for older drivers to learn how to adjust the seat position of their car to best "fit" them. The perceived effectiveness, usefulness, and impact on behavior change of the CarFit© program is well documented (Cosentino, Hernandez, & Hocking, 2008; Dickerson, Painter, Cosentino, Hocking, & Hernandez, 2008; Stav, 2010). However, there are no publications regarding the number of older drivers who do not meet the sitting criteria of the CarFit© program. As a result, the frequency of older drivers positioned outside of safe seating guidelines is unknown, and therefore requires investigation.

Research question 5.

What percentage of drivers sit outside of the safe seating guidelines presented by CarFit©?

Hypothesis 5.

It is hypothesized that the likelihood of noncompliance with CarFit© criteria will increase with respect to age. This is because older drivers show an over representation of airbag and rollover related fatalities per 100 million vehicle miles traveled; therefore, it is assumed that older drivers are not meeting the CarFit© requirements.

Research question 6.

What percentage of smaller stature drivers sit outside of the safe seating guidelines presented by CarFit©?

Hypothesis 6.

It is hypothesized that the likelihood of noncompliance with CarFit© criteria will increase with decreasing stature. This is because as stature decreases the driver will need to move the seat more forward and upward to accommodate reach of the vehicle controls and proper view of the road, therefore increasing the likelihood of not complying with several CarFit© criterion.

2.5 Gap Four: Knowledge of seat adjustors.

The older driver population began driving prior to many technologies available in today's vehicles. For instance, the first Baby Boomers reached driving age six years prior to the first seat belt law in 1968 (National Highway Traffic Safety Administration, 1972) and seven years prior to the first head restraint law in 1969 (National Highway Traffic Safety Administration, 2000a). As time progressed so did other technologies, such as the popular inclusion of power seats in all lines of vehicles rather than just the luxury vehicles, and the inclusion of safety equipment, such as airbags in 1998. However, most drivers never received training regarding the new technologies equipped in vehicles, and eventually the driver's knowledge becomes eclipsed by the advancements within the vehicle. Anecdotal information from conducting the pilot study of this research allowed the investigator to infer that the large portion of older drivers did not know how to adjust their seat position. A search of the literature yielded no publication documenting a driver's ability to adjust the seat position, and therefore it is unknown if the driver knows how to adjust the vehicle seat.

Research question 7.

Do a larger percentage of younger drivers, rather than older drivers, know how to demonstrate adjustments to their seat and steering wheel?

Hypothesis 7.

It is hypothesized that the majority of older drivers do not know how to demonstrate a number of seat adjustments, and that when compared to a younger driver population, the portion of older drivers that cannot demonstrate the adjustments will be significantly larger than the younger population. This is because of the researcher's prior experience and observations at CarFit© events, where older drivers frequently required training on the seat adjustment controls.

CHAPTER THREE

PART ONE: PILOT STUDY WITH OLDER ADULTS FROM THE COMMUNITY

3.1 Introduction

This chapter provides the details of the study methods used to capture the driver's selected seat position of older adults. The procedures from this study served as a pilot study in order to identify older drivers' selected seat position within their own vehicle. By collecting the data within the participant's own vehicle, the study reflects the most natural setting for measuring a person's seat position. The assumption was made at the start of the study that all drivers are familiar with all of the possible seat and steering wheel adjustments of their vehicle and have positioned their seat prior to driving on the road. Since the data were collected within the participant's own vehicle, the investigator selected measurements that could be taken at various study sites, that would yield accurate measures and that would represent relevant measures for occupant packaging specific to the driver's seat position.

The chapter sections that follow are section 3.2 that provides a summary of the participants from the experiment. Section 3.3 describes where participant recruitment took place. Section 3.4 describes the sites where the study took place. Next, section 3.5 outlines the tools purchased, created, and borrowed from the National Highway Traffic and Safety Administration (NHTSA) to capture the participant's selected driving position. Section 3.6 presents the flow of the data capture and a summary of the measurements taken. A manual with a detailed description of the measurements can be found in Appendix A, and the corresponding data form can be found in Appendix B. Last, Section 3.7 addresses the lessons learned based on the pilot study.

3.2 Participants

Sixty-two total participants took part in the data capture of selected seat position. Inclusion criteria included the ability to read, write and speak English; possess a valid driver license; supply their own personal sedan, and be over 60 years of age. Participants were excluded from the study if they drove from a wheelchair, used adaptive driving devices, were outside the height range of 152 to 188 cm (60 to 74 in), or drove the following vehicle types: a sport utility vehicle (SUV), a pick-up truck, a mini-van, or a full-size van. One of the participants was excluded from data analyses because he/she arrived in a vehicle other than a sedan or crossover vehicle, and therefore did not meet the inclusion requirements. The data for the remaining 61 participants included in the study are presented in Table 11. The range of the participants' ages was 60 to 82 years with a mean of 69.8 years, and the gender was split 58% female and 42% male. Participants were compensated $25 in exchange for their participation.

Table 11

Part 1 Participant Demographic Information

Characteristic	Combined	Male	Female
Number of participants (n)	61	25	36
Age (years)			
Range (min - max)	60 - 81	61 - 81	60 - 81
Mean	69.8	70.6	69.1
Std. deviation	6.4	6.4	6.4
Stature (mm)			
Range (min - max)	1405 - 1892	1676 - 1892	1405 - 1753
Mean	1692	1778	1628
Std. deviation	98.5	53.3	68.6
Foot length[a] (mm)			
Range (min - max)	224 - 310	251 - 310	224 - 259
Mean	254	272	244
Std. deviation	17.8	12.7	7.6

[a] Foot length was determined by the measurement associated shoe size as determined by the Brannock Device.

3.3 Recruitment

Participant recruitment included fliers and posters placed in local senior organization locations, community awareness presentations, and a study registry.

3.4 Study Site

Data were collected in a parking lot at Clemson University-International Center for Automotive Research (CU-ICAR) and at a senior-focused organization.

Figure 23. Study site at CU-ICAR.

All measurements at each site were captured with the participant's vehicle in a parking space, the vehicle gear in the "park" position, and the vehicle ignition in the "off" position. At times, measurements of the participant required the participant to sit inside the vehicle while measurements were collected. Other measurements required the participants to wait nearby while further data were gathered. Additional details to this process are covered in the procedure section of this chapter.

3.5 Apparatus

Tools.

During the measurements, a standard set of tools such as rulers, combination squares, and tape measurers were used. In addition, two custom tools were created. One, which was on loan from NHTSA, was a digital vernier tool combined laser guide to measure lateral position of items in the vehicle. The second custom tool was the vertical post rule used to measure vertical location of items from ground level. See Appendix C for a complete list of standard and created tools as well as the details regarding their accuracy.

Data records.

During the measurement session, the data were captured using a pen-and-paper data sheet. See Appendix B.1 for full copies of the data form. After the measurement session concluded, the data were entered into a spreadsheet.

3.6 Procedure

The pilot study took place from May 2012 through July 2012 at the study sites mentioned above in section 5.4. The duration of each measurement session was a maximum of 3 hours. All participants in this study received the seating portion of the CarFit© program, as detailed in Chapter One, and feedback from data collectors on improved seating position.

When a participant arrived at the study location, he/she was directed to a designated parking spot and asked to turn off the car, and then exit the car. After greeting and consenting the participant, a brief overview of the study was presented. See Figure 24 for the flow of the study. The participant was then asked to sit in the driver seat inside his/her vehicle and fasten the seat belt.

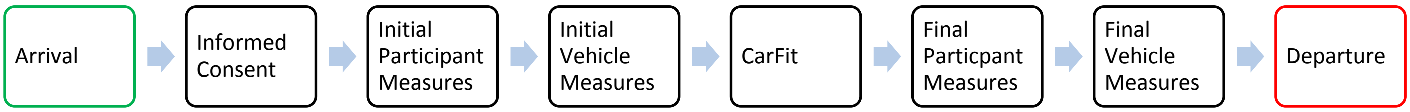


Figure 24. Flow of the measurement session.

With the participant's hands on the steering wheel and the participant's right foot resting on the brake pedal, the initial participant measures were captured. After six different measures with the participant seated in the vehicle, the participant exited the vehicle, stood for one anthropometric measurement, and answered five questions. (A sixth question was asked if the participant answered "no" to one of the five questions.) See phase 2 of the Phases of Measure section, Table 13 or Table 14 below.

After the initial measures, the participant went to a nearby waiting area or stood nearby to observe the rest of the data capture. Meanwhile, the data collector recorded further details about the participant's vehicle and his/her selected seat position. After this information was collected, the participant returned and continued through the seating portion of the CarFit© procedures. Once the participant was repositioned into the optimal seating position per the CarFit© process, the initial measures were then recaptured and recorded as the final measures.

Phases of measure.

For this pilot study, there were 11 phases of data collection described in Table 12. A list of the measures for each phase of measure is shown below in Table 14 with details of how the measure was taken in Appendix A. In addition, a sample data form is provided in Appendix B.1.

Table 12

Phases of Measure

Phase	Description
1	Study identification information
2	Measurements with participant present
3	Vehicle product information
4	Initial and final seat position measures
5	Measurements of vehicle space
6	Measurement of the adjustable pedal envelope
7	Measurements of pedals with laser
8	Appearance of brake pedal
9	Appearance of acceleration pedal
10	Photographs of vehicle
11	Measurements requiring calculations

Phase 1 recorded the study identification information: participant number, the date that the collection occurred, and the data collectors that performed the data measurements. Next, phase 2 measurements with the participant present were collected. The participant present data included six measures that provided information on how a person fits within the vehicle, six questions about the driver and vehicle ownership, and one anthropometric measure.

Table 13

Measurements and Questions Taken with the Participant Present

	Measurements	Questions
1	Ground to eye level	What is the participant's shoe size?
2	Top of leg to steering wheel bottom	What is the participant's gender?
3	Top of steering wheel to eye level	What is the participant's age?
4	Center of steering wheel to eye level	Is the participant the only driver?
5	Top of head to roof	What percentage does the participant drive vehicle?[a]
6	Back of head to head rest	Was the vehicle purchased new or used?
7	Participant stature	

[a] Question asked only if driver answers *no* to being the only driver of the vehicle.

Once the data in phase 2 were collected, the participant was excused to either wait inside the study site's facilities or, at the participant's discretion, observe the data capture. At this point phase 3 began, and specifics about the vehicle such as the make, model, engine type, driveline, and seating accommodations were recorded. In phase 4, further data on the participant's selected seat position, including the ranges of the vehicle seat selection options, were collected. In phase 5, data about the vehicle's brake and accelerator pedal size and position were captured. In addition, measurements to describe the height of the vehicle floor above the ground were taken during phase 5. See Table 14 below. If the participant's vehicle had adjustable pedals, then in Phase 6 the seat and pedals were adjusted to the extreme locations to capture the participant's available choices; otherwise, the data collector marked "no" on the sheet and continued to phase 7. For phase 7, the data collector used the Vernier laser position gauge to find the center of the driver seat and measure the displacement to the locations on the brake pedal, accelerator pedal, and steering wheel shown in Figure 25, 26, and 27. The laser measurements data in phase 7 is part of the standard data collection process for NHTSA. The brake pedal and accelerator data are not used in this dissertation; however, the steering wheel data are used to provide the diameter of the steering wheel.

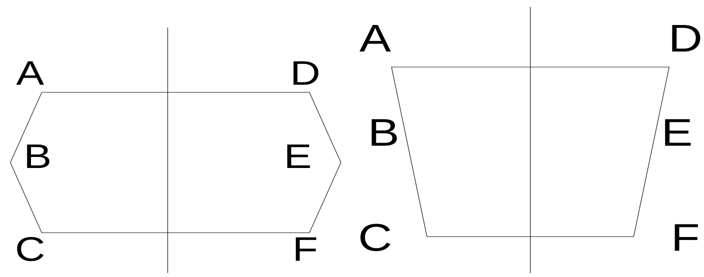


Figure 25. Generic shapes of a brake pedal.

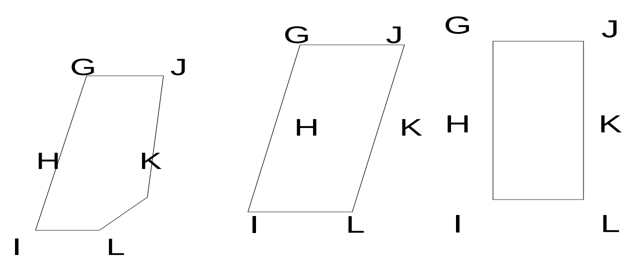


Figure 26. Generic shapes of an acceleration pedal.

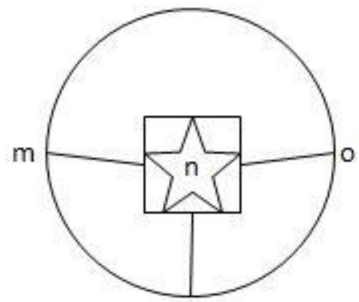


Figure 27. Generic shape of a steering wheel.

In phase 8, the data collector noted the general shape of the brake pedal by either circling the shapes shown in Figure 25 or drawing one in the provided space on the data sheet if the shape was neither. Similarly, in phase 9 the data collector noted the general shape of the acceleration pedal by either circling the shapes shown in Figure 26 or drawing one in the provided space if the shape was none of those above.

As the last phase before retrieving the participant, phase 10, the data collector took two photos of the driver compartment and of the driver side footwell, similar to the photos found in Figure 28.

Figure 28. Sample passenger cabin and driver footwell.

After the data collector took the photographs for phase 10, the participant was asked to return from the nearby waiting location and then asked to sit in the vehicle. Next, the investigator instructed the participant on the CarFit© seating guidelines (see description below). Following this instruction, the participant was asked to adjust the seat accordingly. Once the CarFit© seating position was complete, the data collector then recaptured the initial measures from phase 2 and all ten seat position measures from phase 4. See the asterisked items below in Table 14. The list below is the CarFit© information provided to the driver.

It is recommended that

- There is at least 5.1 cm (2 in) of vertical space between the top of the driver’s thigh and the bottom of the steering wheel.

- The driver's straight-line vision is at least 7.6 cm (3 in) above the top of the steering wheel
- The driver is sitting at least 25.4 cm (10 in) back from the center of the steering wheel
- The head restraint should be positioned to allow a maximum of 5.1 cm (2 in) between the back of the person's head and the center of the head restraint.
- There is at least 10.2 cm (4 in) of space between the top of the driver's head and the ceiling of the vehicle
- The driver should not have to fully extend the leg or extend the toes to press on the gas and brake pedals to push them to their full range.
- The driver does not have to over extend the arms to reach the steering wheel and vehicle controls.

After the CarFit© data portion was collected, the data collector answered any questions the participant had. Then the participant was thanked for taking part in the study and was able to leave. Finally, in phase 11, the data collector used values in the previous phases of measure to calculate other values of interest, such as vehicle floor to eye level and gap between pedals. See Table 14 for a complete list of measurements requiring calculations.

Table 14

Measurements and Vehicle Information Captured for Study

	1. Study Identification Information	2. Measurements with Participant Present	3. Vehicle Product Information	4. Initial and Final Seat Position Measures[a]	5. Measurements of Vehicle Space
A	Participant Number	Ground to eye level[a]	Make	Seat track length/position	Vertical height of ground to door seal
B	Date	Top of leg to steering wheel bottom[a]	Model	Angle of seat base	Door seal to vehicle floor
C	Data Collectors	Top of steering wheel to eye level[a]	Trim	Angle of seat back	Top of brake pedal to top of acceleration pedal
D		Center of steering wheel to eye level[a]	Year	Distance of center of brake pedal to front, center and top edge of seat base	Bottom of brake pedal to bottom of acceleration pedal
E		Top of head to roof[a]	Odometer	Position of telescoping steering wheel	Step over height of the brake pedal above acceleration pedal
F		Back of head to head rest[a]	Vehicle Identification Number (VIN)	Position of steering wheel angle	Acceleration pedal height
G		Participant height	Engine type	Vertical height of the top of the steering wheel to the ground	Acceleration pedal length
H		Shoe size	Engine displacement	Seat height at front, center and top edge of seat base	Acceleration pedal angle
I		Gender	Power brakes	Vertical height of the H-point to the ground	Brake pedal height
J		Primary driver percentage	Driveline type	Distance of the H-point to the center of brake pedal	Brake pedal length
K		Purchase the vehicle new or used	Transmission type		Brake pedal angle
L		Number of floor mats present	How the pedals are mounted		
M		Presence of wear pattern on the floor mat	Is the headrest adjustable		
N			Number of seat adjustment		
O			Presence of aftermarket items		

[a] Values captured in the initial position and in the CarFit© position.

Table 14 *continued*

Measurements and Vehicle Information Captured for Study

	6. Measurement of the Adjustable Pedal Envelope	7. Measurements of Pedal and Steering Wheel with Laser	8. Appearance of Brake Pedal	9. Appearance of Acceleration Pedal	10. Photographs of Vehicle	11. Measurements Requiring Calculations
A	Seat in the forward position and brakes lowered completely	Brake top left	Circle or draw the generic shape of the brake pedal	Circle or draw the generic shape of the accelerator pedal	Side photo of the driver's seat	Brake pedal width
B	Seat in the rearward position and brakes lowered completely	Brake center left			Combined photo of the brake and accelerator pedal	Acceleration pedal width
C	Seat in the forward position and brakes raised completely	Brake bottom left				Steering wheel diameter
D	Seat in the rearward position and brakes raised completely	Brake bottom right				Ground to floor
E		Brake center right				Floor to eye level
F		Brake top right				Gap between pedals
G		Accelerator top left				Range of pedals
H		Accelerator center left				Floor to top of steering wheel
I		Accelerator bottom left				Floor to H-point
J		Accelerator bottom right				
K		Accelerator center right				
L		Accelerator top right				
M		Steering wheel center				
N		Steering wheel left				
O		Steering wheel right				

3.7 Lessons Learned

During the pilot study, the investigator made several observations with regard to the data collection process and captured data. The primary observation was that a number of participants were unfamiliar with the various adjustments possible, not only to the seat but also to the steering wheel. For example, when participants were asked to adjust the telescope (the in and out motion) of the steering wheel in order to accommodate their new seat position, many participants were unfamiliar with how to accomplish a telescope adjustment. As a result of participant inexperience, the investigator taught the participants how to perform the unknown adjustment during the CarFit© portion of the study. Going forward, items to capture future participant's knowledge regarding the seat and steering wheel adjustments should be added, specifically by asking the participant to demonstrate each of the available adjustments. The second observation during this pilot study was that the data collection measured the distance from the brake to the H-point Jig; however, the anthropometrics of the participant's legs were not captured. Therefore, the length of the upper legs and lower legs should be added to the data measures. The third observation had to do with phase 5 measurements of the vehicle space and phase 7 measurements of pedals with the laser. These measurements are taken to quantify the position of the accelerator and brake pedals in space; however, the lateral distances to the center console and the left footwell wall are neglected. Therefore, the distance from the right edge of the accelerator pedal to the left wall of the center console, and the distance from the left edge of the brake pedal to the left footwell wall should be added to the measurement data points. In addition, two questions should be added to the participant present data capture. The first question should ask the participant, “Have you ever participated in this study before?” This question should be added with future parts of the study in mind where demographics may overlap. In order to identify qualitative information regarding the driver’s seat selection, the second additional question should be an open-ended question that asks, “Why did you select this seat position?”

It should be noted that the CarFit© seat position guidelines were given to all participants in this study; however, confirmation of this was not recorded during part one of this study. To improve this, data points should be added to confirm that all CarFit© seat position guidelines are read to the participant. Lastly, participants expressed difficulty with being able to focus on a point in the distance and assess when the short edge of a ruler was parallel to that point without changing where they were focusing. To correct this issue, the Kreg© Multi Mark ™ tool should be used to provide a larger reference for the participant. Table 15 summarizes the observations made during the data collection and presents the changes made to future data captures.

Table 15

Lessons Learned During the Pilot Study and the Resulting Changes Used for Future Data Capture

	Observation	Adjustment to the Data Sheet
1	Some participants were unfamiliar with all available seat and steering wheel adjustments.	Have participants demonstrate each seat and steering wheel adjustment available.
2	There was no anthropometric data for comparison to the H-point to brake measurement.	Include the length of the lower and the upper leg.
3	There was a need to identify participants who might have already participated.	Add the question, "Have you ever participated in this research before?"
4	There was no input as to why the driver may have selected the seat position.	Add the question, "Why did you select this seat position?"
5	There was incomplete information about the position of the brake and accelerator pedals.	Include the distance from the right edge of the accelerator pedal to the center console wall, and the distance from the left edge of the brake pedal to the left footwell wall.
6	There was no confirmation about the specifics of the data given.	Add check boxes to indicate that the CarFit© guidelines were read to the participant.
7	Some participants had difficulty with focusing on an object in the distance and judging the height of the short edge of the ruler.	Change the tool used to measure the straight-line viewing distance above the steering wheel.

CHAPTER FOUR

PART TWO: 20 YOUNGER PARTICIPANTS FROM THE COMMUNITY

4.1 Introduction

As discussed earlier in the review of the literature presented in Chapter One, the average age of participants in previous seat position research studies was substantially lower than age of participants reported in the pilot study. In order to provide appropriate comparison between these influential studies, SAE standards, and the older population data collected in the pilot study from Chapter Three, data were collected with a younger driver population. This chapter provides the details of the study methods used to capture drivers' selected seat position of younger adults from the community. It is important to note that these methods reflect the same measures taken during the pilot study, with the additional measures outlined in the Lessons Learned section above in Chapter Three.

The following chapter sections present the methods for part 2 of the study. Section 4.2 provides a summary of the participants from this study. Section 4.3 describes where participant recruitment took place. Section 4.4 describes the study sites. Next, section 4.5 acknowledges the tools used to capture the participant's selected driving position. Last, section 4.6 presents the flow of the data capture and a summary of the measurements taken. A manual with a detailed description of the measurements can be found in Appendix A, and the corresponding data form can be found in Appendix B.2.

4.2 Participants

Twenty total participants between the ages of 30 to 39 years of age took part in the data capture of selected seat position. The mean age of the participants was 32.7 years, and the gender was split, 50% female and 50% male.

Table 16

Part 2 Participant Demographic Information

Characteristic	Combined	Male	Female
Number of Participants (n)	20	10	10
Age (years)			
Range (min - max)	30 - 39	30 - 39	30 - 34
Mean	32.7	33.1	32.2
Std. Deviation	2.4	33.1	1.4
Stature (mm)			
Range (min - max)	1575 - 1905	1676 - 1905	1575 - 1829
Mean	1725	1791	1659
Std. Deviation	94.0	66.0	68.6
Foot Length[a] (mm)			
Range (min - max)	226 - 295	236 - 295	226 - 277
Mean	257	262	251
Std. Deviation	20.3	20.3	15.2

[a] Foot length was determined by the measurement associated shoe size as determined by the Brannock Device.

Inclusion and exclusion criteria for Part 2 was the same as Part 1of the study, except the participant age range was from 30 to 39 years of age, and the vehicle type was limited to four door sedans. Participants were compensated $100 in exchange for their participation. The amount of compensation for part two of the study was increased to be consistent with the larger, NHTSA study.

4.3 Recruitment

Participant recruitment included fliers, posters, and electronic communication within the Greenville Health System (GHS) and Clemson University International Center for Automotive Research (CU-ICAR), and by word of mouth.

4.4 Study Site

Data were collected in a parking lot at GHS's Roger C. Peace Rehabilitation Hospital, as shown in Figure 29.

Figure 29. Study site at the Roger C. Peace Rehabilitation Hospital parking lot.

4.5 Apparatus

Tools.

The tools used for measuring the data for this study were identical to the standard tools and tools created for the pilot study procedures. The tools are listed in Appendix C.

Data records.

See Appendix B.2 for full copies of the data form.

4.6 Procedure

Part 2 of the study took place from October 2013 through December 2013 at the study site mentioned above in section 4.4. The flow of the study remained primarily the same; however, the study was augmented by an additional phase where the participants demonstrated their ability to adjust the seat and steering wheel. See Figure 30 for the new study flow. The new phase is highlighted in yellow. The duration of each measurement session was a maximum of 3 hours, which is the same duration as the pilot study found in the section 3.6.

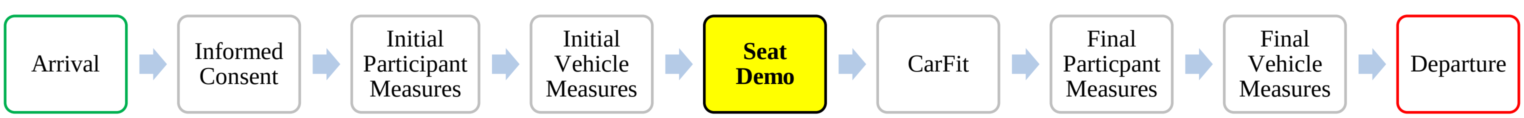


Figure 30. Flow of the measurement session.

Phases of measure.

For this study, there were 12 phases of data collection as described in Table 17. A list of the new measures added for this study in phases 1, 2, 5, and 11 can be found below in Table 19, with details of how the measure was taken in Appendix A. In addition, a sample data form for part two of the study is provided in Appendix B.2.

Table 17

Phases of Measure

Phase	Description
1	Study identification information
2	Measurements with participant present
3	Vehicle product information
4	Initial and final seat position measures
5	Measurements of vehicle space
6	Measurement of the adjustable pedal envelope
7	Measurements of pedals with laser
8	Appearance of brake pedal
9	Appearance of acceleration pedal
10	Photographs of vehicle
11	Participant demonstrates adjustments
12	Measurements requiring calculations

[a] New phase of data capture added as a result of lessons learned

Additional measures and the logic behind these additions are described above in Chapter Three, section 3.7 Lessons Learned. The following measures in the data capture were added into the study. In phase 1, the study identification information, the additional item was to ask if the participant had ever participated in the study before. The participant present measurements of phase 2 added the length of the upper leg and the length of the lower leg, along with the question, "Why did you select this seat position?" In addition, for phase 2 a change in the measurement protocol was made, where instead of a six-inch stainless steel ruler used to capture the line of sight above the steering wheel, the Kreg® Multi-Mark™ was used. See Appendix A for further detail in this change of protocol. For phase 5, measurements of vehicle space were added: the distance from right edge of the accelerator pedal to the left center console wall, and the distance from the left edge of the brake pedal to the left footwell wall. Phase 11 is an entirely new phase of data capture. In Phase 11, the participant is asked to demonstrate the ability to adjust both the steering wheel and the seat adjustments individually. See Table 18 for the list of adjustments the participant was asked to demonstrate or Appendix B.2 in the data sheet.

Table 18

Seat and Steering Wheel Adjustments the Participant Was Asked to Demonstrate

	Seat Adjustments Asked of Participant
1	Please put on and then remove your seatbelt.
2	Please move your seat downward.
3	Please move your seat upward.
4	Please move your seat forward.
5	Please move your seat backward.
6	Please recline your seatback.
7	Please bring your seatback to an upright position.
8	Please adjust the tilt of your seat bottom.
9	Please tilt your steering wheel to a different position.
10	Please show how the telescope feature of your steering wheel works.
11	Please adjust your pedals.
12	Please describe how you can adjust your headrest up and down.
13	Please describe how you can tilt your headrest.

Also in Phase 11, documentation that the data collector read the CarFit© guidelines was added. After the data collector read each item, it was checked off on the data sheet to confirm that all information was read to the participant. See Table 11 items and Appendix B.2 for the data sheet.

Table 19

Measurements and Vehicle Information Added to the Data Capture

	1. Study Identification Information	2. Measurements with Participant Present	5. Measurements of Vehicle Space	11. Seat Adjustment Demonstration
A	Have you ever been a participant in this study before?	Why did the driver select this seat position	Left edge of brake pedal to left footwell wall	Place seat belt on and off
B		Length of lower leg	Right edge of accelerator pedal to center console	Move seat up
C		Length of upper leg		Move seat down
D				Move seat forward
E				Move seat backward
F				Recline seatback
G				Bring seatback upright
H				Tilt seat bottom
I				Tilt steering wheel
J				Telescope steering wheel
K				Adjust pedals
L				Adjust the height of the head rest
M				Tilt the head rest
N				Read that there should be at least 2 inches between the leg and steering wheel
O				Read that the line of sight should be at least 3 inches above the steering wheel
P				Read that the driver should sit at least 10 inches from the steering wheel
Q				Read that the back of the should be no more than 2 inches from the center of the head rest
R				Read that there should be at least 4 inches between the driver's head and the ceiling
S				Read that driver should not have to fully extend their leg to press the full range of the pedals
T				Read that the driver should not have to fully extend their arms to reach the steering wheel

CHAPTER FIVE

PART THREE: OLDER ADULTS IN A CLINICAL SETTING

5.1 Introduction

Part 3 of this study was the measurement of driver selected seat position of older adults referred by a physician to the Driving Rehabilitation Program at Roger C. Peace (RCP) Rehabilitation Hospital. Hence, this part of the study was the measurement of older adults in a clinical setting. The purpose of this third part to the study was to increase the sample size of the study and to include the allegorical results found during the pilot study. Similar to Part 2, Part 3 captured all of the measurements taken in the pilot study as well as the seven measurements discussed in Section 3.7 for older drivers.

The measurement of driver selected seat position of older adults in a clinical setting was conducted as a subcomponent of a much larger NHTSA study; therefore, much of the participant inclusion/exclusion criteria, recruitment, and screening of participants was dictated by the larger study. For the most part, the data capture was identical to the data capture in part 2 of this study, described in Chapter Four, with slight variations to the protocol in order to prevent interference with the flow of the larger study. For example, informed consent was done at the first of three meetings of the larger study and prior to the arrival of participants for our data capture, and the measurement of the upper and lower legs was performed by an occupational therapist during a segment of the larger study.

The chapter sections that follow indicate the differences between part 3 of the study and part 2 of the study. Section 5.2 describes the intended participants and specific inclusion and exclusion criteria for both the driver selected seat position study and the larger study. Section 5.3 explains how participants will be recruited. The study site is addressed in Section 5.4. The tools used to capture the participant's selected driving position are identified in section 5.5. Last, section 5.6 depicts the differences in the data capture procedures between part 3 and part 2 of the study.

5.2 Participants

Thirty-six participants took part in the data capture of driver selected seat position. Inclusion and exclusion criteria for both the driver selected seat position study and the larger study are listed below.

(Items in bold font are inclusion and exclusion requirements for both the driver selected seat position study and the larger study; whereas, items marked with an asterisk (*) are inclusion and exclusion requirements for the larger study. Items with no markings are only important to the driver selected seat study.)

Inclusion criteria:

- Having the ability to read, write, and speak in English
- Possessing a valid driver license
- Being a minimum age of 60 years old
- Having a height between 152 and 188 cm (60 and 74 in)
- Supplying their own personal vehicle

- Having a minimum of three years of driving experience*
- Making a minimum of three roundtrip trips per week*
- Meeting the South Carolina vision requirement for driving licensure*
- Having the ability to complete the study within six weeks*
- Having the ability to wear comfortable snug-fitting shoes*
- Meeting the criteria to fall within one of the four groups of the larger study*

Exclusion criteria:

- Drives a pickup truck, full size van, or very large SUV for example: Expedition, Tahoe, Escalade
- Drives from a wheel chair
- Uses adaptive driving devices
- Having a driving evaluation administered by a Driving Rehabilitation Specialist (DRS) within the last year*
- Actively receiving treatment from an occupational therapist*
- Currently uses orthopedic support braces for right lower extremity (casts, splits, boots)*
- In order to rule out health conditions that could compromise study completion, we will also use the following question to screen for exclusion: *Has your doctor told you not to drive for any reason?**
- Absent proprioception*
- Has a reported history of Parkinson's disease*

- Has been driving legally for less than 1 year after having a seizure*
- Has history of stroke resulting in no driving*
- Driving less than 3 years after having a stroke*
- Has any injury or problems with the right leg affecting ability to walk in the last year (with the exception of surgery for hip fracture or hip replacements in the Orthopedic Surgery Group)*

5.3 Recruitment

Participant recruitment came from physician referrals to RCP, and from meetings with physicians and staff members of the Greenville Health System (GHS) to inform them about the purpose of this study. In addition, flyers were posted within physicians' offices and areas of GHS that experience large volumes of older adult foot traffic. Last, a study registry was used to make phone calls to qualifying individuals. Although these participants were recruited using GHS resources, there was no reason to believe that there was a medical reason to study these participants.

5.4 Study Site

The study site was the same study site for the measurement of younger drivers detailed in Chapter Four, section 4.4.

5.5 Apparatus

Tools.

Tools used for measuring the data for this study were identical to the standard tools and tools created for the pilot study procedures and listed in Appendix C.

Data records.

See Appendix B.3 for full copies of the data form.

5.6 Procedure

Part 3 of this study took place from July 2012 through July 2014 at the study site mentioned in Chapter Four. The flow of this study was similar to the flow illustrated in part 2 in Chapter Four. However, since this study was part of a larger, ongoing research project, participants were consented at the first of three visits to the site, prior to our data capture. Also, after the initial participant measures, the participant went inside RCP to participate in the larger study. See Figure 31.

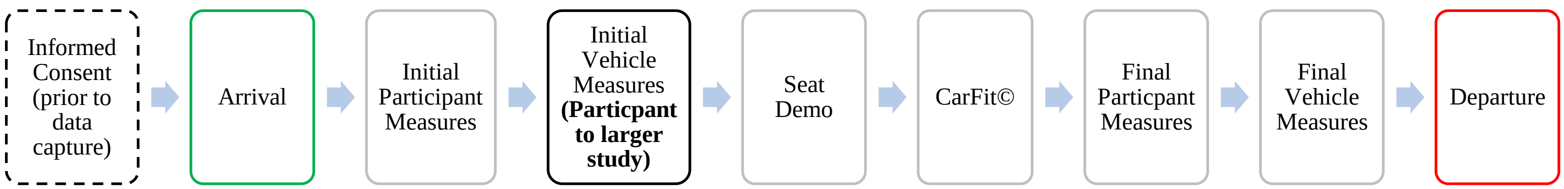


Figure 31. Flow of the research.

Phases of measure.

For this study of older adults in a clinical setting, the phases of measure for part 3 were the same as the phases of measure in part 2 of the study. See Chapter Four for more details. One difference is that the length of the lower and upper leg measurements were captured by an occupational therapist as part of the larger study and shared with this study. See the measurement manual in Appendix A for details regarding the measurements.

CHAPTER SIX

ANALYSIS OF DRIVER SELECTED SEAT POSITION

6.1 Introduction

This chapter presents the analysis for the driver selected seat position measurements and will provide the results and discussion with regards to the three hypotheses for Gap One: Self-Regulation of Seat Position stated in Chapter Two, section two. Hypothesis 1 states that older drivers prefer a more forward driving position in the vehicle than the SAE J4004 recommended practice predicts. Hypothesis 2 states that younger drivers select a seat position that will not differ from the SAE J4004 recommended practice. Finally, Hypothesis 3 states that older drivers will differ significantly from the younger population and sit more vertical, forward, and upright than younger drivers.

The chapter sections that follow are section 6.2, which discusses how the collected data are used for this analysis. Section 6.3 describes the analysis technique. Section 6.4 is the results and discussion of measurements related to the SAE J4004 recommended practice. Section 6.5 is the results and discussion of the CarFit© and posture measurements. Last, Section 6.6 is a summary of the results and discussions from Sections 6.4 and 6.5.

6.2 Data Sets

There are four data sets for this dissertation. They are the older drivers from the community setting, older drivers from the clinical setting, younger drivers, and the SAE model. Figure 32 shows the generic data structure for a nondescript measurement. For all measurements taken in this study, the older and younger driver data sets will always be represented; however, the SAE model data sets will only be represented in the measurement relevant to the Ball of Foot Reference Point (BOFRP) to the H-point measure.

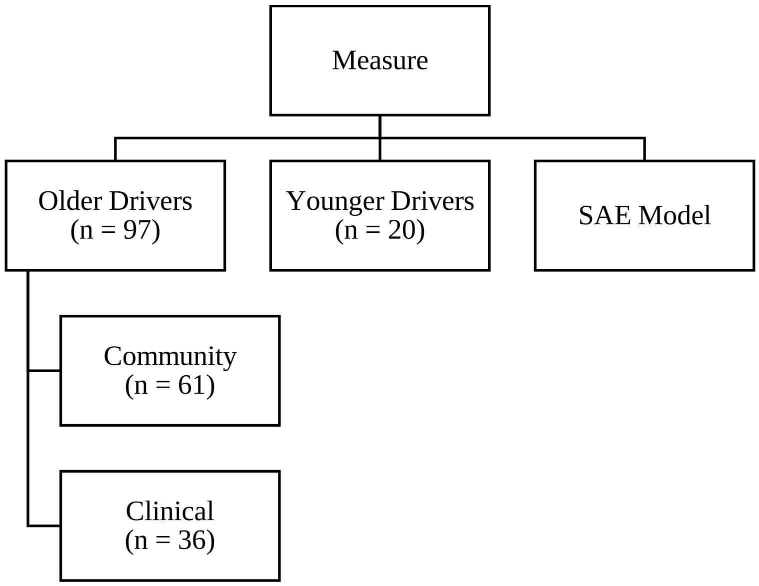


Figure 32. Structure of available data for analysis of covariance.

The younger driver data set needs no adjustment for the data analysis plan, and remains as described in Chapter Four. The older driver data set needs special care because the data were collected at two different times, and there were data points added for the older drivers in a clinical setting. As articulated in Chapter Three, there were lessons learned, and data points were added for the studies; however, all of the measures analyzed in this chapter were captured throughout all three parts of the study. Therefore, this chapter of the dissertation will combine all the older driver data that were collected in both the community and clinical settings, giving a sample of n=97. See Figure 33.

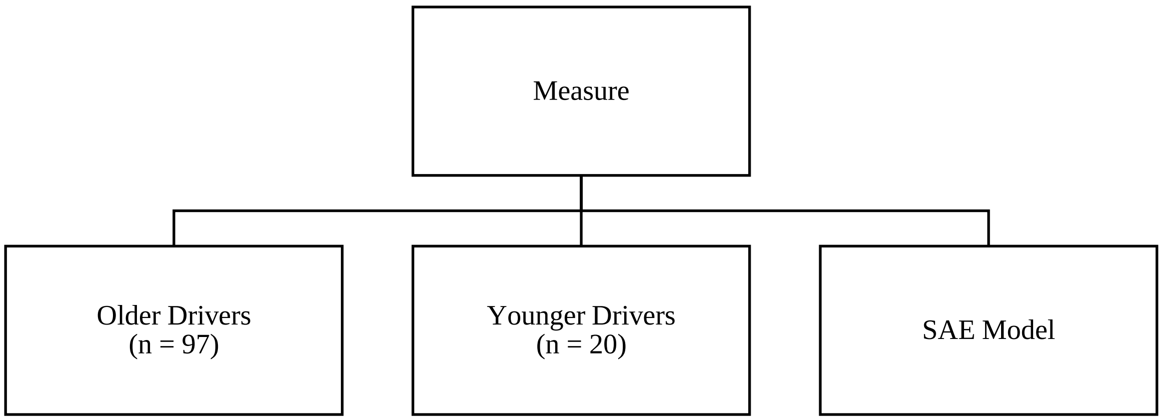


Figure 33. Final data structure for analysis of covariance.

6.3 Statistical Analyses

Driver selected seat position measurements were compared using mixed-model analysis of covariance (ANCOVA) with variables age, gender, stature and the initial/final seat position measurements. The initial/final seat position measurements were each within subject variables, while age and gender were between subject variables, and stature was the covariate. Age was transformed into a dichotomous variable, where participants ages 60 and over were grouped into the older driver category, and participants ages 30 to 39 were grouped into the younger driver category. The output of the ANCOVA models is the F-ratio (F), Fisher's p-value (p-value), and the degree of freedom for the model (df_1) and the residual (df_2). The F-ratio is a measure of the variance that can be explained by the model to the residual variance of the model. The p-value is a measure of the Type I error, which is defined as the false identification of an effect. The degree of freedom is the number of scores used in the model computation. To test the assumption of homogeneity of regression slopes, an ANCOVA model was run and allowed the covariate to interact with potential main effects. If none of the covariate and main effect interactions were significant, then homogeneity of regression slopes was assumed, and the standard full factorial ANCOVA model was used in place of the model. That being said, the tests for the assumption of homogeneity of regression slopes proved valid for all measures except for

- measured ball of foot reference point (BOFRP) to H-point,
- calculated BOFRP to H-point,
- difference between calculated and measured BOFRP to H-point,
- BOFRP to steering wheel center,
- seat base angle,
- steering wheel angle,
- center of steering to sternum, and
- top of leg to the bottom of the steering wheel measures.

Therefore, the covariate was allowed to interact with the main effects for these analyses. Note that for all analyses, Type I error rate was set at 0.05. Effect size was calculated using Rosenthal's *r*, which is used to indicate the proportion of influence that the independent variables (age, gender, and stature) have on the repeated measures. See Equation 14.

$$r = \sqrt{\frac{F}{F + df_2}} \qquad \text{Equation 14}$$

Where,

F is the F-ratio test statistic and

df_2 is the degrees of freedom for the residual.

The strategy for the analysis is as follows:

- The ANCOVA for the measured and calculated BOFRP to H-point will demonstrate how older and younger drivers differ from one another, thereby providing affirmation to the fore /aft portion of Hypothesis 3 which states that older drivers will sit more vertical, forward, and upright than younger drivers sit.
- The ANCOVA for vehicle floor to H-point will demonstrate the vertical difference between older and younger drivers, providing affirmation to the vertical portion of Hypothesis 3.
- The ANCOVA for seat back angle will demonstrate the upright difference between older and younger drivers for Hypothesis 3.
- The ANCOVA for the difference between the measured and calculated BOFRP to H-point will demonstrate how older and younger drivers differ from the SAE J4004 recommended practice, thereby answering Hypothesis 1 which states that older drivers prefer a more forward driving position in the vehicle as compared to the SAE J4004 recommended practice and Hypothesis 2 which states that the

driving position of younger drivers will not differ significantly in the vehicle as compared to the SAE J4004 recommended practice..

- The remaining variables in section 6.4 are measurements that contribute to the computation of the SAE model. These ANCOVA will provide support for Hypotheses 1, 2, and 3.
- The ANCOVA for the CarFit© measures in section 6.5 demonstrate seating preference relative to other vehicle controls and will be used to support Hypothesis 3, different seating position between older and younger drivers.

6.4 Driver Selected Seat Position Analysis for Measurements Related to the SAE J4004 Recommended Practice

This research hypothesizes that older drivers prefer a more forward driving position than the SAE J4004 recommended practice predicts and that younger drivers will not differ significantly from the SAE J4004 recommended practice. The variables used in SAE J4004 recommended practice, described in Equation 9 above in Section 1.7 Recommended Practices and Standards, are depicted below in Figure 34.

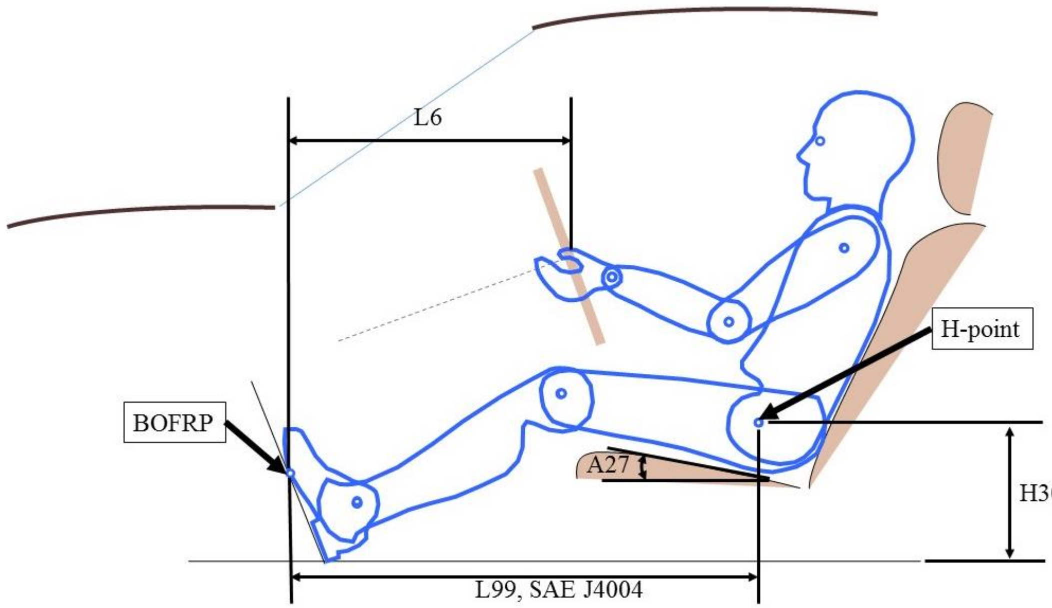


Figure 34. Depiction of variables used to calculate driver selected seat position using SAE J4004 recommended practice. L99 = measured BOFRP to H-point; SAE J4004 = SAE J4004 calculated BOFRP to H-point; H30 = vehicle floor to H-point; L6 = BOFRP to steering wheel center; A27 = seat base angle.

The remainder of this section will show the results of the mixed-model ANCOVAs to test these hypotheses. Table 20 below shows a summary table for the ANCOVA results. The complete ANCOVA table for all of the ANCOVA models and the relevant full factorial ANCOVA models are listed in Appendix D.

Table 20

Summary of Significant Effects for Measurements Related to SAE J4004 BOFRP to H-point Calculation

Variable	*F*	*p*-value	*r*
Measured BOFRP to H-point (L99)			
L99 x SAE J4004 x Age x Stature	5.950	0.016	0.228
L99 x SAE J4004 x Age	5.771	0.018	0.224
L99 x Gender x Stature	4.775	0.031	0.205
L99 x Gender	4.755	0.031	0.204
Stature (covariate)	72.005	0.000	0.631
Difference between SAE J4004 and L99 (*Difference*)			
Difference x Age x Stature	5.950	0.016	0.228
Difference x Age	5.771	0.018	0.224
Gender x Stature	4.775	0.031	0.205
Gender	4.755	0.031	0.204
Vehicle Floor to H-point (H30)			
Stature (covariate)	4.132	0.044	0.191
BOFRP to Center of Steering Wheel (L6)			
L6 x Age x Stature	4.355	0.039	0.196
L6 x Age	4.406	0.038	0.197
Seat Base Angle (A27)			
A27 x Age x Gender x Stature	4.306	0.040	0.195
A27 x Age x Gender	4.129	0.045	0.191
Steering Wheel Angle (A18)			
A18 x Stature	8.351	0.005	0.267
A18	8.512	0.004	0.269

Note. For all tests, $df_1 = 1$ and $df_2 = 109$.

Calculated and measured Ball of Foot Reference Point to H-point.

This subsection presents the ANCOVA results for the measured BOFRP to H-point (L99) and calculated BOFRP to H-point (SAE J4004). The mean (*M*) and standard error (*SE*) summary statistics for the initial and final L99 and SAE J4004 measurements by age and gender are listed below in Table 21 for review of the collected sample; however, the estimated marginal means (EMM) will be used to interpret the results of the ANCOVAs throughout the remainder of the dissertation.

Table 21

Summary of Measured and Calculated BOFRP to H-point in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Measured BOFRP to H-point (mm)								
Initial	895	7	858	7	880	19	837	15
Final	894	6	855	6	887	17	849	16
Calculated BOFRP to H-point (mm)								
Initial	904	6	846	6	901	17	846	15
Final	902	6	845	6	900	14	854	16

Note. *M* = mean; *SE* = standard error.

As indicated above, the assumption of homogeneity of regression slopes is not upheld, and therefore, the covariate stature is allowed to interact with the main effects. The results of the ANCOVA are summarized in Table 20, and the complete ANCOVA table is listed in Appendix D. The ANCOVA results indicate that there was a 4-way interaction effect between L99, SAE J4004, age, and stature, $F(1, 109) = 5.950$, $p = 0.016$, $r = 0.228$. In addition, there was a 3-way interaction between L99, gender, and stature, $F(1, 109) = 4.775$, $p = 0.031$, $r = 0.205$. Note that the number of ways an interaction is determined is by the number of independent variables that interact. For example, the L99, SAE J4004, age and stature interact; therefore, this is a 4-way interaction, and the L99, gender, and stature interaction is a 3-way interaction.

First, the 4-way interaction of SAE J4004, L99, by age, evaluated at the stature sample mean of 1695 mm indicates that within the SAE J4004 measure there was a difference between the initial and final L99 measurements as shown in Figure 35. Within the initial SAE J4004 measurement, there was a L99 increase of 17 mm for older drivers (Initial: *M* = 862 mm, *SE* = 7 mm; Final: *M* = 879 mm, *SE* = 5 mm) and 23 mm for younger drivers (Initial: *M* = 832 mm, *SE* = 15 mm; Final: *M* = 855 mm, *SE* = 11 mm). By comparison, within the final SAE J4004 measurement, there was a L99 increase of 9 mm for older drivers (Initial: *M* = 867 mm, *SE* = 6 mm; Final: *M* = 876 mm, *SE* = 5 mm) and 16 mm for younger drivers (Initial: *M* = 848 mm, *SE* = 13 mm; Final: *M* = 864 mm, SE = 11 mm). See Figure 35.

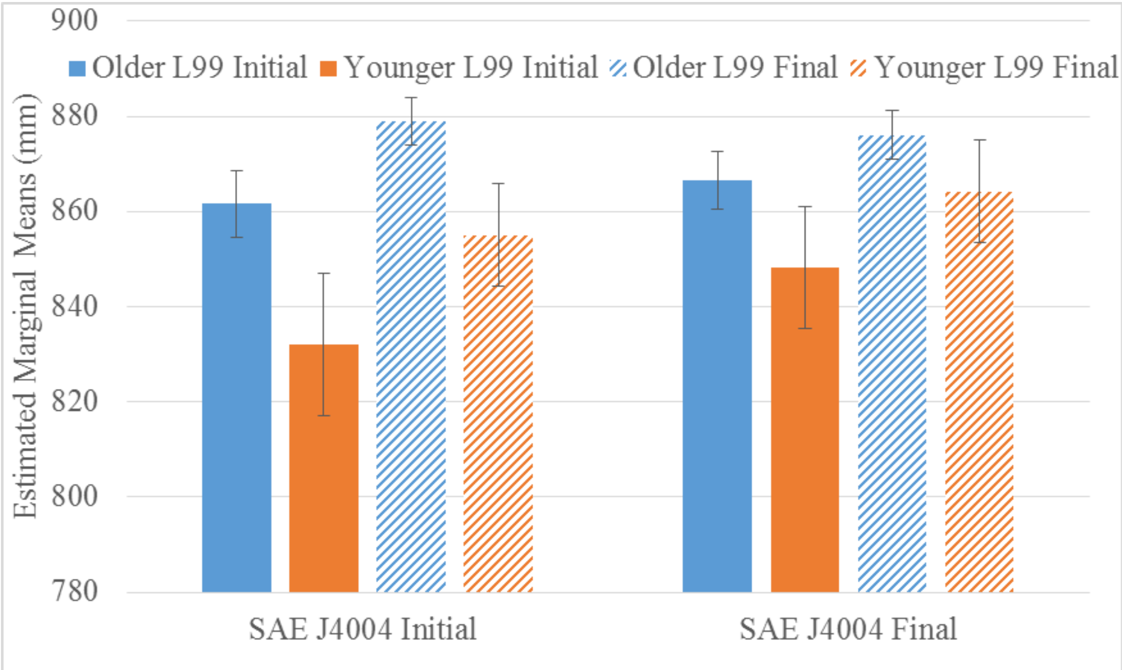


Figure 35. Estimated marginal mean for the 4-way interaction of measured and calculated BOFRP to H-point, age, with the stature covariate evaluated at the sample mean of 1,695 mm.

The difference of the L99 measure within the SAE J4004 calculation indicates that there was a difference of the measured values from the calculated value of the driver selected seat position. The measured and calculated difference occurred both before and after the driver obtained CarFit© training. This finding supports the idea that the selected seat position of the driver is different from the calculated value determined by SAE J4004.

More important to this research, the 4-way interaction shows that when within the SAE J4004 measure there is also age-related difference. Within the initial SAE J4004, there was an initial/final L99 difference of 30/24 mm between older drivers (Initial: M = 862 mm, *SE* = 7 mm; Final: *M* = 879 mm, *SE* = 5 mm) and younger drivers (Initial: *M* = 832 mm, *SE* = 15 mm; Final: *M* = 855 mm, *SE* = 11 mm). Within the final SAE J4004 measurement, the initial/final L99 difference was 19/12 mm between older drivers (Initial: *M* = 867 mm, *SE* = 6 mm; Final: *M* = 876 mm, *SE* = 5 mm) and younger drivers (Initial: *M* = 848 mm, *SE* = 13 mm; Final: *M* = 864 mm, *SE* = 11 mm). See Table 22 for the summary of EMM and *SE*.

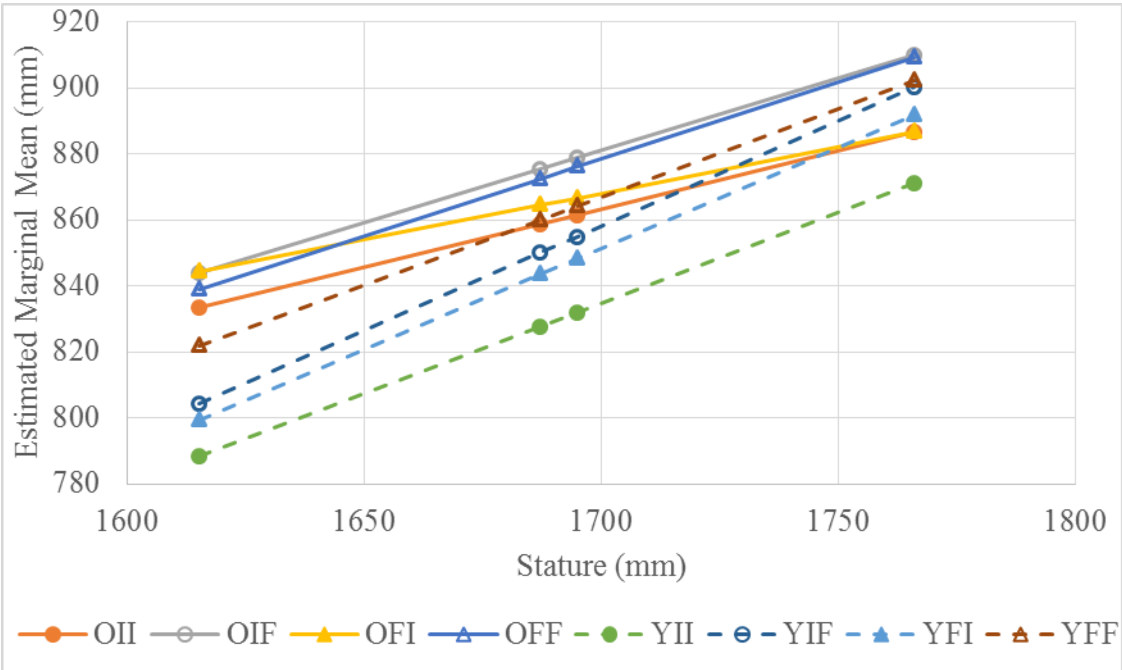
Table 22

Estimated Marginal Means by Measured and Calculated BOFRP to H-point, Age, and the Stature Covariate Evaluated at 1695 mm

	J4004 Initial				J4004 Final			
	L99 Initial		L99 Final		L99 Initial		L99 Final	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Older	862	7	879	5	867	6	876	5
Younger	832	15	855	11	848	13	864	11

Note. *M* = mean; *SE* = standard error.

Since the assumption of homogeneity of regression slopes was not upheld, the stature covariate was allowed to interact with the main effects. Figure 36 shows how the EMM change as the stature covariates are evaluated at the sample mean (stature = 1695 mm) and the 25th, 50th, and 75th population percentile values. Table 23 is a tabulation of Figure 36 with the addition of the associated *SE*.



OII	Older driver, Initial SAE J4004, Initial L99	YII	Younger driver, Initial SAE J4004, Initial L99
OIF	Older driver, Initial SAE J4004, Final L99	YIF	Younger driver, Initial SAE J4004, Initial L99
OFI	Older driver, Final SAE J4004, Initial L99	YFI	Younger driver, Final SAE J4004, Initial L99
OFF	Older driver, Final SAE J4004, Final L99	YFF	Younger driver, Final SAE J4004, Final L99

Figure 36. Estimated marginal means for the 4-way interaction of age, measured and calculated BOFRP, and stature.

Table 23

Estimated Marginal Means by Measured and Calculated BOFRP to H-point, Age, and Stature in Millimeters (mm)

	Stature (%)		25th Percentile		50th Percentile		Sample Mean		75th Percentile	
	Stature (mm)		1615		1687		1695		1766	
			M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Older	SAE J4004 Initial	L99 Initial	834	10	859	7	862	7	887	9
		L99 Final	844	7	876	5	879	5	910	6
	SAE J4004 Final	L99 Initial	844	8	864	6	867	6	887	7
		L99 Final	839	7	872	5	876	5	909	6
Younger	SAE J4004 Initial	L99 Initial	788	22	828	15	832	15	871	15
		L99 Final	804	16	850	11	855	11	900	11
	SAE J4004 Final	L99 Initial	799	19	843	13	848	13	892	13
		L99 Final	822	16	860	11	864	11	902	11

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

Table 24 shows the difference between the initial and final L99 measure by age and SAE J4004, whereas Table 25 shows the age difference for initial and final L99 and SAE J4004. The sparklines at the end of Table 24 and Table 25 plot the general trend for the associated row. These sparklines give a sense of direction for the differences within the given line item. It can be seen from Table 24 that the difference between the final and initial L99 values increases with stature for older drivers, whereas the L99 trend is inversely related for younger drivers. In addition, Table 25 shows that the difference between older and younger drivers decreases as stature increases. In other words, as stature increases the impact of age decreases. These trends can also be seen in Figure 36 above.

Table 24

BOFRP to H-point Estimated Marginal Mean Difference for Measured BOFRP to H-point Repeated Measure by Age, Calculated BOFRP to H-point Repeated Measure, and Stature in Millimeters (mm)

	Stature (%)	25th Percentile	50th Percentile	Sample Mean	75th Percentile	
	Stature (mm)	1615	1687	1695	1766	Sparkline
Older	SAE J4004 Initial	11	17	17	23	
	SAE J4004 Final	-5	8	9	23	
Younger	SAE J4004 Initial	16	22	23	29	
	SAE J4004 Final	22	17	16	10	

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015).

Table 25

BOFRP to H-point Estimated Marginal Mean Difference for Age by Measured and Calculated BOFRP to H-point Repeated Measure and Stature in Millimeters (mm)

	Stature (%)	25th Percentile	50th Percentile	Sample Mean	75th Percentile	
	Stature (mm)	1615	1687	1695	1766	Sparkline
SAE J4004 Initial	L99 Initial	45	31	30	16	
	L99 Final	40	26	24	10	
SAE J4004 Final	L99 Initial	45	21	18	-5	
	L99 Final	17	12	12	7	

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015).

The next interaction effect to discuss is the 3-way interaction effect of L99, gender, and stature. The results show that the EMM increase between the initial and final L99 measurement for both males and females. Male drivers showed a 21 mm increase from their initial L99 measurement (*M* = 840 mm, *SE* = 12 mm) to their final L99 measurement (*M* = 861 mm, *SE* = 9 mm). Female drivers had a 12 mm increase from their initial L99 measurement (*M* = 864 mm, *SE* = 8 mm) to their final L99 measurement (*M* = 876 mm, *SE* = 6 mm). Furthermore, there was a decrease from 24 mm to 15mm in the difference between males (Initial: *M* = 840 mm, *SE* = 12 mm; Final: *M* = 861 mm, *SE* = 9 mm) and females (Initial: *M* = 864 mm, *SE* = 8 mm; Final: *M* = 876 mm, *SE* = 6 mm) for the initial and final L99 measurement, respectively. See Figure 37.

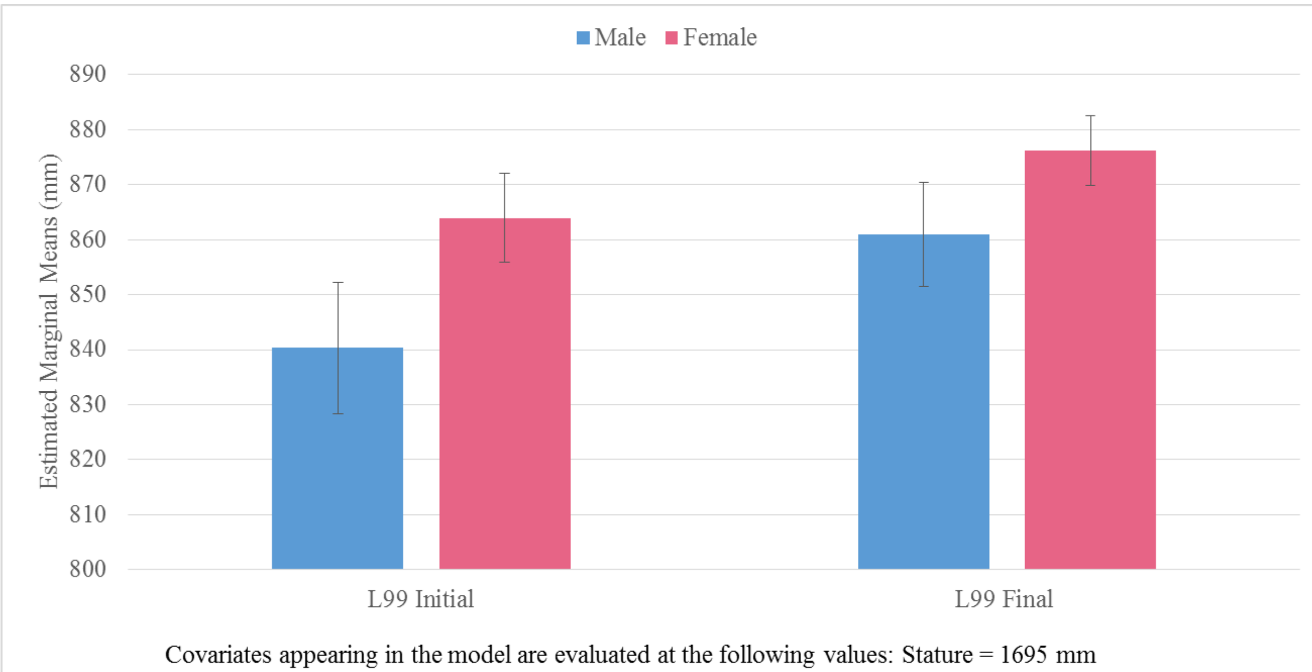


Figure 37. Estimated marginal mean for the 3-way interaction of measured BOFRP to H-point, gender, with the stature covariate evaluated at 1695 mm.

Again, since the assumption of homogeneity of regression slopes was not upheld, the stature covariate was allowed to interact with the main effects. Figure 38 shows how the estimated marginal mean varies with stature for the 25th, 50th, 75th population percentile values, and the sample mean (stature = 1695 mm). Table 26 is a tabulation of the estimated marginal mean values displayed in Figure 38 with the associated *SE*.

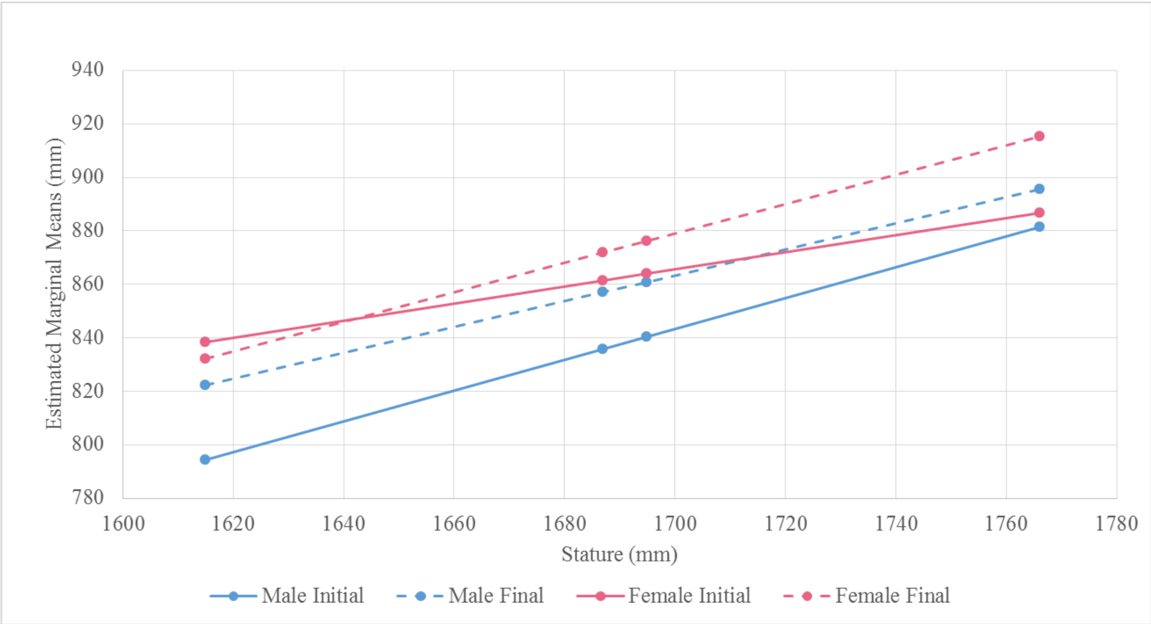


Figure 38. Estimated marginal means for the 3-way interaction of gender, measured BOFRP, and stature.

Table 26

Estimated Marginal Means by Gender, Measured BOFRP to H-point, and Stature in Millimeters (mm)

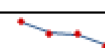
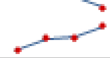
Stature (%)		25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)		1615		1687		1695		1766	
		M	SE	M	SE	M	SE	M	SE
Male	L99 Initial	794	20	836	13	840	12	881	7
	L99 Final	822	16	857	10	861	9	895	6
Female	L99 Initial	839	8	861	8	864	8	887	14
	L99 Final	832	6	872	6	876	6	915	11

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

Table 27 shows the difference between the initial and final L99 measures by gender with stature. Sparklines are used again at the end of the rows to show the general trend for each line item. Table 27 shows that as stature increases that the difference between the initial and final L99 decreases for male and increases for females. In other words, as stature increases the L99 measure is inversely related to gender.

Table 27

BOFRP to H-point Estimated Marginal Mean Difference for the Repeated Measure by Gender and Stature in Millimeters (mm)

Stature (%)	25th Percentile	50th Percentile	Sample Mean	75th Percentile	
Stature (mm)	1615	1687	1695	1766	
Male	28	21	21	14	
Female	-6	10	12	29	

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015).

Difference between calculated and measured Ball of Foot Reference Point to H-point.

This subsection looks at the statistical significance of the difference between the measured and calculated BOFRP to H-point values (*Difference*). See Equation 15.

$$Difference_j = SAE\ J4004_j - L99_j \qquad \text{Equation 15}$$

Where,

SAE J4004 is the calculated BOFRP to H-point

L99 is the measured BOFRP to H-point

j represents either initial or final value

The summary statistics for the initial and final *Difference* computation by age and gender is provided below in Table 28.

Table 28

Summary of Difference between the Calculated and Measured BOFRP to H-point in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Difference between SAE J4004 and L99 (mm)								
Initial	9	6	-13	7	21	9	9	11
Final	8	5	-11	6	13	11	6	13

Note. *M* = mean; *SE* = standard error.

Homogeneity of regression slopes is not upheld for the *Difference* ANCOVA; therefore, the covariate stature is allowed to interact with the main effects of the ANCOVA. The results of the ANCOVA is summarized above in Table 20, with the complete ANCOVA table in Appendix D. Table 20 states that there was a 3-way interaction between the *Difference*, age, and the covariate stature (F(1, 109) = 5.950, p = 0.016, r =0.228) as well as a 2-way interaction between gender and the covariate stature (F(1, 109) = 4.755, p = 0.031, r = 0.205).

The 3-way interaction of *Difference*, age, and stature indicates that the SAE J4004 model does in fact differ by age group. The results of the ANCOVA are shown below in Figure 39 and Table 29. The results indicate that older drivers' selected seat position initially differs by *M* = 17 mm, *SE* = 7 mm from the SAE J4004 model, and that younger drivers differ by *M* = 23 mm, *SE* = 14 mm. After CarFit© training, older drivers differed from the SAE J4004 model by *M* = 9 mm, *SE* = 6 mm, and younger drivers by *M* = 16 mm, *SE* = 13 mm. All of the previous values were positive; therefore, these EMM for the selected seat positions were more forward than the SAE J4004 model predicted.

Table 29

Estimated Marginal Means by Difference, Age, with the Stature Covariate Evaluated at 1695 mm

	Initial *Difference*		Final *Difference*	
	M	*SE*	*M*	*SE*
Older Driver	17	7	9	6
Younger Driver	23	14	16	13

Note. *M* = mean; *SE* = standard error.

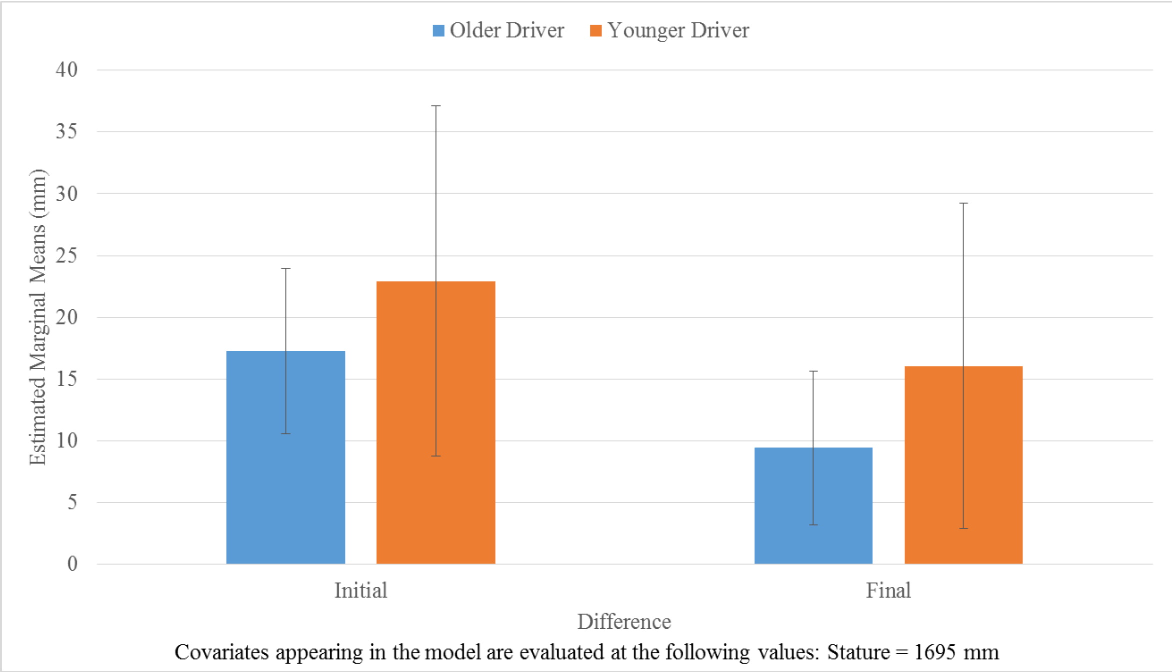


Figure 39. Estimated marginal means for the 3-way interaction of *Difference*, age, with the stature covariate evaluated at 1695 mm.

The assumption of homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 40 shows the EMM for *Difference* by age and stature, while Table 30 is a tabulation of these values with the associated *SE*. Important features of Figure 40 are the following:

- As older drivers increase in stature, the estimated marginal mean converges to one another.
- Older driver initial position has a greater *Difference* than older driver final position.

- Smaller stature older drivers after CarFit© training have a negative *Difference*; therefore, the selected seat position is further away than the SAE J4004 model.
- Initial position for older and younger drivers has the same trend and appears to be parallel.
- Final position for older and younger drivers has an inversely- related trend.

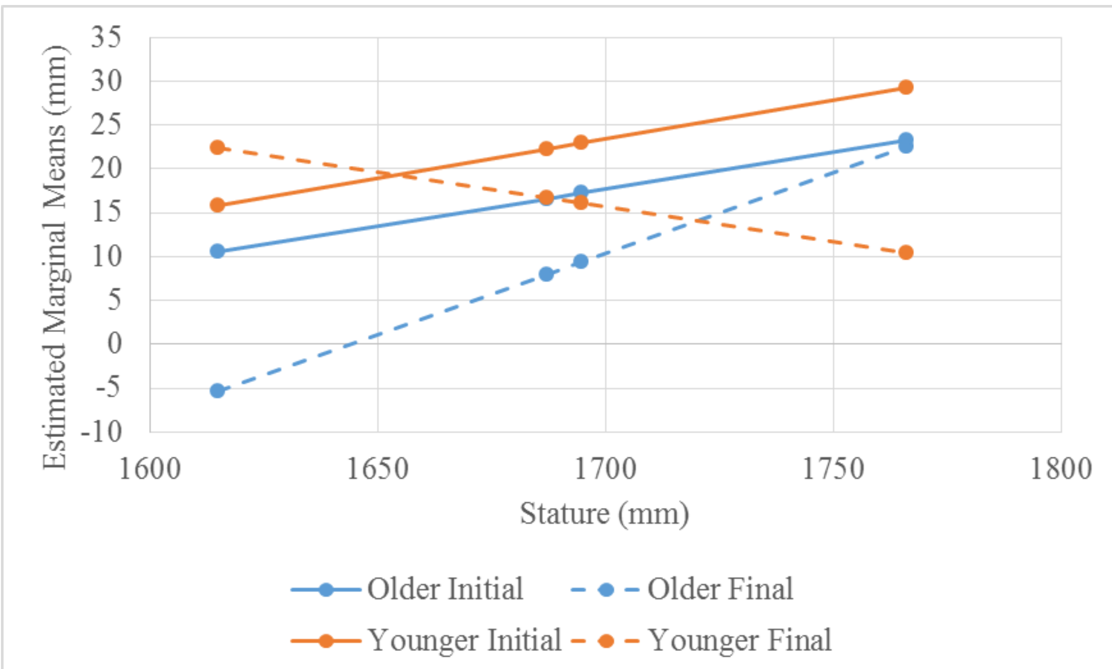


Figure 40. Estimated marginal means for the 3-way interaction of *Difference*, age, and stature.

Table 30

Estimated Marginal Means by Difference, Age, and Stature in Millimeters (mm)

Stature (%)		25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)		1615		1687		1695		1766	
		M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Initial	Older Driver	11	9	17	7	17	7	23	8
	Younger Driver	16	21	22	15	23	14	29	15
Final	Older Driver	-5	9	8	6	9	6	23	8
	Younger Driver	22	20	17	14	16	13	10	13

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

These findings suggest that an age-related difference does occur between SAE J4004 and L99. Noting that an age-related difference does occur, in order to improve the accuracy of the SAE J4004 recommended practice, it would be appropriate to add another term to Equation 9 in order to accommodate age-related differences.

The second interaction that showed significance was the 2-way interaction between gender and stature. It can be seen in Figure 41 that the *Difference* EMM for males decreases as stature decreases, whereas it increases for females. In other words, males are inversely related to females and that as stature increases, the difference between the SAE J4004 model and the measured BOFRP to H-point decreases for males and increases for females. Table 31 shows that tabulation of the EMM results with the associated *SE*. Important points to note for Figure 41 are as follows:

- Female drivers exhibit a positive slope for the difference EMM by stature. The positive slope indicates that as stature increases for females, they tend to sit further from the SAE J4004 recommended practice.
- Male drivers are inversely related to female drivers. In other words, as stature increases in male drivers, the difference between L99 and SAE J4004 is decreased.
- The EMM for the 25th percentile female is negative, which means that shorter statured female drivers tend to sit behind the SAE J4004 recommend practice; however, as stature increases, the female selected seat positions shift to be in front of the SAE J4004 recommended practice.

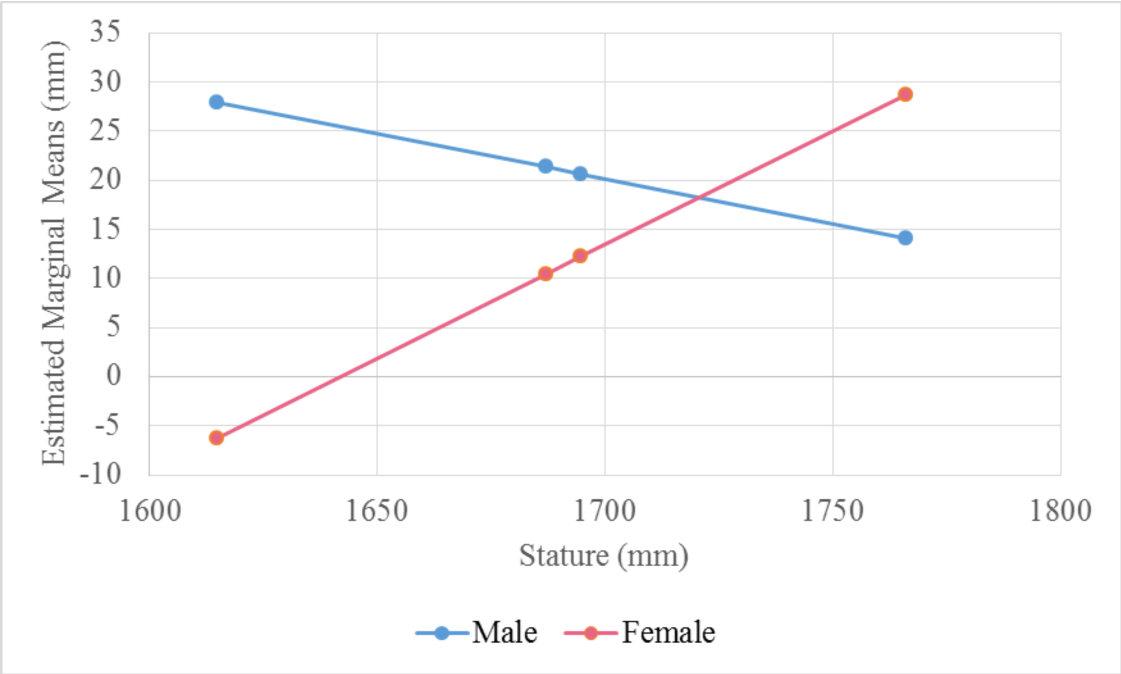


Figure 41. Estimated marginal means for the 2-way interaction of gender and stature.

Table 31

Estimated Marginal Means by Gender

Stature (%)	25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)	1615		1687		1695		1766	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Male	28	19	21	12	21	12	14	7
Female	-6	8	10	8	12	8	29	13

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

SAE International (2008c) states that gender was purposefully excluded from Equation 9 because the variance was expected to be accounted for through the individual's stature. Nonetheless, this research has shown that gender does in fact account for some variance between the measured and calculated BOFRP to H-point values. Therefore, the findings of this research suggest that a second term to include gender be added to Equation 9 of the SAE J4004 recommended practice.

Vehicle Floor to H-point.

This subsection presents the ANCOVA results for the vehicle floor to H-point (H30). The summary statistics for the initial and final H30 measurements by age and gender are listed below in Table 32.

Table 32

Summary of Vehicle Floor to H-point in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Vehicle Floor to H-point (mm)								
Initial	319	6	320	5	303	13	297	7
Final	311	6	319	5	309	12	268	23

Note. *M* = mean; *SE* = standard error.

The covariate stature was the only variable that was significant concerning the H30 measurement, $F(1, 109) = 4.132$, $p = 0.044$, $r = 0.191$. This result is expected in light of past research. See Flannagan et al. (1998); Flannagan et al. (1996); Philippart et al. (1985); Philippart et al. (1984); and Schneider et al. (1979).

The general trend of H30 found in this research was to decrease as stature increases. See Figure 42. Besides being well documented in previous research, this outcome is expected because a person of greater stature would require more space within the vehicle to meet a desired level of comfort. A lower H30 would therefore provide a taller individual greater headroom, space between the top of his or her leg and the bottom of the steering wheel, and a release of thigh pressure from the seat base. Since these results are not new findings with regards to the H30 measurement, no further investigation is necessary; however, the confirmation of past research shows that the methods and analysis chosen for this research are consistent with past research.

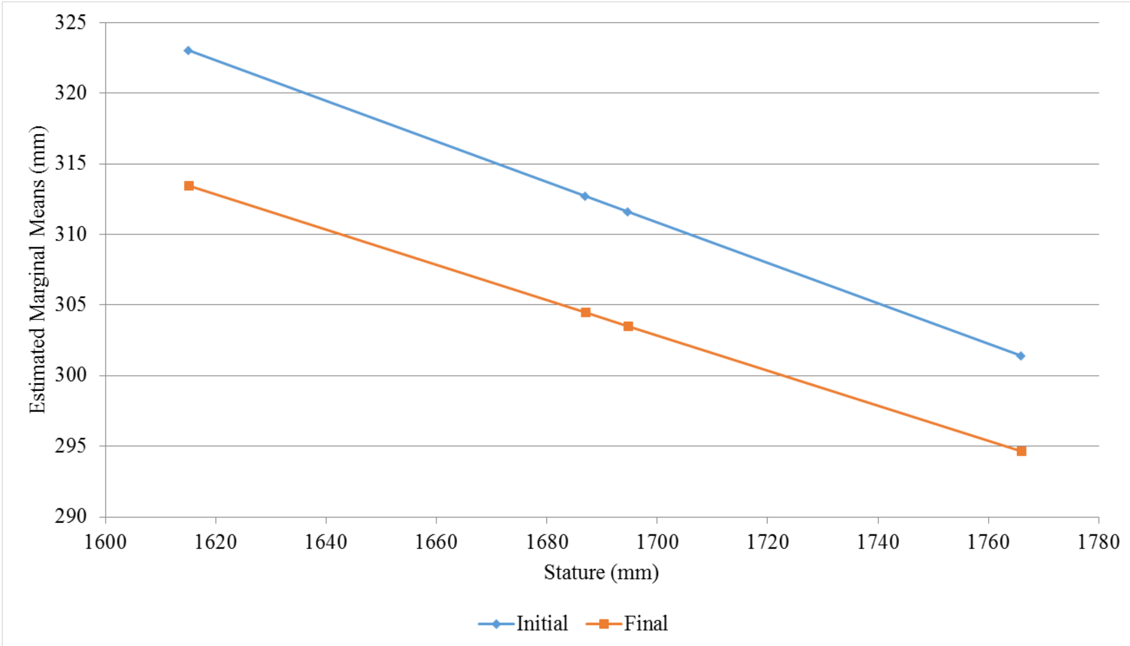


Figure 42. Estimated marginal means for vehicle floor to H-point by stature.

Ball of Foot Reference Point to steering wheel center.

This subsection presents the ANCOVA results for the BOFRP to steering wheel center measurement (L6). The summary statistics for the initial and final L6 measurements by age and gender are listed below in Table 33.

Table 33

Summary of BOFRP to Steering Wheel Center in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
BOFRP to Steering Wheel Center (mm)								
Initial	545	9	552	8	519	16	515	18
Final	541	10	550	8	514	14	510	15

Note. *M* = mean; *SE* = standard error.

Again, homogeneity of regression slopes is not met, and the covariate stature was allowed to interact with the main effects. The result of the L6 ANCOVA is summarized above in Table 20, with the complete ANCOVA table in Appendix D. Table 20 states that the L6 ANCOVA revealed a significant 3-way interaction between the L6, age, and the covariate stature, $F(1, 109) = 4.355$, $p = 0.039$, $r = 0.196$.

The 3-way interaction between L6, age, and the covariate stature evaluated at the covariate stature sample mean (1695 mm) can be seen below in Figure 43. The results indicate that the initial L6 measurement was 53 mm greater for older drivers ($M = 553$ mm, $SE = 9$ mm) compared to younger drivers ($M = 500$ mm, $SE = 20$ mm). Similarly, the final L6 measurement was 40 mm greater for older drivers ($M = 548$ mm, $SE = 10$ mm) compared to younger drivers ($M = 508$ mm, $SE = 21$ mm). This indicates that the initial and final fore/aft placement of the steering wheel was closer to the older driver as compared to the younger driver.

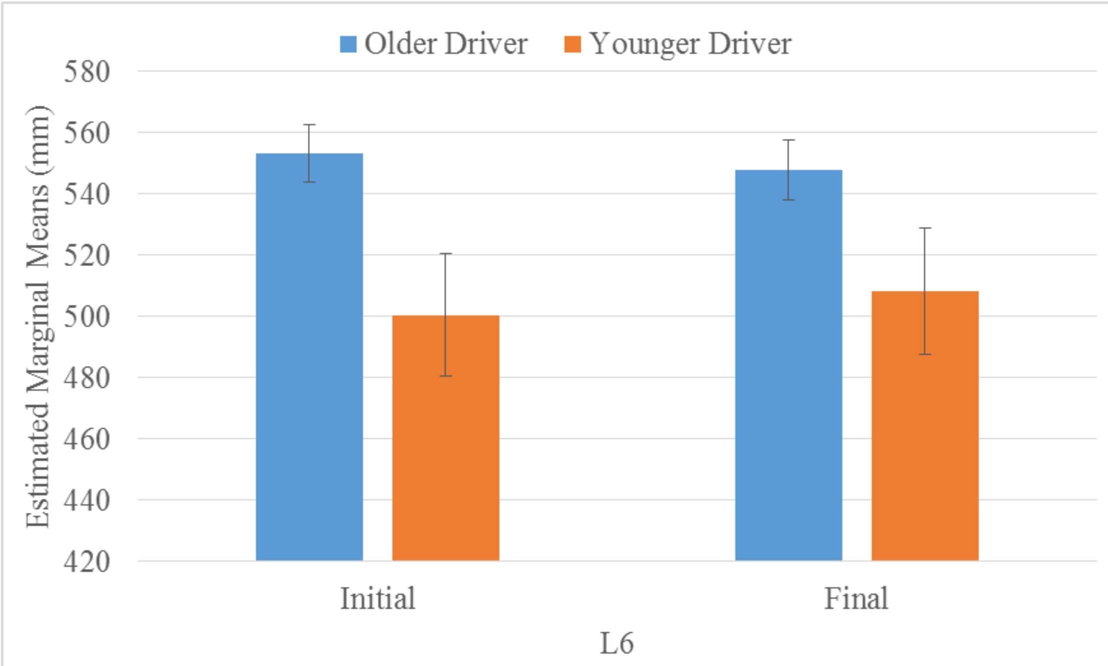


Figure 43. Estimated marginal mean for the 3-way interaction of measured BOFRP to steering wheel center by age with the stature covariate evaluated at 1695 mm.

The homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 44 shows the EMM for L6 by age and stature, while Table 34 is a tabulation of these values with the associated *SE*. Important features of Figure 44 include the following:

- The difference between the initial and final measurement for both older and younger drivers decreases when the EMM is evaluated at increasing stature values.
- The older driver initial line is the only line that has a negative slope.

- The slopes for the initial and final older driver lines appear to be quite small. This indicates that there is little change with stature for an older driver.
- The slope of the younger driver final measurements line is less steep than the initial younger driver line; therefore, the final younger driver line demonstrates that after CarFit© training younger drivers experience less change across stature.

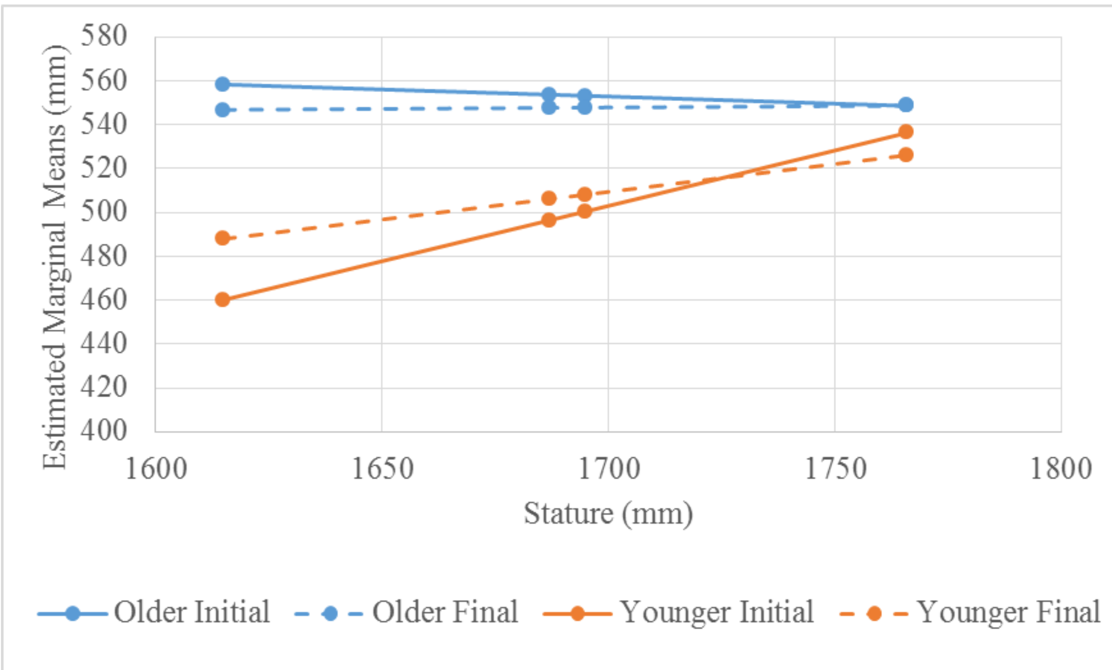


Figure 44. Estimated marginal means for the 3-way interaction of BOFRP to steering wheel center, age, and stature.

Table 34

Estimated Marginal Means by BOFRP to Steering Wheel Center, Age and Stature in Millimeters (mm)

Stature (%)		25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)		1615		1687		1695		1766	
		M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Initial	Older Driver	558	13	554	10	553	9	549	11
	Younger Driver	460	30	496	21	500	20	536	21
Final	Older Driver	547	14	548	10	548	10	549	12
	Younger Driver	488	31	506	21	508	21	526	21

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

L6 represents one of the terms used to compute the BOFRP to H-point values in the SAE J4004 recommended practice, and L6 shows that there is an age-related difference for its measurement. This finding further affirms the need for an age-related term to be added to the SAE J4004 recommended practice.

Seat base angle.

This subsection presents the ANCOVA results for the seat base angle (A27). The summary statistics for the initial and final A27 measurements by age and gender are listed below in Table 35.

Table 35

Summary of Seat Base Angle in Degrees (deg)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Seat Base Angle (deg)								
Initial	10	1	11	1	12	2	13	2
Final	11	1	11	1	11	2	12	1

Note. *M* = mean; *SE* = standard error.

Homogeneity of regression slopes is not met, and the covariate stature was allowed to interact with the main effects. The result of the A27 ANCOVA is summarized above in Table 20, with the complete ANCOVA table in Appendix D. Table 20 states that the A27 ANCOVA discovered a significant 4-way interaction between the A27, age, gender, and the covariate stature, $F(1, 109) = 4.306$, $p = 0.040$, $r = 0.195$.

The 4-way interaction between A27, age, gender, and the covariate stature evaluated at the covariate stature sample mean (1695 mm) can be seen below in Figure 45. The EMM indicates that the older male increased the A27 1 degree from initial to final seat position, while the older female driver showed no change between the initial and final seat position. Conversely, younger male drivers decreased their seat angle by 1 degree from their initial/final position, and younger female drivers decreased their seat base angle by 2 degrees. Initially, older females selected an A27 measurement of 1 degree greater than older males; however, the final position shows that older female drivers selected less than a 1 degree difference from older male drivers. Meanwhile, younger female drivers initially selected an A27 measurement 6 degrees greater than younger males. The final

A27 measurement for younger females was 5 degrees greater than younger male drivers. In other words, younger male drivers were found to select an A27 position significantly different in both the initial and final position, while younger females were marginally different in the initial position. Both older male and female drivers show negligible difference from one another as well as within the repeated measure.

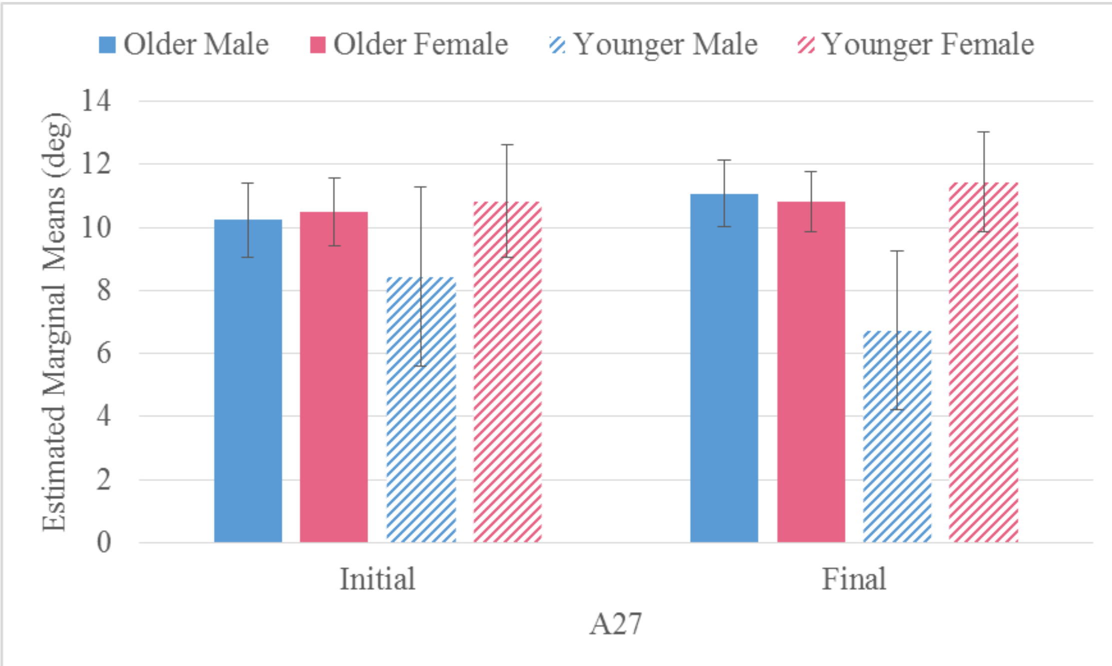


Figure 45. Estimated marginal mean for the 4-way interaction of seat base angle by age and gender with the stature covariate evaluated at 1695 mm.

The homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 46 shows the EMM for A27 by age, gender and stature, while Table 36 is a tabulation of these values with the associated *SE*. Important features of Figure 46include the following:

- Only younger female drivers violate the homogeneity of regression slopes.
- Both older male and older female drivers exhibit a degree or less across the stature variable.

Table 36

Estimated Marginal Means for Seat Base Angle by Age, Gender, and Stature in Degrees (deg)

Stature (%)			25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)			1615		1687		1695		1766	
			M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Initial	Older Driver	Male	10	2	10	1	10	1	10	1
		Female	11	1	11	1	11	1	10	2
	Younger Driver	Male	6	5	8	3	8	3	11	2
		Female	12	2	14	2	14	2	16	3
Final	Older Driver	Male	11	2	11	1	11	1	11	1
		Female	11	1	11	1	11	1	11	2
	Younger Driver	Male	4	4	6	3	7	3	10	1
		Female	12	2	12	2	11	2	11	3

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

Although the age and gender related significance does look promising to this research, the small effect size of the 4-way interaction effect ($r = 0.195$) and that the *SE* is equal to or greater than the difference between the EMM in the contingency table, the significant result from the ANCOVA is likely due to the low sample size for the younger male (n = 10) and younger female (n = 10) participants. Therefore, to make conclusive findings with regards to this effect would require further investigation with larger sample sizes for the younger male and female population.

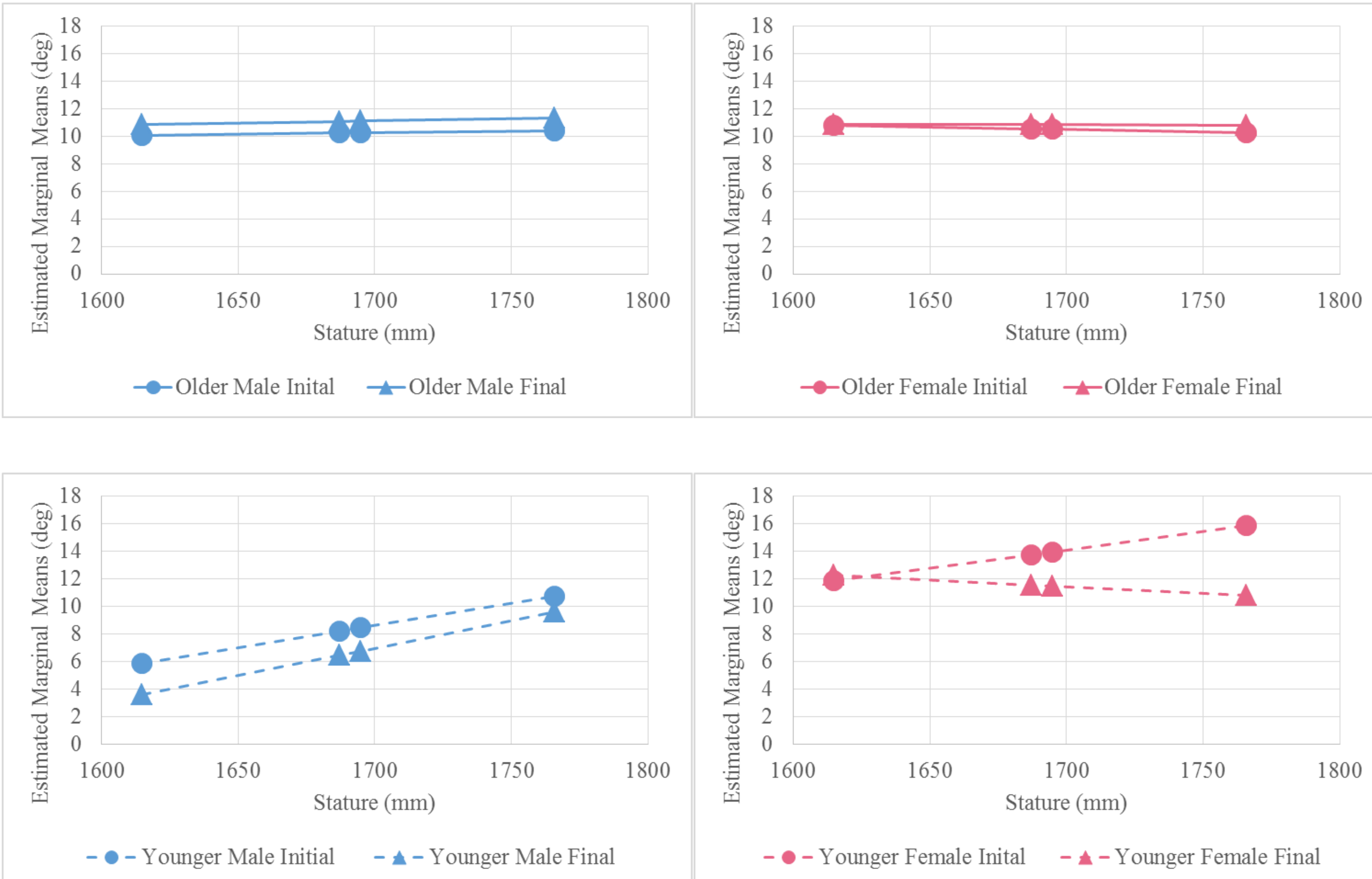


Figure 46. Estimated marginal means for the 4-way interaction of seat base angle, age, gender and stature.

Seat back angle.

The ANCOVA revealed no significant main effects or interaction effects for the seat back angle measure. The summary statistics for the initial and final seat back angle measurements by age and gender are listed below in Table 37, and the complete ANCOVA tables are shown in Appendix D.

Table 37

Summary of Seat Back Angle in Degrees (deg)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Seat Back Angle (deg)								
Initial	9	1	10	1	11	2	13	2
Final	9	1	9	1	11	2	10	2

Note. *M* = mean; *SE* = standard error.

Hip angle.

The ANCOVA revealed no significant main effects or interaction effects for hip angle measure. The summary statistics for the initial and final hip angle measurements by age and gender are listed below in Table 38, and the complete ANCOVA tables are shown in Appendix D.

Table 38

Summary of Hip Angle in Degrees (deg)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Hip Angle (deg)								
Initial	89	1	89	1	90	3	90	2
Final	87	1	88	1	91	2	89	2

Note. *M* = mean; *SE* = standard error.

Steering wheel angle.

This subsection presents the ANCOVA results for the steering wheel angle (A18). The summary statistics for the initial and final A18 measurements by age and gender are listed below in Table 39.

Table 39

Estimated Marginal Means by Steering Wheel Angle, Age, Gender, and the Stature Covariate Evaluated at 1695 mm in Degrees (deg)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Steering Wheel Angle (deg)								
Initial	26	1	23	1	28	2	29	1
Final	26	1	22	1	30	2	27	1

Note. *M* = mean; *SE* = standard error.

Homogeneity of regression slopes is not upheld for the steering wheel angle ANCOVA; therefore, the covariate stature is allowed to interact with the main effects of the

ANCOVA. The results of the ANCOVA are summarized above in Table 20, with the complete table in Appendix D. Table 20 shows that there was a 2-way interaction effect between the repeated A18 measure and stature, $F(1,109) = 8.351$, $p = 0.005$, $r = 0.267$. The results show that there was less than 1 degree of difference between the initial and final A18 EMM when evaluated at the stature sample mean (stature = 1695 mm). See Figure 47.

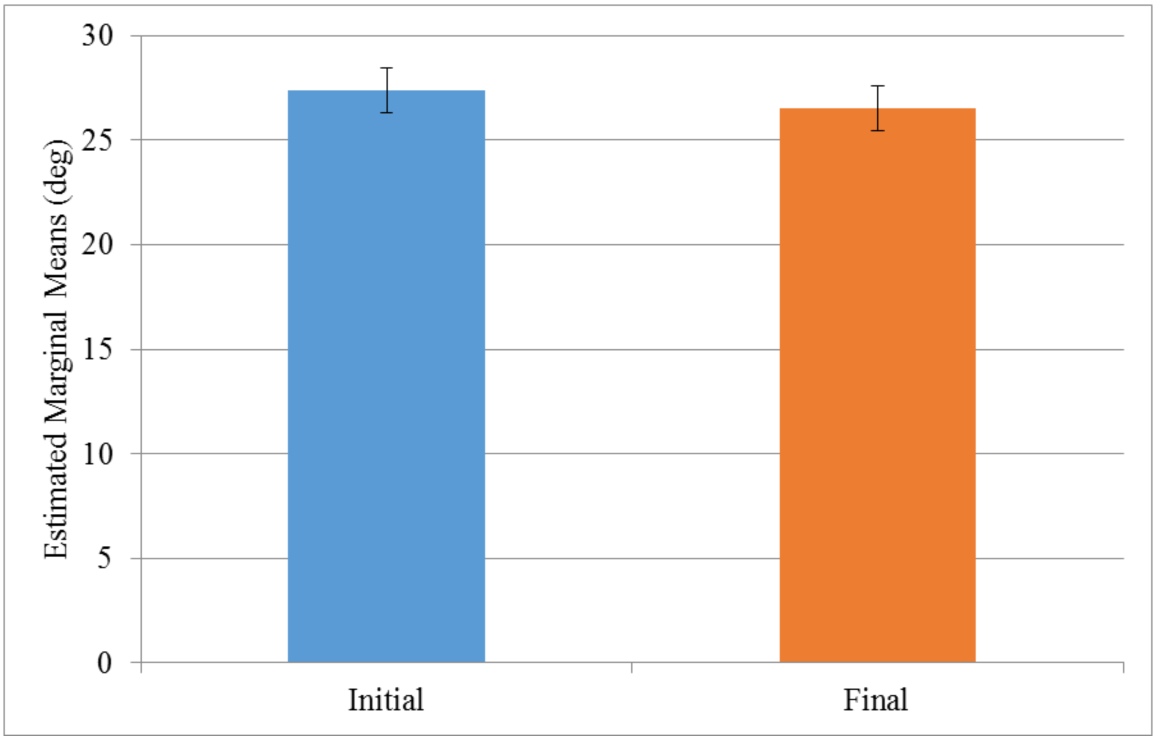


Figure 47. Estimated marginal means for the steering wheel angle with the stature covariate evaluated at 1695 mm.

The assumption of homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 48 shows the EMM for the repeated measure A18 and stature, while Table 40 is a tabulation of these values with the associated *SE*. Important features of Figure 48 are the following:

- The total difference across stature for the initial position was 3 degrees.
- The total difference across stature for the final position was 1 degree.
- The maximum difference between any stature was 3 degrees for 25th percentile person.

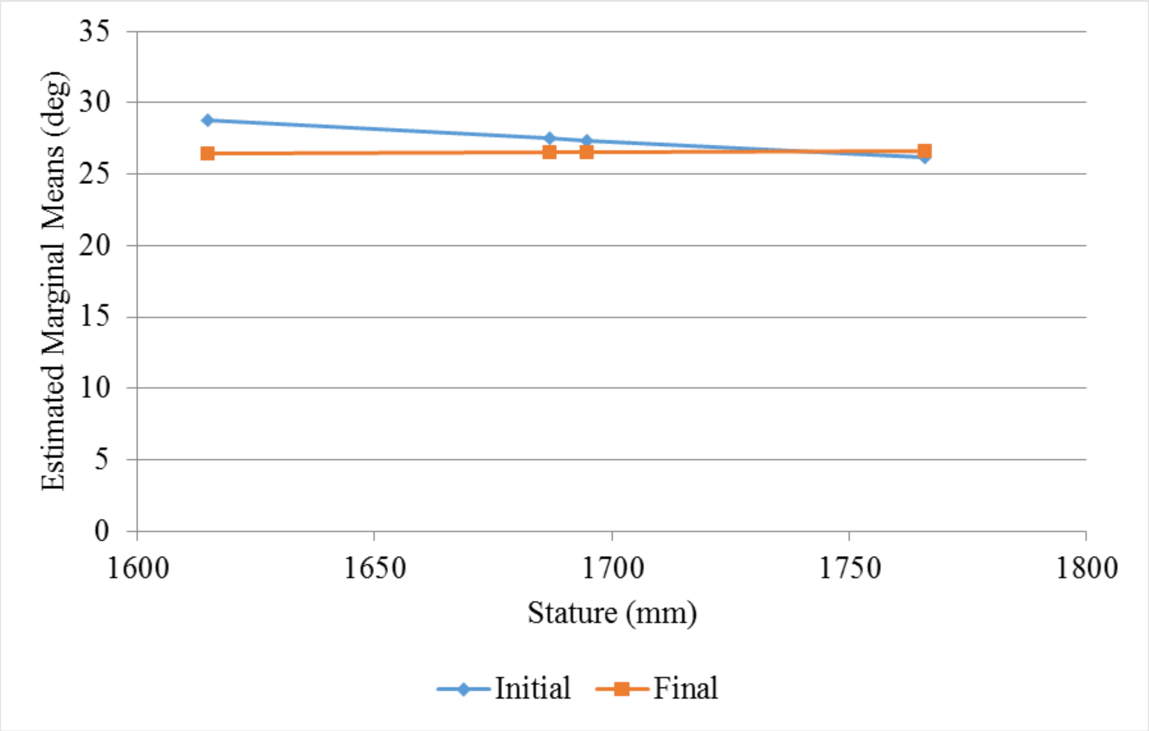


Figure 48. Estimated marginal means for steering wheel angle by stature.

Table 40

Summary of Steering Wheel Angle in Degrees (deg)

Stature (%)	25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (deg)	1615		1687		1695		1766	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Initial	29	2	28	1	27	1	26	1
Final	26	2	27	1	27	1	27	1

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

Although this measure showed to be significant, the maximum EMM difference across stature was only 3 degrees for the initial position and 1 degree for the final position. The *SE* for the EMM was up to 2 degrees for this measure. The marginal change across stature and the *SE* overlap show little merit for the findings regarding steering wheel angle.

Vehicle floor to top of steering wheel.

The ANCOVA revealed no significant main effects or interaction effects for the vehicle floor to top of steering wheel (VF2SW) measure. The summary statistics for the initial and final VF2SW measurements by age and gender are listed below in Table 41, and the complete ANCOVA tables are shown in Appendix D.

Table 41

Summary of Vehicle Floor to Top of Steering Wheel in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Vehicle Floor to Top of Steering Wheel (mm)								
Initial	810	5	813	4	799	6	783	21
Final	812	5	811	4	806	6	801	6

Note. *M* = mean; *SE* = standard error.

6.5 Driver Selected Seat Position Analysis for CarFit© Measurements

Five CarFit© measurements were collected with the participant sitting in his/her personal vehicle, as illustrated in the Figure 49. In addition to the measured values, the vehicle floor to top of steering wheel measurement was subtracted from the vehicle floor to eye level measurement in order to obtain the physical location of the participant's eye level relative to the steering wheel.

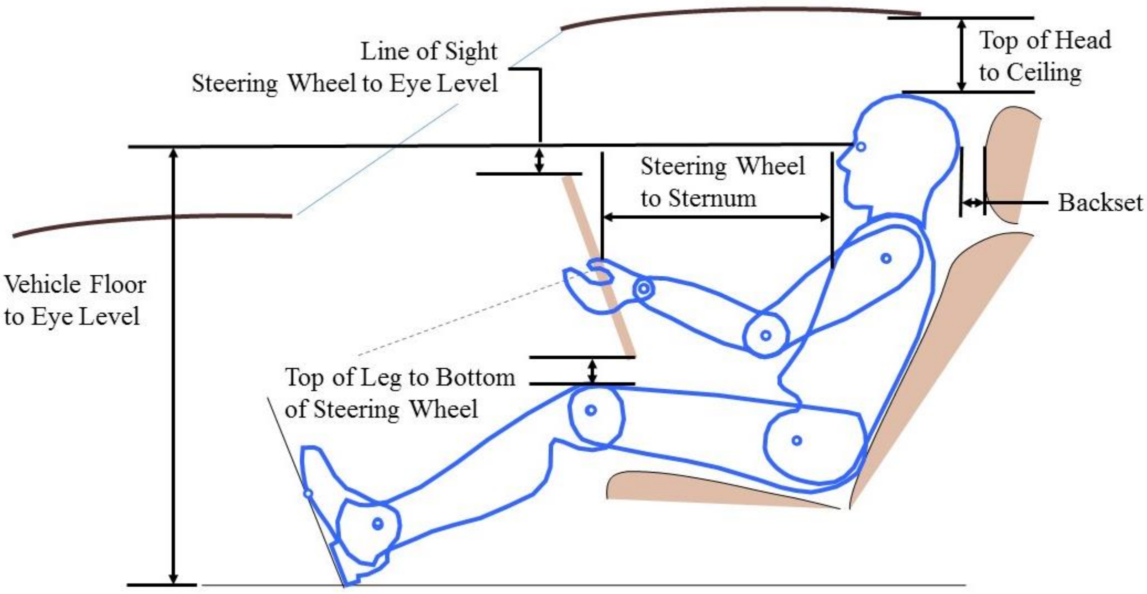


Figure 49. Depiction of CarFit© measurements captured in this research.

The remainder of this section will show the results of the mixed-model ANCOVAs for the CarFit© measurements in order to support Hypothesis 3 from 2.2 Gap One: Self-regulation of seat position, which states that the older drivers will differ significantly from the younger drivers by sitting more vertical, forward, and upright than younger drivers sit. Table 42 below shows a summary table for the CarFit© ANCOVA results. The complete ANCOVA table for all of the ANCOVA models and the relevant full factorial ANCOVA models are listed in Appendix D.

Table 42

Summary of Significant Effects for CarFit© and Posture Measurements

Variable	*F*	*p*-value	*r*
Center of Steering Wheel to Sternum (Chest2SW)			
Chest2SW x Age x Stature	13.577	0.000	0.333
Chest2SW x Age	12.996	0.000	0.326
Stature (covariate)	43.855	0.000	0.536
Top of Leg to Bottom of Steering Wheel (Leg2SW)			
Age x Stature	7.023	0.009	0.246
Age	6.403	0.013	0.236
Stature (covariate)	10.361	0.002	0.295
Line of Sight above Steering Wheel (LoS)*			
Gender	8.212	0.005	0.261
Vehicle Floor to Eye Level (VF2Eye)*			
Gender	12.027	0.001	0.311
Steering Wheel to Eye Level (SW2Eye)*			
Age	5.871	0.017	0.223
Gender	14.165	0.000	0.335

Note. For all tests, $df_1 = 1$ and $df_2 = 109$ unless annotated with * then, $df_1 = 1$ and $df_2 = 112$.

Center of steering wheel to sternum.

This subsection presents the ANCOVA results for the center of steering wheel to sternum (Chest2SW) measurement. The summary statistics for the initial and final Chest2SW by age and gender are listed below in Table 43.

Table 43

Summary of the Center of Steering Wheel to Sternum Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Center of steering wheel to sternum								
Initial	402	9	361	6	428	10	397	13
Final	405	7	357	6	440	18	406	18

Note. *M* = mean; *SE* = standard error.

The boxplot in Figure 50 summarizes the distance the participants sat from the steering wheel. The horizontal, dashed line represents the suggested minimum value of 254 mm (10 in) suggested by the CarFit© education program. Interestingly enough, all participants sat more than 254 mm away from the center of the steering wheel, and thereby all participants passed the CarFit© criterion. It should be noted that this was the only CarFit© measure criterion that all participants passed.

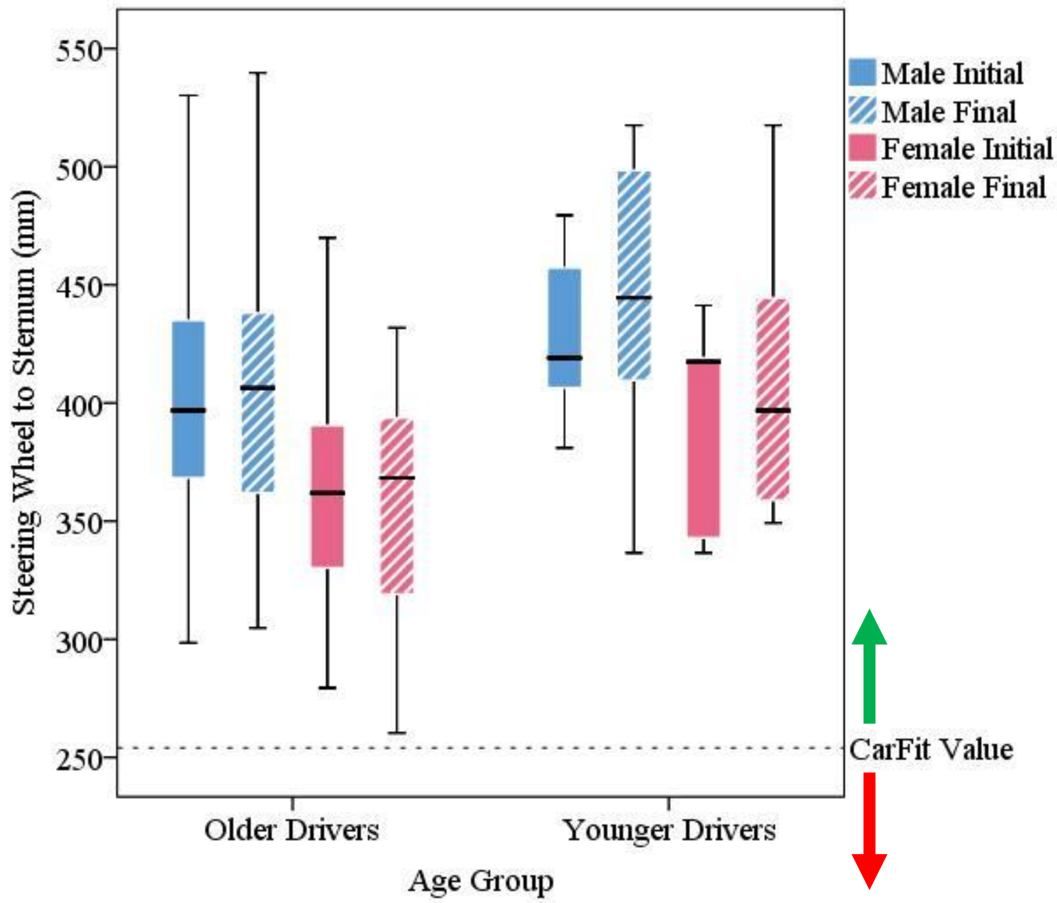


Figure 50. Boxplot diagram comparing the center of steering wheel to sternum measurement between initial/final position, age and gender.

The assumption of homogeneity of regression slopes is not upheld for Chest2SW, and therefore, the covariate stature is allowed to interact with the main effects. The ANCOVA results are summarized in Table 42 above, and the complete ANCOVA table is listed in Appendix D. Table 42 shows an interaction between the initial and final Chest2SW distance, age, and the covariate stature, $F(1,109) = 13.577$, $p = 0.001$, $r = 0.333$. The age effect indicates that older drivers ($M = 369$ mm, $SE = 6$ mm) initially selected a seat position 30 mm closer to the steering wheel than younger drivers (*M* = 399 mm, *SE* = 14 mm), and after CarFit© education, older drivers (*M* = 370 mm, *SE* = 6mm) differed from younger drivers (*M* = 403 mm, *SE* = 13 mm) by 33 mm. See Figure 51.

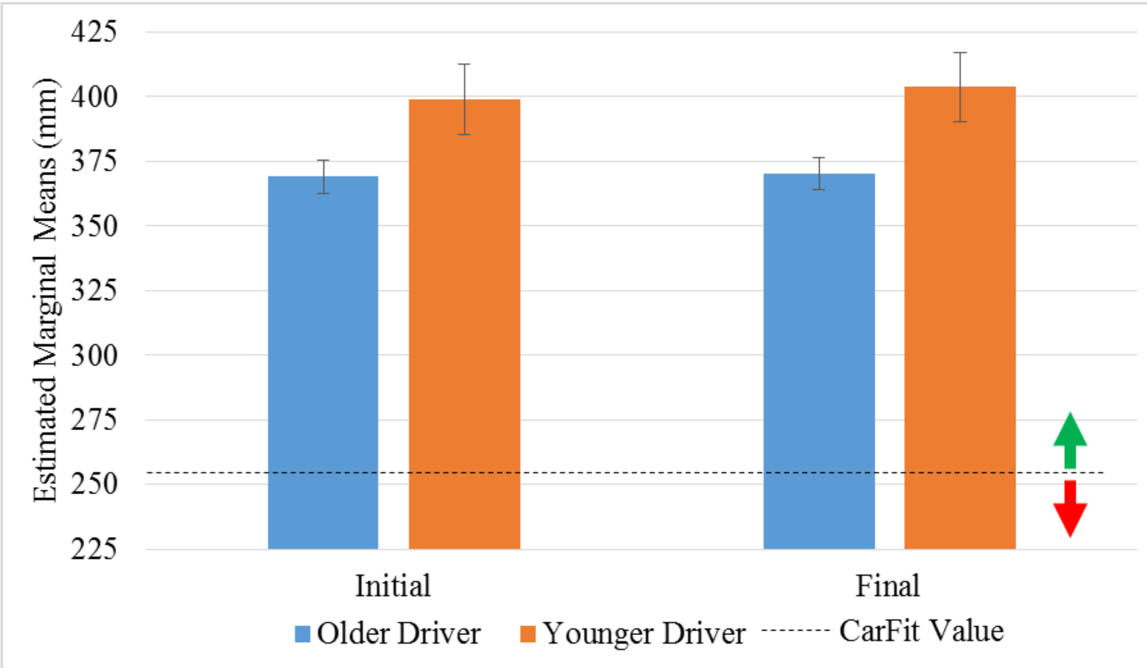


Figure 51. Estimated marginal means for the initial and final center of steering wheel to sternum, by age, with the stature covariate evaluated at 1695 mm.

Since the assumption of homogeneity of regression slopes was not met, the stature covariate was allowed to interact with the main effects. Figure 52 shows the EMM for Chest2SW by age and stature, and Table 44 tabulates the EMM with the associated *SE*. Important aspects of Figure 52 are the following:

- Chest2SW increases with stature for both older and younger drivers.

- There is a 2 mm change from the initial to final position for both older drivers at the NHANES 50th percentile for stature. In addition, there is a 1 mm change at the sample means stature.
- Older drivers exhibit a decrease in slope from the initial line to the final line. Since the initial and final EMM at the sample mean differ by 1 mm, the decrease in slope indicates that on average after CarFit© education the smaller stature older driver moved further from the steering wheel, while the larger stature older driver moved closer.
- There is a 2 mm increase from the initial to final position for both younger and older drivers at the NHANES 50th percentile for stature; however, there is a 5 mm increase for younger drivers and a 1 mm increase for older drivers at the sample means stature.
- Younger drivers exhibit a sharp increase in slope from the initial line to the final line. Since the initial and final EMM at the NHANES 50th percentile individual only differ by 2 mm, the increase in slope indicates that on average after CarFit© education the smaller stature younger driver moved closer to the steering wheel, while the larger stature younger driver moved farther from the steering. This change is the opposite effect from older drivers.

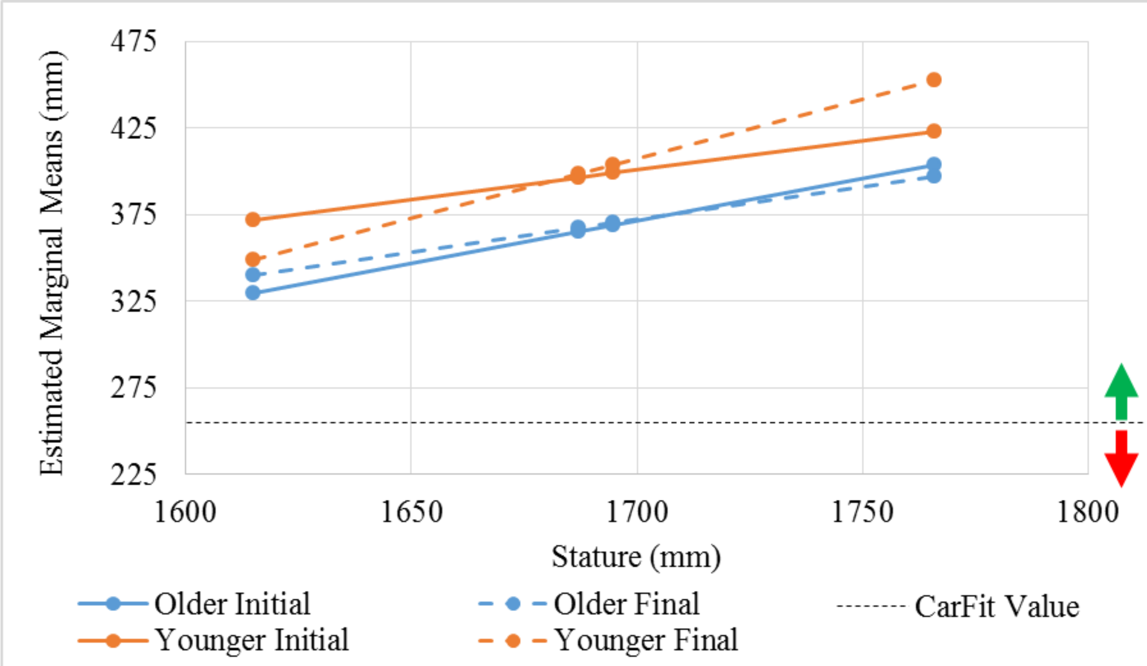


Figure 52. Estimated marginal means for the initial and final center of steering wheel to sternum, by age, and stature.

Table 44

Estimated Marginal Means by Center of Steering Wheel to Sternum, Age, and Stature in Millimeters (mm)

Stature (%)		25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)		1615		1687		1695		1766	
		M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Initial	Older Driver	330	9	365	7	369	6	404	8
	Younger Driver	372	20	396	14	399	14	423	14
Final	Older Driver	340	9	367	6	370	6	397	8
	Younger Driver	349	20	398	14	404	13	453	14

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

Although all participants passed this measurement, which implies that participants are aware of the required distance, the Chest2SW measurement is still considered important for safety education. As mentioned in the literature review above, airbags have been known to cause severe injuries (Conroy et al., 2007; Jernigan & Duma, 2003; Jernigan et al., 2005; National Highway Traffic Safety Administration, 2008a). An improper seat position, placing the driver was too close to the steering wheel, would intensify the impact from the airbag, and therefore increase the likelihood of a severe injury. The airbag impact, combined with the frailty of many older drivers, would be more severe and possibly result in loss of life for an older driver. Therefore, retention of this measurement as part of the CarFit© education program is highly recommended.

Backset.

The ANCOVA revealed no significant main effects or interaction effects for backset measure. The summary statistics for the initial and final backset measurements by age and gender are listed below in Table 45, and the complete ANCOVA tables are shown in Appendix D. The boxplot in Figure 53 depicts the backset descriptive statistics, and the dotted line shows the maximum CarFit© criterion of 51 mm (2 in).

Table 45

Summary of the Backset Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Backset (mm)								
Initial	70	7	51	6	67	9	40	13
Final	50	6	46	6	58	12	37	13

Note. *M* = mean; *SE* = standard error.

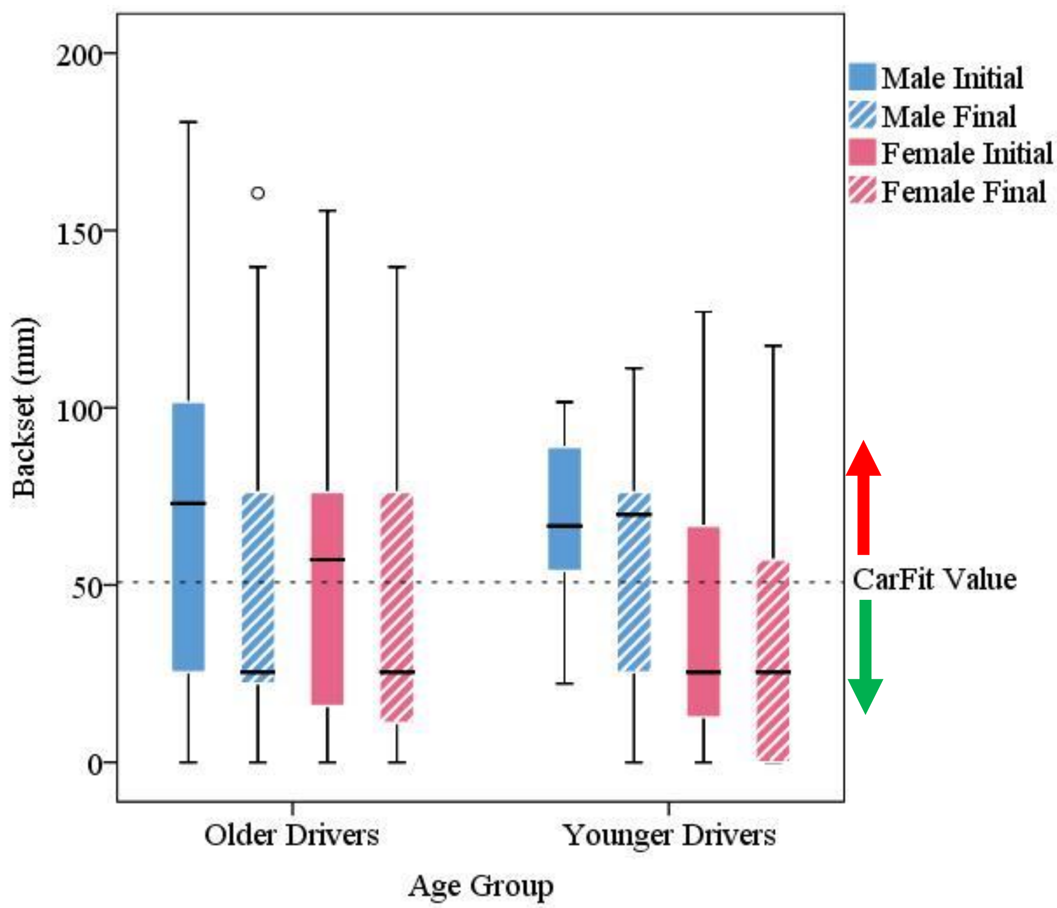


Figure 53. Boxplot diagram comparing the backset measurement between initial/final position, age and gender.

The backset measure is best accomplished by the adjustment of the seat back angle, which also showed no significant results. The seat back angle is most often selected for the purpose of comfort rather than any safety requirement (Jonsson, Stenlund, & Bjornstig, 2008; Jonsson, Stenlund, Svensson, & Bjornstig, 2008). Depending on the availability of other seat adjustment options, such as head restraint tilt, the proper backset measurement could be accomplished; however, head restraint tilt appeared in only 10 of the 117 vehicles that were measured. Recently, federal legislation has mandated that the backset distance be designed in the vehicle to be less than 50.8 mm (2 in) when the seat back angle is set to 25 degrees; however, this legislation has been met with consumer backlash with drivers' complaints about their heads being pushed forward (Kolich, 2010; National Highway Traffic Safety Administration, 2011a).

Although this measure did not show statistical significance, the measurement has great safety and economic impact. As mentioned above in the literature review, the backset measurement has been shown to influence an individual's level of risk for whiplash during a collision event. According to the Insurance Institute for Highway Safety (2013b), whiplash claims in 2007 represented 25% of all insurance claim payouts for crash injuries, totaling $8.8 billion. With the frequency of whiplash events occurring and the economic impact of the associated injuries, the backset measurement is most definitely an important measurement to be taught to all drivers.

Top of head to ceiling.

The ANCOVA revealed no significant main effects or interaction effects for the top of head to ceiling measure. The summary statistics for the initial and final top of head to ceiling measurements by age and gender are listed below in Table 46, and the complete ANCOVA tables are shown in Appendix D. The boxplot in Figure 54 depicts the top of head to ceiling descriptive statistics, and the dotted line shows the minimum CarFit© criterion of 102 mm (4 in).

Table 46

Summary of the Top of Head to Ceiling Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Top of Head to Ceiling (mm)								
Initial	96	6	146	5	112	15	129	9
Final	99	6	147	6	108	9	127	11

Note. *M* = mean; *SE* = standard error.

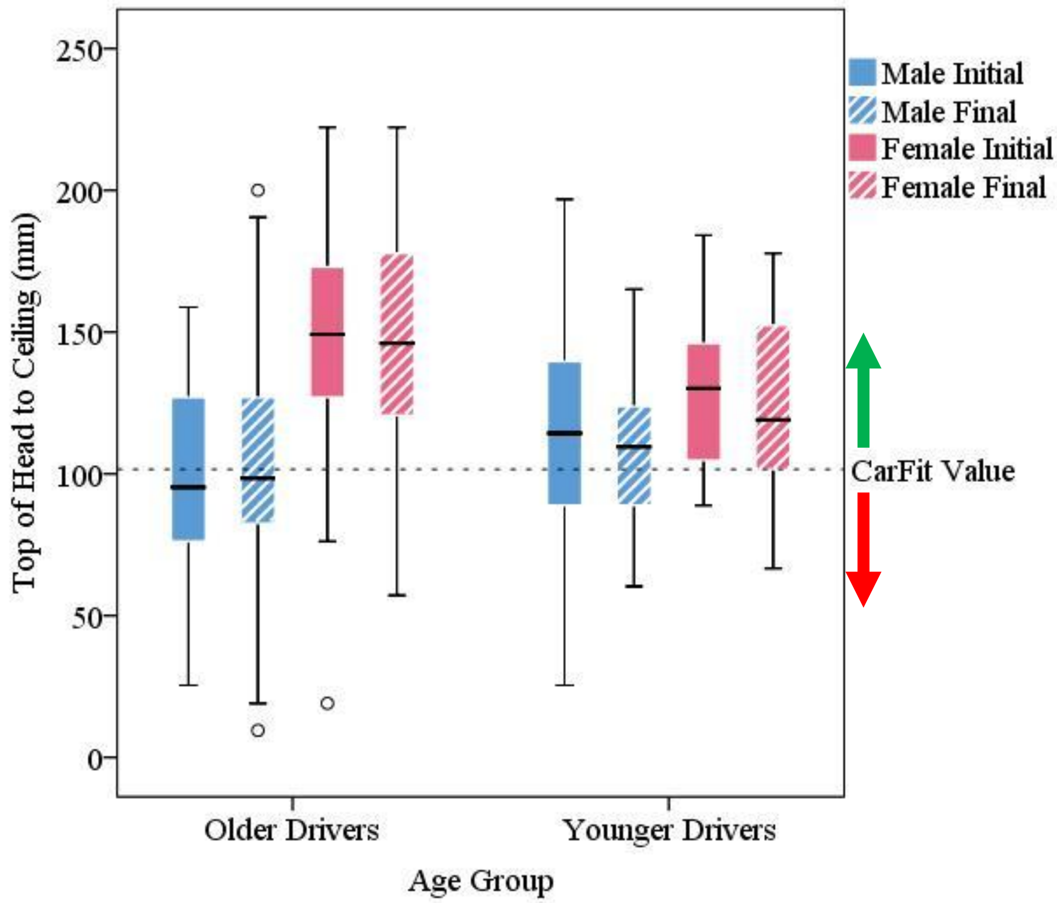


Figure 54. Boxplot diagram comparing the top of the head to the ceiling measurement between initial/final position, age and gender.

Since the top of head to ceiling measurement showed no significant effects, it should be noted that two measurements (top of leg to bottom of steering wheel and line of sight above the steering wheel) did show significant effects and act as competing measures for the top of head to ceiling measurements. For example, in order for a small-statured driver to obtain a proper line of sight over the steering wheel, the driver may have to raise the seat, thereby decreasing the value of the top of head to ceiling measure. Similarly, the top of leg to bottom of steering wheel measurement can be accomplished by either adjusting the steering wheel or by adjusting the vertical height of the seat. Either adjustment would thereby impact the driver's top of head to ceiling measurement. Therefore, it is assumed that the driver will make a compromise between the three values based on safety priorities and comfort preferences.

Nonetheless, with new federal legislation passed in 2008 to increase the roof crush resistance (National Highway Traffic Safety Administration, 2008b), the top of head to ceiling measurement may become obsolete as new cars permeate the roadways.

Top of leg to bottom of steering wheel.

This subsection presents the results for the top of leg to bottom of steering wheel (Leg2SW) measurement. The summary statistics for the initial and final Leg2SW by age and gender are listed below in Table 47.

Table 47

Summary of the Top of Leg to Bottom of Steering Wheel Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Top of leg to bottom of steering wheel								
Initial	50	4	63	3	30	8	54	7
Final	52	3	62	3	47	6	53	7

Note. *M* = mean; *SE* = standard error.

The boxplot in Figure 55 summarizes the Leg2SW measurement. The horizontal, dashed line represents the CarFit© suggested minimum value of 51 mm (2 in). Figure 55 does not indicate that after CarFit© training more people passed this measure, rather the figure indicates that the participants showed a more central shift towards the suggested CarFit© value.

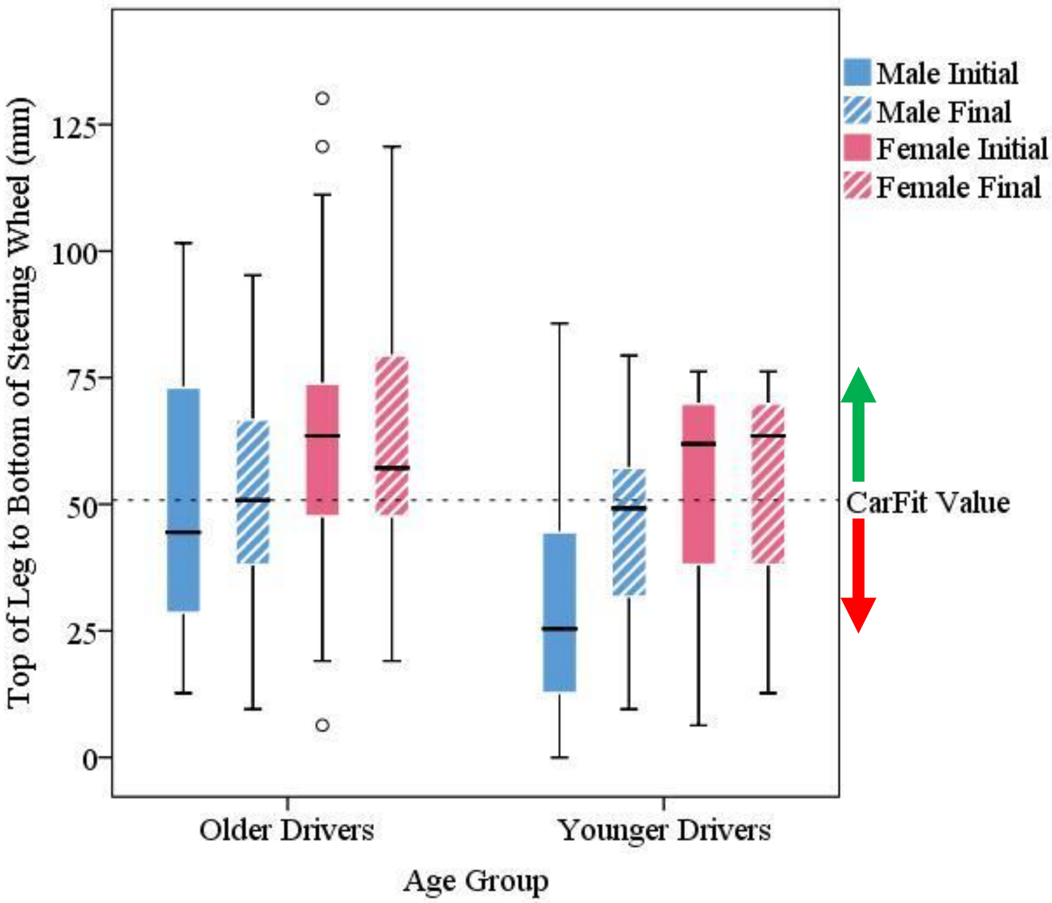


Figure 55. Boxplot diagram comparing the top of leg to the bottom of steering wheel measurement between initial/final position, age and gender.

The assumption for homogeneity of regression slopes was not met by the Leg2SW ANCOVA, and therefore, the covariate stature was allowed to interact with the main effects. The results of the ANCOVA for Leg2SW are summarized in Table 42 above with the complete table in Appendix D. Table 42 shows that there was a significant interaction effect between the age and stature of the participants, $F(1,109) = 7.023$, $p = 0.009$, $r = 0.246$. The interaction plots in Figure 56 show that initially, older drivers ($M =$

63 mm, *SE* = 3 mm) tend to have a greater top of leg to bottom of steering wheel gap than younger drivers (*M* = 53 mm, SE = 7 mm).

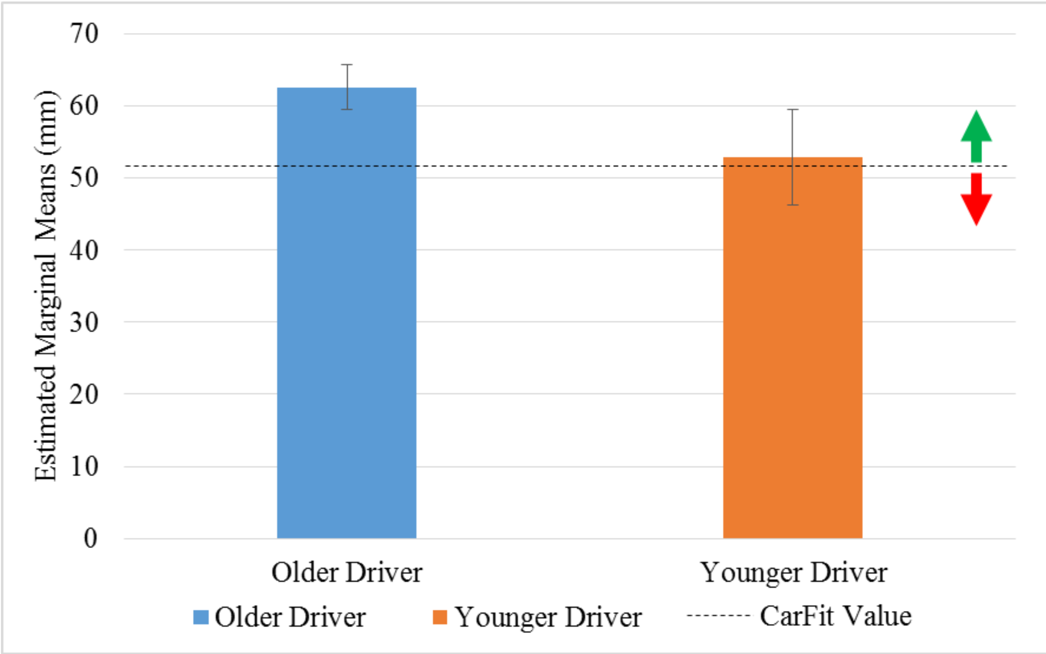


Figure 56. Estimated marginal means for the top of leg to bottom of steering wheel, by age, with the stature covariate evaluated at 1695 mm.

The assumption of homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 57 shows the EMM for Leg2SW with the covariate stature, while Table 48 is a tabulation of the EMM with the associated *SE*. The major finding represented in Figure 57 is that there is little to no change across stature for older drivers, while there is a 34 mm decline with stature for younger drivers.

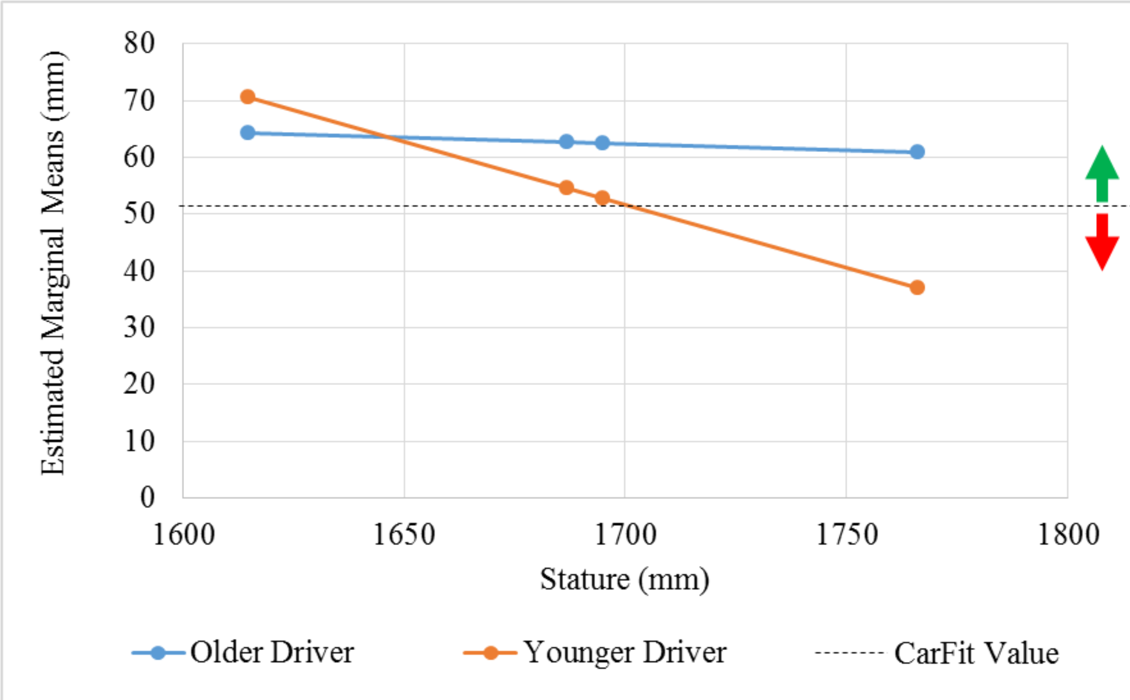


Figure 57. Estimated marginal means of the age interaction with the stature covariate for top of leg to bottom of steering wheel measurement.

Table 48

Estimated Marginal Means by Top of Leg to Bottom of Steering Wheel, Age, and Stature in Millimeters (mm)

Stature (%)	25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)	1615		1687		1695		1766	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Older Driver	64	4	63	3	63	3	61	4
Younger Driver	71	10	55	7	53	7	37	7

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015); *M* = mean; *SE* = standard error.

It is expected that persons with greater stature will have longer legs, and therefore, it would be expected that persons of greater stature would have less space between the top of their legs and the bottom of their steering wheel. In addition, the Leg2SW measurement has substantial impact on ingress and egress of the vehicle. The researcher noted that several older participants mentioned that they preferred to make adjustments prior to exiting the vehicle in order to help facilitate ingress and egress. This observation is further supported by the fact that older drivers have been shown to select a seat position that favors easy ingress and egress of the vehicle.

Line of sight above the steering wheel.

This subsection presents the ANCOVA results for the line of sight above the steering wheel (LoS) measurement. The summary statistics for the initial and final LoS by age and gender are listed below in Table 49.

Table 49

Summary of the Line of Sight Above the Steering Wheel Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Line of sight above steering wheel								
Initial	101	5	73	3	115	9	86	5
Final	89	4	70	3	101	11	78	3

Note. *M* = mean; *SE* = standard error.

The boxplot in Figure 58 summarizes the measurement from the top of the steering wheel to the participant's line of sight. The horizontal, dashed line represents the suggested minimum value of 76 mm (3 in). For all drivers there appears to be a central tendency towards the CarFit© suggested values. The central shift toward the CarFit© value is much more apparent in male drivers than in female drivers. The gender difference was also detected by the ANCOVA.

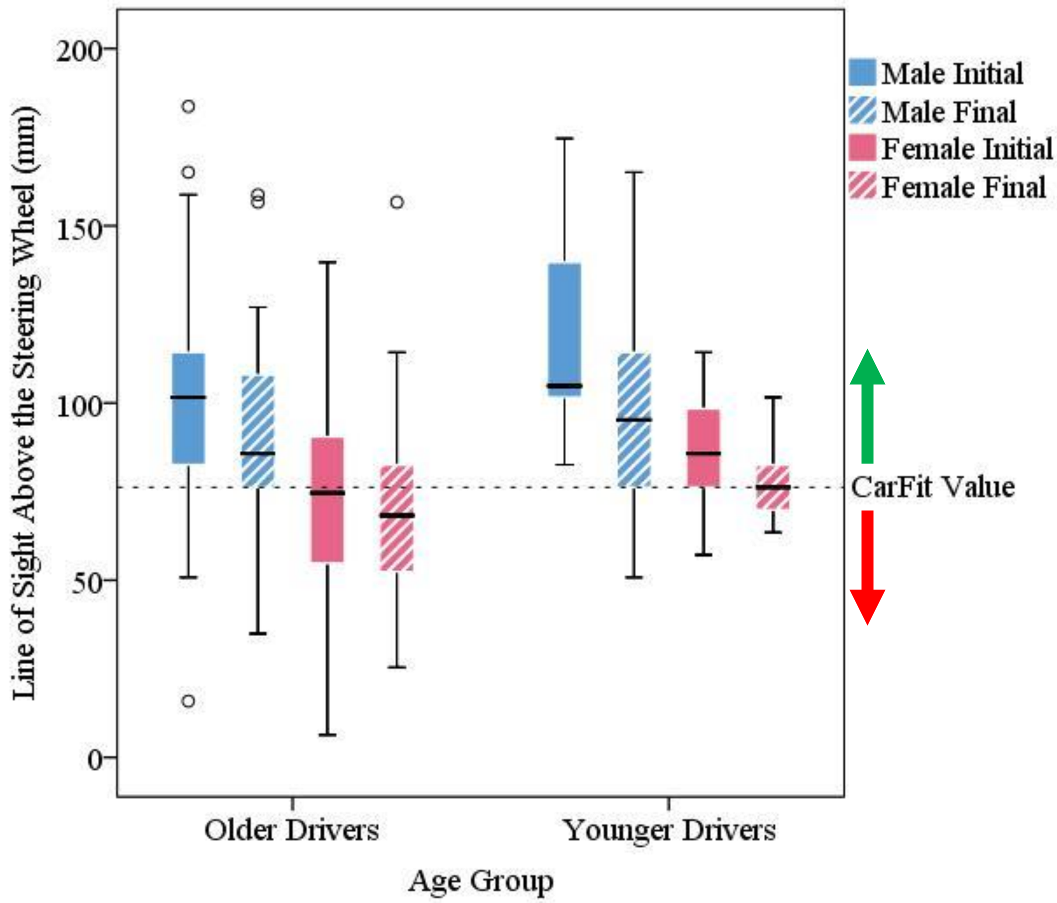


Figure 58. Boxplot diagram comparing the line of sight above the steering wheel measurement between initial/final position, age and gender.

The assumption of homogeneity of regression slopes was maintained, and the standard full factorial ANCOVA was used to detect a main effect of gender, $F(1,112) = 8.212$, $p = 0.005$, $r = 0.261$. Table 42 above summarizes the significant main effect of gender, and the full ANCOVA tables are shown in Appendix D. The result of this effect is that males' (M = 100 mm, SE = 5 mm) line of sight over the steering wheel was on average

23 mm higher than females' (*M* = 77 mm, *SE* = 5 mm) line of sight over the steering wheel, as shown in Figure 59.

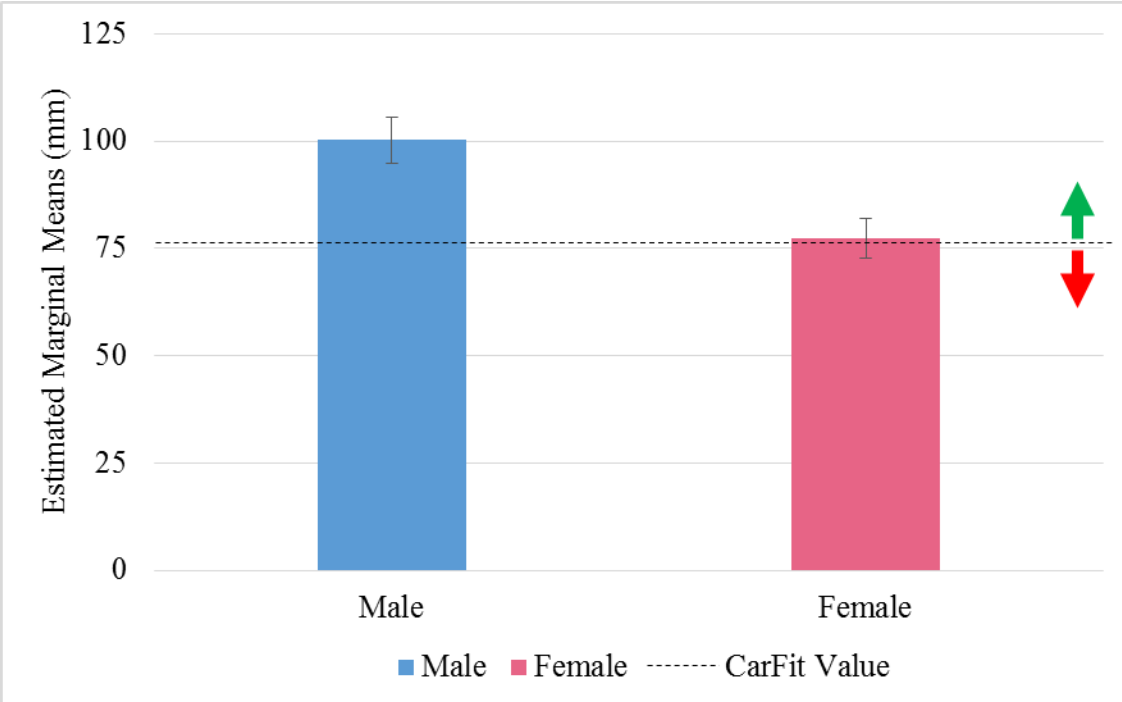


Figure 59. Estimated marginal means for the line of sight above the steering wheel, by gender, with the stature covariate evaluated at 1695 mm.

The gender difference for LoS implies that males have less impedance from the steering wheel in their vision than female drivers. Furthermore, the EMM value for female drivers exceeds the CarFit© value by only 1 mm; whereas, the EMM value for male drivers met the criteria by 24 mm. The increased LoS is viewed as a positive posture position within the CarFit© guideline, and therefore more safe. However, the LoS guideline presents quite a challenge to position because it competes with both the top of head to ceiling measure and the top of leg to bottom of steering wheel measure. In addition, the measure is subject to the driver's line of sight preference. For example, the measure is captured by first asking the driver to look forward as if he or she were following a vehicle in front of them. Next, a ruler is placed on the steering wheel and positioned upwards until the top of the ruler is level with the driver's vision. See Appendix A for more details on the measurement capture. In the measurement process, the participant selects the height of the measure, and even if the participant selects a seat position that will more than adequately afford him/her the proper line of sight above the steering wheel, the vision height selected by the individual may compromise this measurement. Therefore, when CarFit© training is taking place, it is important for the instructor performing the CarFit© training to educate the individual about the seat position adjustments, as well as discuss the need for improved forward vison in front of the vehicle, particularly for individuals that are not able to be repositioned to obtain the LoS measurement.

Vehicle floor to eye level.

This subsection presents the ANCOVA results for the vehicle floor to eye level (VF2Eye) measurement. Although the VF2Eye measurement is not a CarFit© measurement, this measure is included in this section because it is a measure to the individual, which qualifies it as a posture measure. In addition, VF2Eye is used to compute the top of steering wheel to eye level measure in the following subsection; therefore, it seemed beneficial to include the ANCOVA analysis for this measure. The summary statistics for the initial and final VF2Eye by age and gender are listed below in Table 50.

Table 50

Summary of the Vehicle Floor to Eye Level Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Vehicle floor to eye level								
Initial	917	7	869	6	918	12	877	6
Final	918	7	874	5	927	14	878	12

Note. *M* = mean; *SE* = standard error.

As stated previously, this measurement is not a part of the CarFit© measurement program, so there is no suggested value for this measure, and therefore, no boxplot is used to evaluate the distribution; however, this measurement is used in the following sub-section, Top of steering wheel to eye level, to provide a comparison measurement for the line of sight above the steering wheel.

Homogeneity of regression slopes was upheld, so a standard full factorial ANCOVA of vehicle floor to eye level measurement was used to show a significant main effects of gender, $F(1, 112) = 12.027$, $p = 0.001$, $r = 0.311$. See Table 42 for a summary of the ANCOVA results and Appendix D for the complete tables. The gender main effect showed that the vertical location of the eye above the vehicle floor for males ($M = 920$ mm, $SE = 9$ mm) was 45 mm higher than females ($M = 875$ mm, $SE = 8$ mm). See Figure 60. This result is perhaps expected, as it has been shown by Fromuth and Parkinson (2008) and Parkinson (2015) that sitting height will vary anthropometrically by gender. Given the anthropometric gender variance and that there is also a gender effect for LoS, a gender effect would be expected for the VF2Eye measurement level as well.

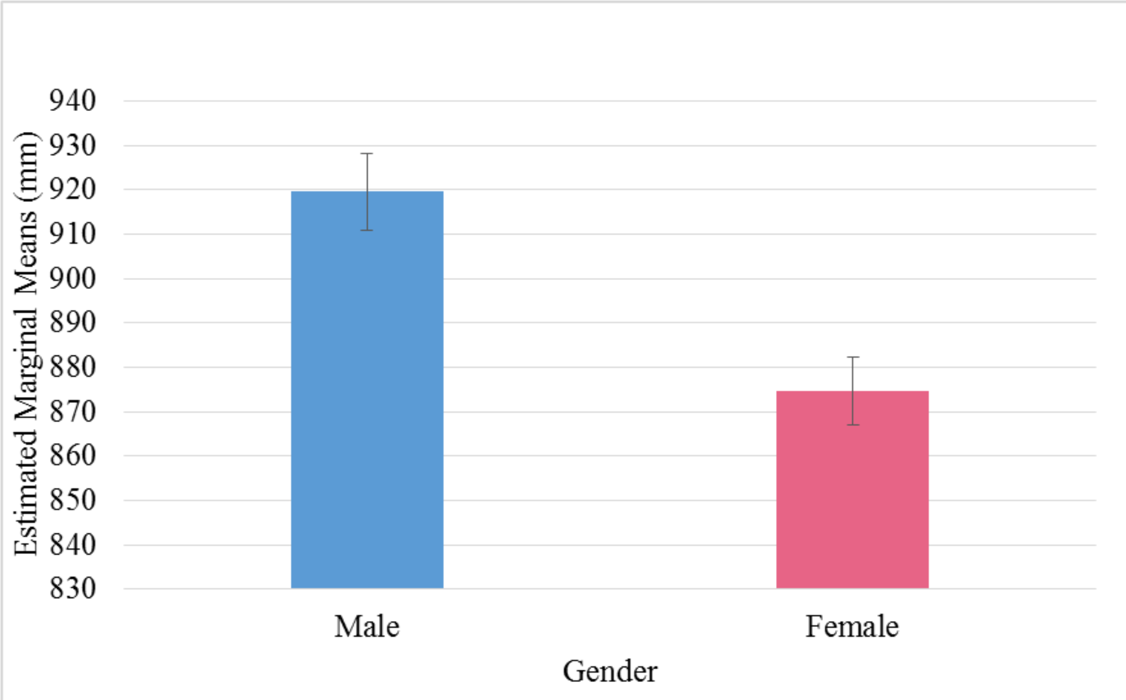


Figure 60. Estimated marginal means for vehicle floor to eye level, by gender, with the stature covariate evaluated at 1695 mm

Top of steering wheel to eye level.

This subsection presents the ANCOVA results for the top of steering wheel to eye level (SW2Eye) measurement. The vertical location of the participant's eye above the steering wheel was computed by taking the difference between VF2Eye and VF2SW. See Equation 16. This computation gave reference for the vertical location of the participant's eye above the steering wheel.

$$SW2Eye = VF2Eye - VF2SW \qquad \text{Equation 16}$$

Where,

SW2Eye is the steering wheel to eye level measurement

VF2Eye is the vehicle floor to eye level measurement

VF2SW is the vehicle floor to top of steering wheel measurement

This measure was computed in order to further examine the complexities associated with the LoS measurement. Since the participants selected the LoS height with their forward vision, the SW2Eye measurement was computed to assess whether the physical location of the eye satisfied the CarFit© requirements. This measure is not part of the CarFit© education program; however, since it relates closely to the line of sight above the steering wheel measure, the minimum value of 76.2 mm (3in) was used. The summary statistics for the initial and final SW2Eye by age and gender are listed below in Table 51.

Table 51

Summary of the Top of Steering Wheel to Eye Level Measurement in Millimeters (mm)

	Older Driver				Younger Driver			
	Male		Female		Male		Female	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Top of steering wheel to eye level								
Initial	107	5	56	6	119	10	94	25
Final	106	5	63	4	122	13	77	11

Note. *M* = mean; *SE* = standard error.

The boxplot in Figure 61 summarizes the SW2Eye. The horizontal, dashed line represents the minimum value of 76 mm (3 in) suggested for the LoS measure by the CarFit© education program.

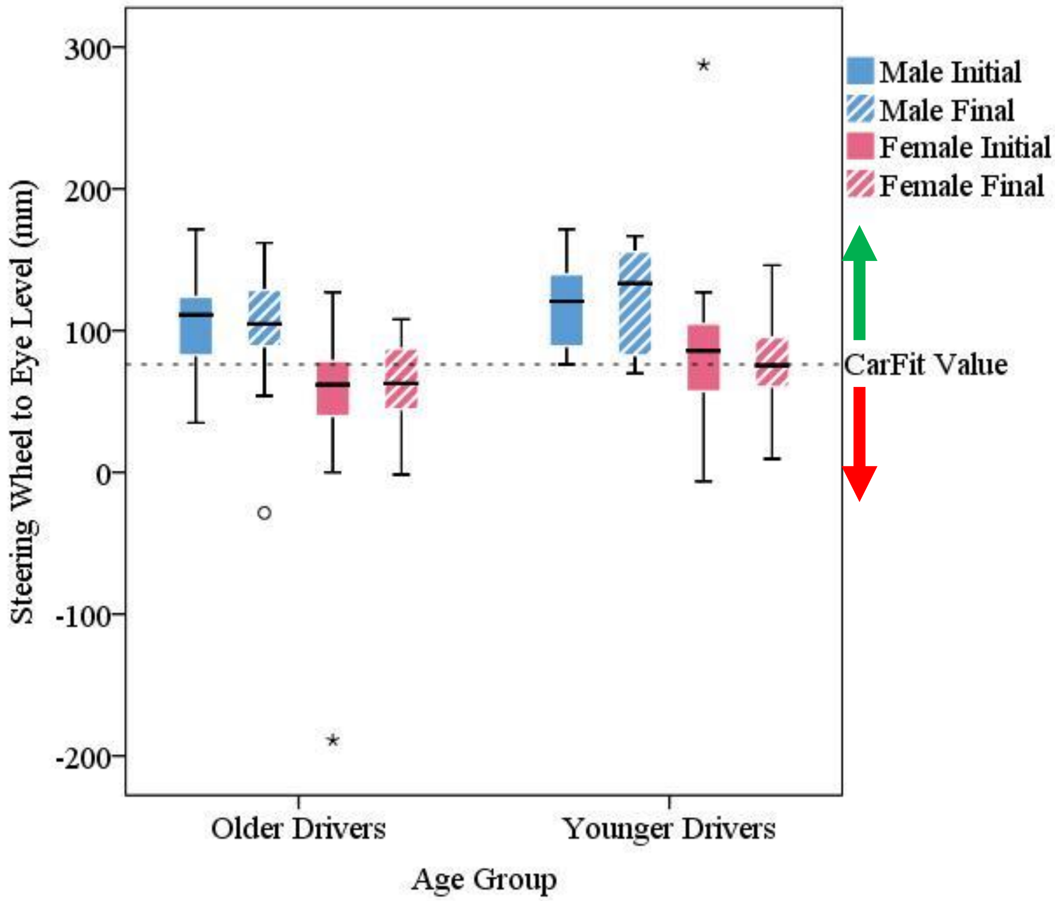


Figure 61. Boxplot diagram comparing the top of steering wheel to eye level measurement between initial/final position, age and gender.

Table 42 shows significant main effects of age ($F(1, 112) = 5.871$, $p = 0.017$, $r = 0.223$) and gender ($F(1, 112) = 14.165$, $p < 0.001$, $r = 0.311$). The main effect of age shows the eye location of older drivers (M = 83 mm, SE = 3 mm) to be 20 mm lower than younger drivers (*M* = 103 mm, *SE* = 8 mm). See Figure 62. The main effect of gender showed that the vertical location of the eye for males (*M* = 113 mm, *SE* = 7 mm) to be 30 mm higher than for females (*M* = 73 mm, *SE* = 6 mm). See Figure 63.

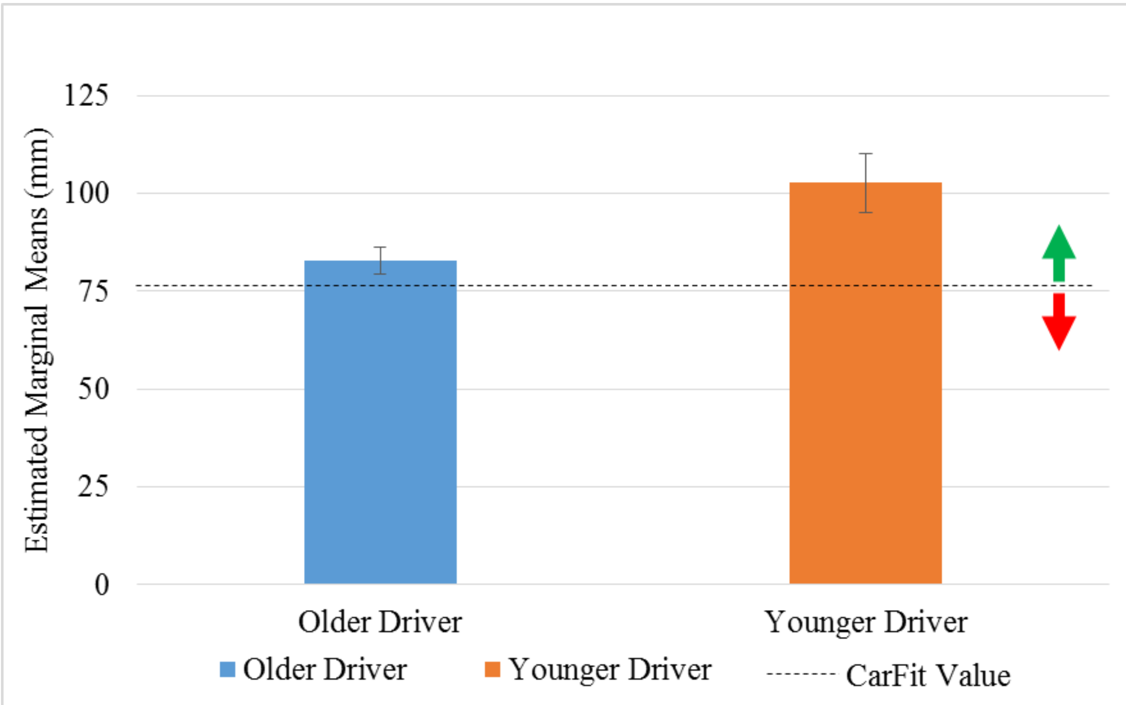


Figure 62. Estimated marginal means for top of steering wheel to eye level, by age, with the stature covariate evaluated at 1695 mm.

Although there is significant difference between older and younger drivers for this measure, both age categories are positioned above the suggested value for this measure. Albeit, older drivers only pass by 7 mm. Therefore, it would be beneficial to encourage older drivers to reposition their seats to accommodate a better LoS.

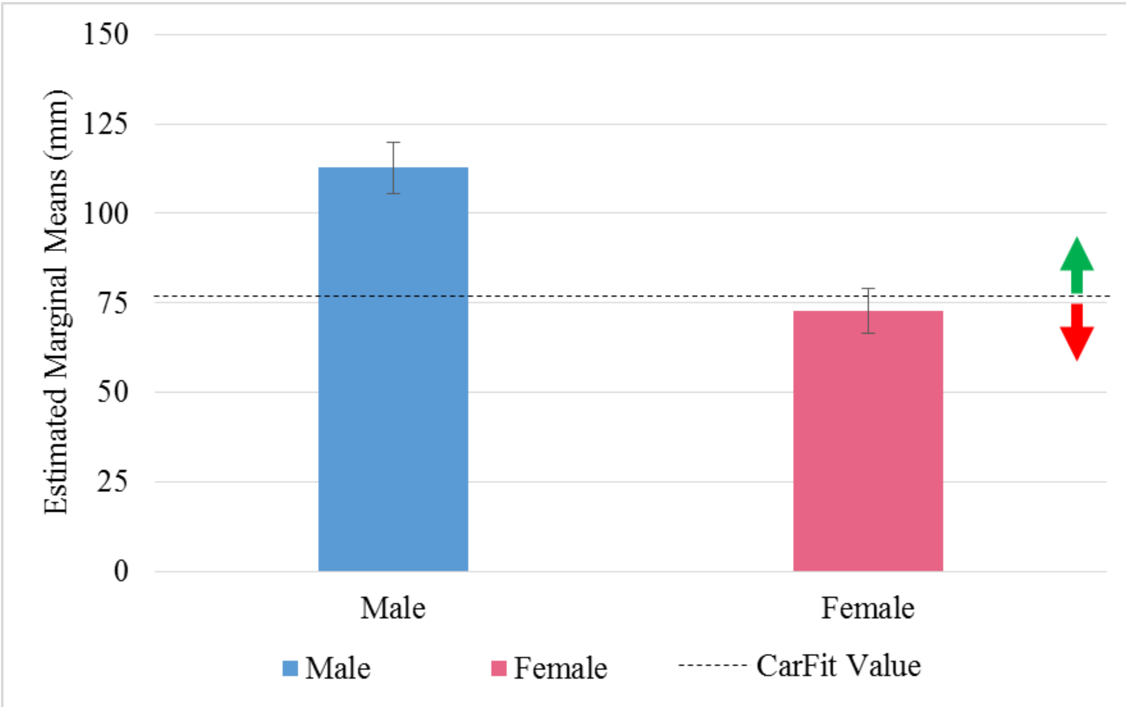


Figure 63. Estimated marginal means for top of steering wheel to eye level, by gender, with the stature covariate evaluated at 1695 mm.

The significant gender differences show that the average male driver sits 27 mm above the suggested value, whereas the average female driver sits 3mm below the suggested value. Figure 64 shows the EMM for both the LoS as well as the SW2Eye by gender. The difference between the EMM for females was 4 mm with LoS being the greater value. This suggests that the average female is looking upward from her sitting position to view the roadway. The mean difference for males was 13 mm with SW2Eye being the greater value, suggesting that the average male had a downward view of the roadway. Considering that the EMM for female drivers' LoS was only 1 mm above the recommended value and SW2Eye was 3 mm below the recommended value suggests that a seat adjustment for female drivers would prove beneficial to the LoS measures.

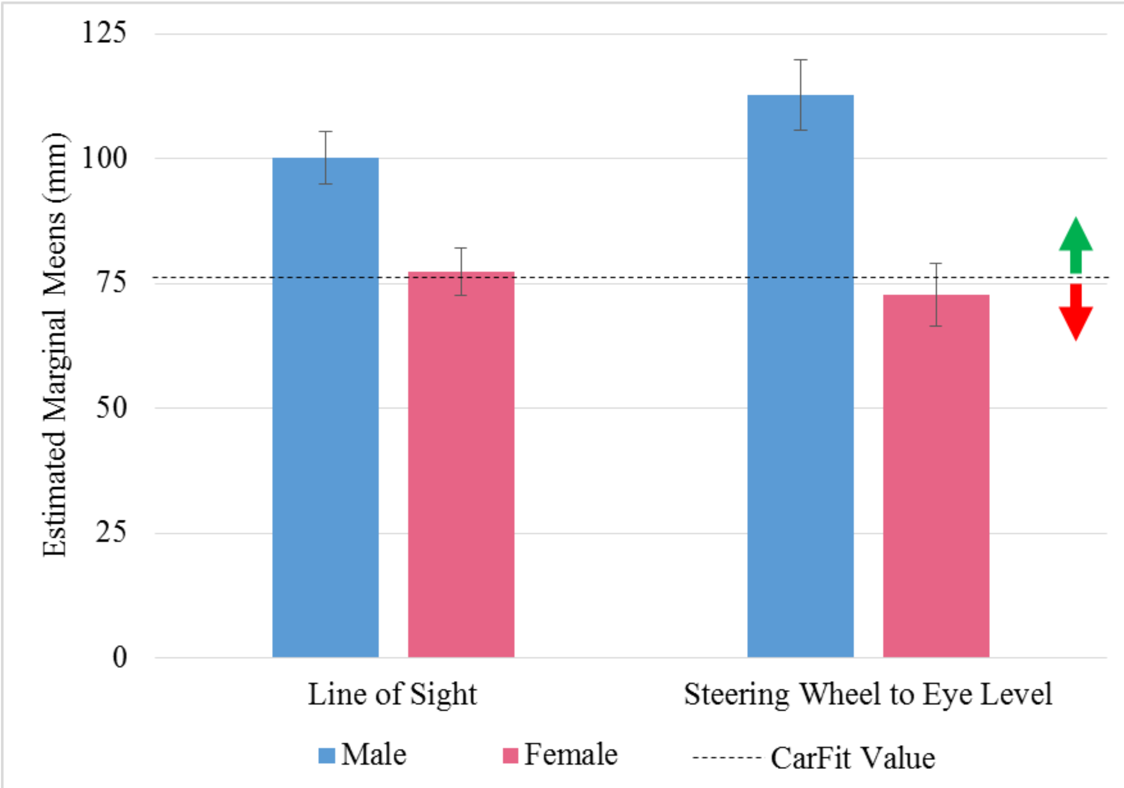


Figure 64. Comparison of the drivers' line of sight above the steering wheel to the vertical eye location above the steering wheel.

6.6 Summary of Driver Selected Seat Position Analysis

The goals of this chapter were to demonstrate that

- older drivers differ from younger drivers in their selected seat position;
- older drivers differ from the SAE J4004 recommended practice; and
- younger drivers do not differ from the SAE J4004 recommended practice.

To accomplish these three tasks, a series of mixed-model ANCOVAs was performed. Primary interests include the ANCOVA for the L99 with the SAE J4004 calculation, and the ANCOVA with difference between the L99 and SAE J4004 calculation. The other ANCOVAs from this chapter serve as support to address the three aforementioned goals.

The first major finding of this research is that age showed as an interaction effect with L99 and SAE J4004, and stature ($F(1, 109) = 5.950$, $p = 0.016$, $r = 0.228$). This finding indicates that age contributes to the variance of the fore/aft position for driver selected seat position. Particularly, this interaction supports part of Hypothesis 3, which states that older drivers will differ significantly from younger drivers by sitting more vertical, forward, and upright than younger drivers sit. Although the fore/aft wording of this hypothesis was shown to be true by the L99 and SAE J4004 ANCOVA, the vertical and upright portion of this hypothesis was not proven correct. The H30 measure which would support the vertical portion of this hypothesis only showed a main effect with stature ($F(1, 109) = 4.132$, $p = 0.044$, $r = 0.191$), and the seat back angle measure which would support the upright portion of this hypothesis showed no significant results whatsoever. In addition, Hypothesis 3 states that older drivers will sit more forward than younger drivers, but this research shows the opposite. The difference in the L99 EMM evaluated at the sample mean for stature show that older drivers initially sat 30 mm behind younger drivers, and after CarFit© training, this value was reduced to 18 mm behind younger drivers.

Further examination of measurements shows that the Chest2SW ($F(1, 109) = 13.577$, $p < 0.0001$, $r = 0.333$) and SW2Eye ($F(1, 112) = 5.871$, $p = 0.017$, $r = 0.223$) significant measures do offer secondary support that that older drivers and younger drivers select different seat positions. The Chest2SW measure showed in interaction with both age and stature, thereby further supporting the fore/aft difference between age groups. In the case of Chest2SW, the EMM results do align with directionality of the hypothesis and show that older drivers sat initially 30 mm closer to the steering wheel than youngers drivers, and after CarFit© training older drivers sat 34 mm closer to the steering wheel than younger drivers. Last, the main effect of age for the SW2Eye measure does show that an age difference does occur for vertical measures of the eye; however, the directionality is opposite of the stated hypothesis, and older drivers were shown to sit 40 mm lower than younger drivers.

The second major finding is that age showed as an interaction effect for the difference between the L99 and SAE J4004 measures and stature ($F(1, 109) = 5.950$, $p = 0.016$, $r = 0.228$). The fact that age shows significant for this variable supports Hypothesis 1 that older drivers select a different seat position than the calculated values to predict driver selected seat position from the SAE J4004 recommended practice. In addition, the EMM for the difference between the calculated BOFRP to the H-point to the measured BOFRP to H-point value were positive, indicating that the calculated value was larger than the measured value, therefore showing that older drivers do sit more forward than the SAE J4004 model predicts. Thus, Hypothesis 1 is fully supported. However, this finding goes against Hypothesis 2, which states that younger drivers will not differ from the SAE

J4004 recommended practice. In fact, the data show that younger drivers had a greater difference from the SAE J4004 values than older drivers. In addition, L6 and A27 both showed an interaction effect with age. The importance of these measurements showing an age effect is that they are both used to compute the SAE J4004 model. Therefore, an age difference does occur between the measured and calculated values as well as two of the values used to compute the SAE J4004.

It was expected that age would be more of an identifier for driver selected seat position. This research shows that age only acted as the main effect for the SW2Eye ANCOVA, and as an interaction effect for six other ANCOVAs. See Table 52 below for a cross-reference summary of the ANCOVA effects. The effect size range for these seven effects was from $r = 0.195$ to $r = 0.333$, which characterized the effects of the ANCOVAs as a small effect ($r \geq 0.10$) to a medium effect ($r \geq 0.30$). That being said, age did show an effect for seven of the previous ANCOVAs, and therefore should be represented in the SAE J4004 recommended practice.

Table 52

Cross Reference Summary of the ANVOCA Effects

Measurement	Age	Gender	Stature	Initial/Final
L99, SAE J4004	I	I	I	I
SAE J4004 and L99 Difference	I	I	I	I
H-point Height			M	
BOFRP to Steering Wheel Center	I		I	I
Seat Base Angle	I	I	I	I
Seat Back Angle				
Hip Angle				
Steering Wheel Angle			I	I
Vehicle Floor to Top of Steering Wheel				
Center of Steering Wheel to Sternum	I		I	I
Backset				
Top of Head to Ceiling				
Top of Leg to Bottom of Steering Wheel	I		I	
Line of Sight Above Steering Wheel		M		
Vehicle Floor to Eye Level		M		
Top of Steering Wheel to Eye Level	M	M		

Note. I = interaction effect; M = main effect.

Gender, although not tied to any specific hypothesis for Gap One of this research, also made substantial contributions in the ANCOVA results. Gender was present in three interaction effects and three main effects. Two of the interactions where gender was involved contained the L99 measure and the difference between the L99 and SAE J4004 measures. In addition, the range of the effect size for gender was from small (r = 0.195) to medium effects (r = 0.335). These contributions to driver selected seat position should not be ignored, and gender should be represented in the SAE J4004 recommended model.

Another finding is that stature had the greatest number of appearances, which showed as an interaction effect nine times and a main effect once. See Table 52. There is no question that stature plays the most significant role in the drivers' selection of seat position. Stature has the most representation in all of the ANCOVA effects. In fact, all of the interaction effects incorporate stature as part of the interactions. Although age and gender show as contributors to driver selected seat position, stature remains the best identifier for driver selected seat position. The importance of stature is an expected outcome and is in agreement with the SAE J4004 recommended practice, which shows that stature influences driver selected seat position and is used as a predictor variable within the SAE J4004 model. Nonetheless, from the results presented in this chapter, the age and gender contributions to driver selected seat position are significant, present in multiple measurements, and show enough of an effect to warrant additional terms in the SAE J4004 recommended practice to predict driver selected seat position.

In terms of the CarFit© selected measurement, a significant effect was found in three of the five measurements (Chest2SW, LoS, and Leg2SW). The backset measurement did not show a significant effect. However, backset distance may be an important consideration of future research efforts to improve driver safety, given that 1) this measurement has been shown by Eriksson (2005) to drastically reduce the likelihood of whiplash during a crash event , 2) whiplash insurance claims have an $8.8 billion economic impact (Insurance Institute for Highway Safety, 2013b), and 3) even after CarFit© training, 50% of the participants still sat outside the 51 mm guideline. As mentioned previously, the last measure, top of head to ceiling, will in time become obsolete as new vehicles begin to populate the roadways.

It has been mentioned that several of the CarFit© guidelines are conflicting and that some drivers may have to compromise one measurement in order to obtain another. Which measure to select depends greatly on the motivation behind the selections. For instance, from this researcher's engineering perspective, the seat selection priority is to protect the occupants *during* a crash; therefore, preference of compromise is to select a seat position that would allow the vehicle's safety features to perform their functions. For example, proper sternum distance from the steering wheel, and a minimized backset distance will reduce the likelihood of an injury given that an accident has occurred. However, informal interviews with Certified Driving Rehabilitation Specialists (CDRSs) have revealed that the therapist perspective is for the driver to select a seat position that would *prevent* an accident from occurring in the first place. Table 53 below ranks the CarFit© measurements according this researcher's view of importance contrasted by opinions given by CDRSs. One should note that difference of order is the placement of the LoS measurement. The CDRSs favor this measure to facilitate a better view of the roadway and to aide a driver's visual search and scanning patterns in order to preempt the occurrence of an accident. Also, it should be noted that the first three measures may influence each other slightly, but they do not cause comprise between one another. For instance, a more upright seat back angle to reduce the backset measure will push the driver's sternum closer to the steering wheel as well, but at a substantially smaller distance than the backset adjustment, and the Chest2SW distance can be accommodated by other adjustments such as seat track, steering wheel telescope, seat track and/or steering wheel angle. Based on the researcher's experience, the Chest2SW, Backset, and LoS measurements should be obtainable for all participants. The interfering factor for these three measures to occur for all drivers is subject to the drivers' preference for comfort, which was not quantified for this study and should be considered for future work.

Table 53

Comparison of an Engineer's and CDRSs' Order of Priority for CarFit© Measures.

Rank	Engineer	CDRS
1	Center of Steering Wheel to Sternum	Line of Sight above Steering Wheel
2	Backset	Center of Steering Wheel to Sternum
3	Line of Sight above Steering Wheel	Backset
4	Top of leg to bottom of steering wheel	Top of leg to bottom of steering wheel
5	Top of head to ceiling	Top of head to ceiling

CHAPTER SEVEN

IMPROVED DRIVER SELECTED SEAT POSITION MODEL

7.1 Introduction

Chapter Six presented the ANCOVA results for the multiple measures of driver selected seat position collected for this study. The findings from Chapter Six suggest that the model in the SAE J4004 recommended practice would be improved by including an age and gender term in conjunction with the existing terms. Therefore, this chapter will address Hypothesis 4 in Gap Two: Description of Older Driver Selected Seat Position, which states that a separate linear regression to include gender and age variables will provide a more accurate model to predict seat track position of older drivers.

The remainder of this chapter presents the technique, results, and discussion used to increase the accuracy of the model in the SAE J4004 recommended practice. The chapter sections that follow are section 7.2, which discusses how the collected data are used for this analysis; Section 7.3, which describes the regression technique; Section 7.4, which is the results and discussion of the linear regression; and Section 7.5, which summarizes the chapter.

7.2 Data Set

There are four data sets for this dissertation. They are the older drivers from the community setting, older drivers from the clinical setting, younger drivers, and the SAE model. The data sets for this chapter will be managed in the same manner described in Chapter Six, where the younger drivers remain unchanged and the older drivers from the two time periods and locations will be combined to make one large data set. Figure 65 shows the generic data structure for a nondescript measurement.

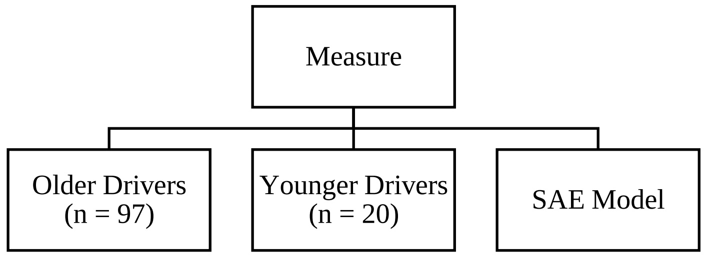


Figure 65. Structure of available data for linear regression.

7.3 Linear Regression Technique

A hierarchical, multivariable, linear regression technique is used to develop a new driver selected seat position equation. The variables used are stature, vehicle floor to H-point (H30), seat base angle (A27), BOFRP to steering wheel center (L6), transmission type (t), age group, and gender. Age was transformed into a dichotomous variable, where participants ages 60 and over were grouped into the older driver category, and participants ages 30 to 39 were grouped into the younger driver category. The hierarchical linear regression will be computed in the following four steps.

1. The known predictors from SAE J4004 recommended practice would be entered as the first layer of the model. The second layer would add the age variable, and the third layer would add the gender variable to the model. This procedure first provides baseline results based on the previous research findings using the

collected data and then adds in the hypothesized variables according to the entered hierarchical layers.

2. To prevent any bias due to the order at which the hypothesized variables are layered, the regression analysis will be rerun with the gender term as the second layer and the age group term as the third layer. Both trials will use the established variables in the SAE J4004 recommended practice as the first layer of the hierarchical model.
3. After the hierarchical layer order is established according to the largest contribution to the regression model, the predictor variables will be tested for independence, linearity, multicollinearity, heteroscedasticity, and normality.
4. To improve the robustness of the regression, bootstrapping will be used with 2,000 bootstrap samples and a 95% bias corrected and accelerated confidence interval.

7.4 Results and Discussion

As stated above in section 1.7 Recommended Practices and Standards, the SAE J4004 recommended practice is used to determine the seat track accommodations of the driver, and Equation 9 above – and repeated as Equation 17 for convenience – is used to predict the selected seat position of any driver. A depiction of these variables is also shown below in Figure 66.

$$X = 16.8 + 0.433(stature) - 0.24(H30) - 2.19(A27) + 0.41(L6) - 18.2t \qquad \text{Equation 17}$$

Where,

Stature is the standing height of the individual in millimeters.

H30 is the vertical height of the H-point above the vehicle floor.

A27 is the cushion angle.

L6 is the BOFRP to steering wheel center, and

t is the transmission type (1 if manual and 0 is automatic).

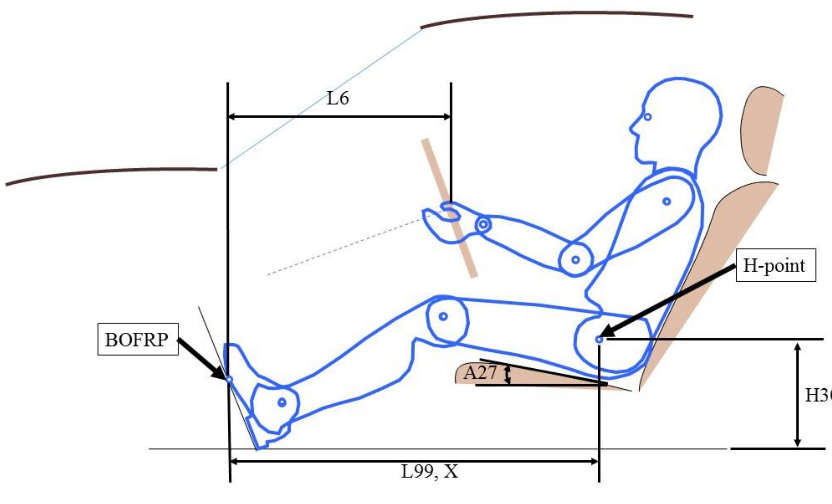


Figure 66. Depiction of variables used to calculate driver selected seat position using SAE J4004 recommended practice.

This research states in Hypothesis 4 that the SAE J4004 recommended practice model to predict the selected seat position of any driver could be improved by the inclusion of age and gender terms into the linear regression analysis as shown Equation 18. The remainder of this section will show the results of the linear regression analysis to test Hypothesis 4.

$$X = b_0 + b_1 Stature + b_2 H30 + b_3 A27 + b_4 L6 + b_5 t + \boldsymbol{b_6 Age} + \boldsymbol{b_7 Gender} \qquad \text{Equation 18}$$

This section presents the linear regression results for analysis in order to improve the accuracy of the SAE J4004 recommended practice to predict the selected seat position of any driver. A scatter plot of H30 by L99 measurements is shown in Figure 67. This plot shows the collected data separated by age, gender, as well as measured and calculated BOFRP to H-point. In addition, the SAE J4004 recommended practice accommodation levels are plotted as dotted lines on the graph. Because one of the exclusion criteria was if the participants were outside the stature range of 152 to 188 cm (60 to 74 in) or 15^{th} to 85^{th} percentile for stature, a 70 percent accommodation range was interpolated from the provided SAE J4004 recommended practice and is shown as the solid black line in Figure 67. Upon examination of Figure 67, it is worth noting that many of the participants sat within the 70 percent accommodation range; however, several sat outside this range and two older males sat outside the 98 percent accommodation range. It is also worth noting that the two participants who sat outside the 98 percentile accommodation range did not qualify statistically as outliers, as their z-scores were 2.22 and 2.30, which is well below the 3.29 value for a statistical outlier and just below the 2.58 value to be considered an extreme value (Field, 2013).

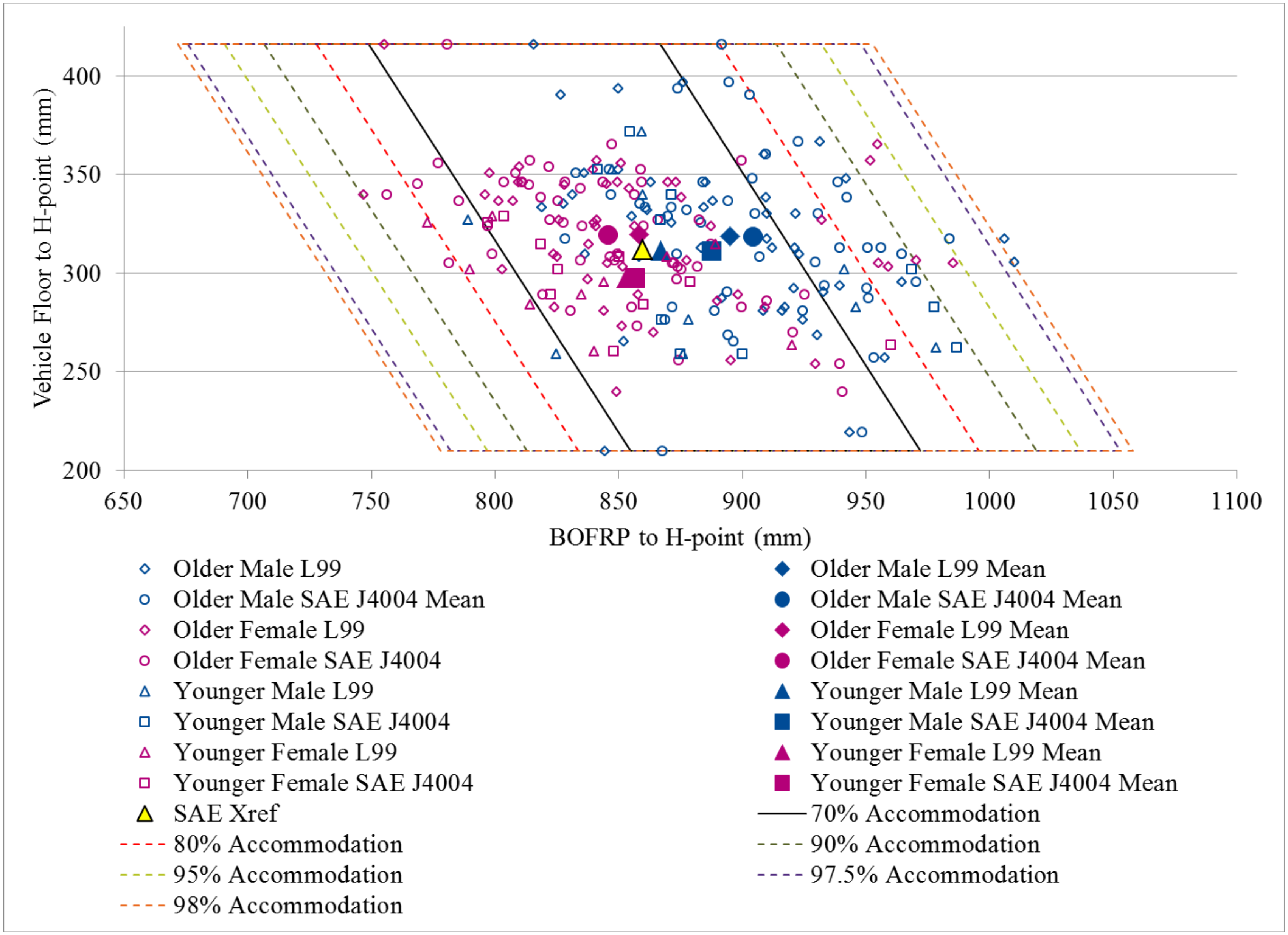


Figure 67. Scatter plot of Vehicle floor to H-point by BOFRP to H-point in millimeters (mm).

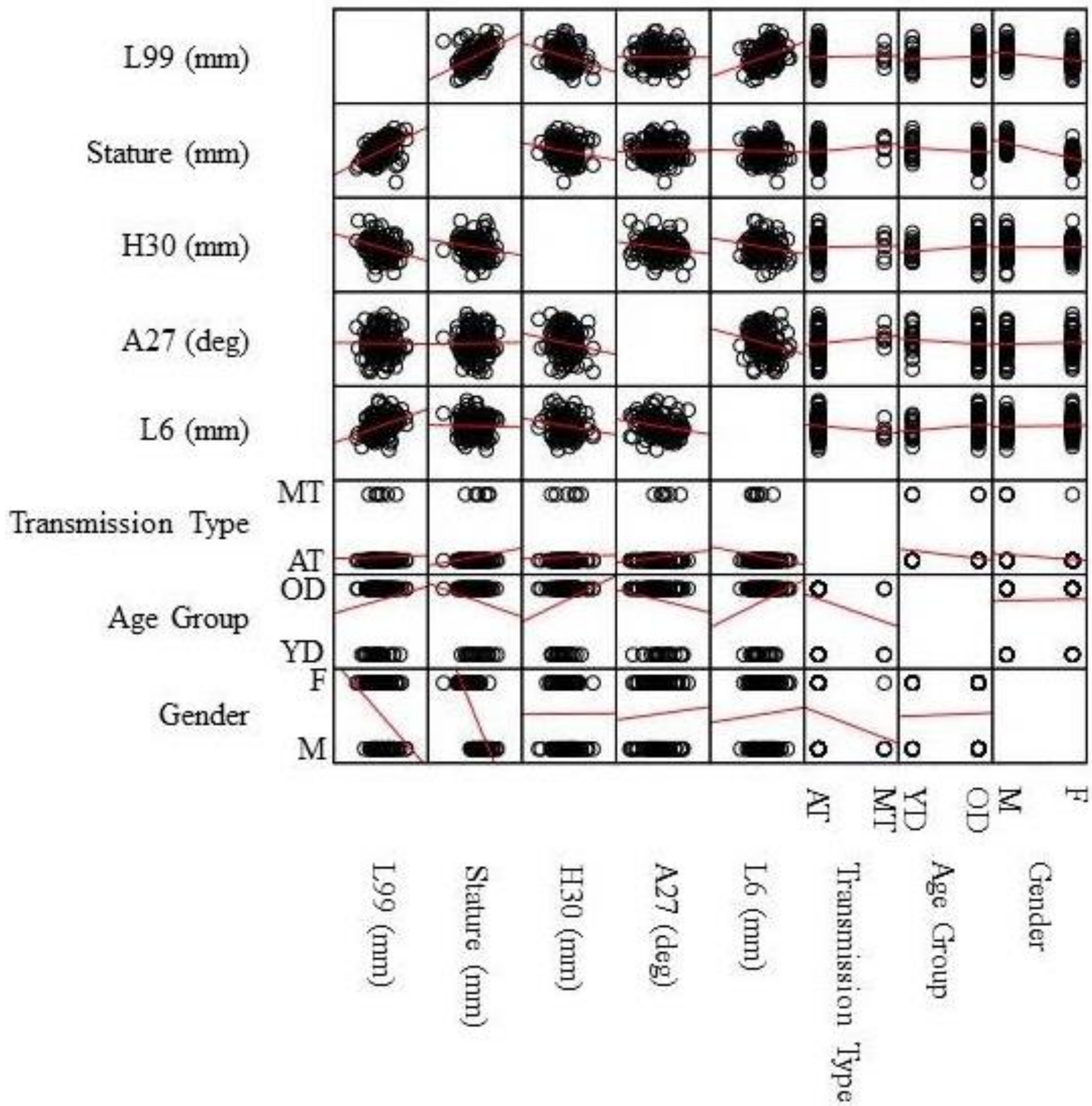


Figure 68. Matrix plot of the relationships between measured BOFRP to H-point and regression variables. *Note.* AT = Automatic Transmission; MT = Manual Transmission; YD = Younger Driver; OD = Older Driver; M = Male; F = Female.

The dichotomous variables (transmission type, age group, and gender) in the matrix plot above in Figure 68 do not contribute to the correlation knowledge for this linear regression; however, as standard linear regression practice, this matrix plot was included for completeness. Figure 69 below contains only the continuous variables shown above in Figure 68 without the dichotomous variables in order to improve the resolution of the matrix plot. The first column and row of the matrix plots shows the scatter plot of the continuous independent variables (stature, H30, A27, and L6) against the dependent variable L99. The red line in each of the scatter plots indicates the regressed data on all of the collected data. Note that stature and L6 both show a positive correlation and that H30 shows a negative correlation. On the other hand, A27 appears to show no correlation whatsoever. See Table 54 for the Pearson's correlation coefficient values. This result is contrary to the results found in Flannagan et al. (1996) in which seat base angle was shown to be a predictor. However, Flannagan et al. measured the participants' seat position with either an 11-degree or 18-degree seat base angle, whereas this study allowed the seat base angle to be on any continuum that the driver selected.

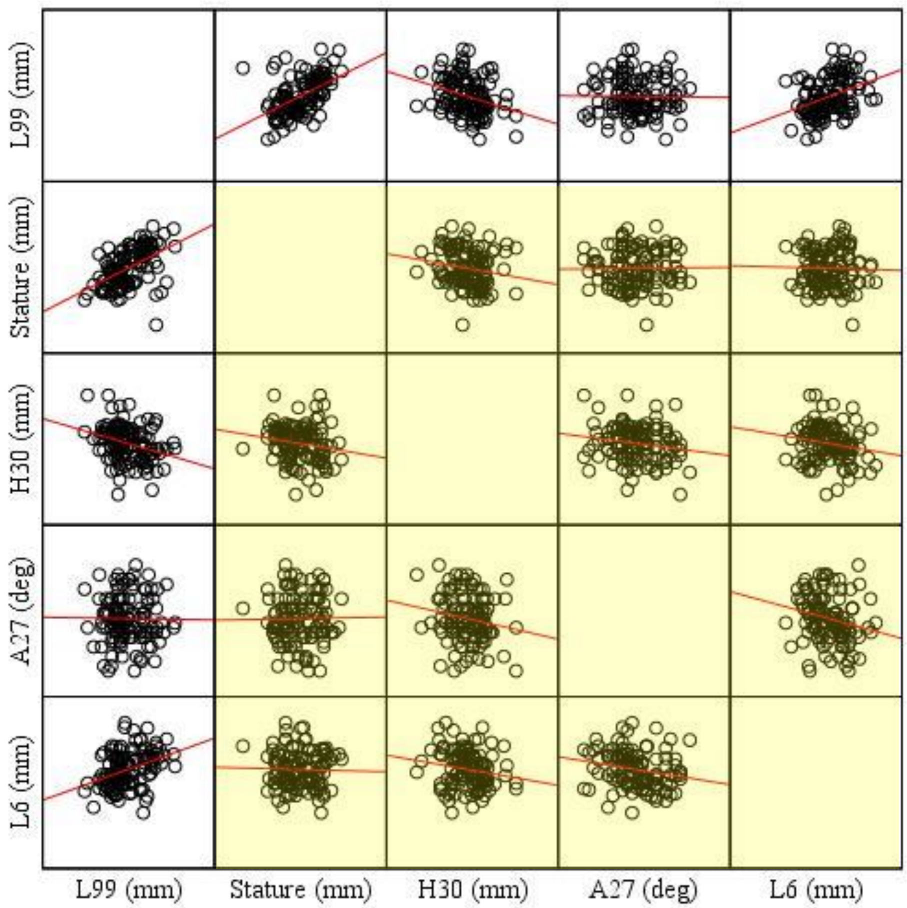


Figure 69. Matrix plot of the relationships between measured BOFRP to H-point and non-dichotomous regression variables.

Table 54

Means, Standard Error, and Pearson Correlations for Continuous Variables

	Descriptive Statistics		Pearson Correlation Coefficient				
Measure	*M*	*SE*	L99	Stature	H30	A27	L6
L99	872	5	—				
Stature	1695	9	0.508*	—			
H30	316	3	-0.300*	-0.174	—		
A27	11	0	-0.012	0.014	-0.172	—	
L6	544	6	0.366*	-0.027	-0.172	-0.210*	—

Note. All * correlations are significant at $p < 0.001$. *M* = mean; *SE* = standard error; L99 = measured BOFRP to H-point; H30 = vehicle floor to H-point; A27 = seat base angle; L6 = BOFRP to steering wheel center.

Hierarchical layer evaluation.

As mentioned above, two diagnostic regressions were run to determine if the order of the hierarchal layers for the hypothesized predictor variables age and gender was affected. The summary for these two diagnostic models is provided below in Table 55.

Table 55

Summary of Linear Regression Model for Measured BOFRP to H-point

Model	*R*	R^2	R^2 Change	*F* Change	df_1	df_2	Sig. *F* Change	Durbin-Watson
1. SAE J4004	0.652	0.426	0.426	16.443	5	111	0.000	
2. Age Group	0.671	0.451	0.025	5.074	1	110	0.026	
3. Age Group and Gender	0.672	0.452	0.001	0.134	1	109	0.715	1.567
1. SAE J4004	0.652	0.426	0.426	16.443	5	111	0.000	
2. Gender	0.652	0.426	0.000	0.009	1	110	0.926	
3. Gender and Age Group	0.672	0.452	0.026	5.159	1	109	0.025	1.567

Note. Change in F-ratio considered significant at $p < 0.05$.

The model summary in Table 55 shows that the predictor variable gender provides negligible change in Pearson's R-value. In addition, in both hierarchical models, gender's contribution to the change in the F-ratio is insignificant with p = 0.715 when entered as the third layer of the hierarchy, and p = 0.926 when entered as the second layer of the hierarchy. Although gender was shown in the previous chapter to account for portions of the variance for select measurements, gender does not contribute significantly to this model as a predictor variable for the L99 measurement. Therefore, the predictor variable gender can be omitted from the following linear regression models, and the generalized regression equation is reduced to the one shown in Equation 19.

$$X = b_0 + b_1 Stature + b_2 H30 + b_3 A27 + b_4 L6 + b_5 t + \boldsymbol{b_6 Age} \qquad \text{Equation 19}$$

Evaluation of bias for hierarchical linear regression model.

After eliminating gender from the regression model, a third diagnostic regression model was run to assess independence, linearity, multicollinearity, heteroscedasticity, and normality of the predictor variables. Independence was assessed by the Durbin-Watson test statistics, which reported a value of 1.564, and meets the Durbin-Watson criteria of greater than 1 and less than 3 (Field, 2013). Therefore, the predictor variables are considered independent. Next, linearity was assessed by examination of the partial regression plots of the dependent variable (L99) versus each predictor variable for outliers. No outliers were found in these plots and linearity was assumed. See Appendix E for the partial regression plots. Multicollinearity was assessed with the variance inflation factor (VIF) and the tolerance statistics. The criteria to pass multicollinearity bias was that the VIF had to be less than 10, and the tolerance statistic had to be greater than 0.2 (Field, 2013). Table 56 shows that the criteria more than adequately met with a maximum VIF of 1.176 for the H30 predictor variable in model 2 and a minimum tolerance statistic of 0.850 again for the H30 predictor variable in model 2.

Table 56

Variance Inflation Factor and Tolerance Statistics for Multicollinearity Bias Evaluation

Model	Predictor	VIF	Tolerance Statistic
1. SAE J4004	Stature	1.056	0.947
	H30	1.122	0.891
	A27	1.110	0.901
	L6	1.112	0.899
	t	1.046	0.956
	Mean	1.089	0.919
2. Age Group	Stature	1.063	0.941
	H30	1.176	0.850
	A27	1.111	0.900
	L6	1.163	0.860
	t	1.079	0.927
	Age	1.154	0.867
	Mean	1.124	0.891

Heteroscedasticity and non-normality can be examined in standardized predicted (ZPred) values versus standardized residual (ZResid) values scatter plot shown below in Figure 70. The scatter or cloud effect of Figure 70, rather than a V or funnel effect, shows that there is no heteroscedasticity in the models. In addition, normality is shown by the regressed red line in Figure 70. Because there is no correlation shown in the regression, then normality is maintained. Last, normality of each of the predictor variables was confirmed with the Q-Q plots shown in Appendix E.

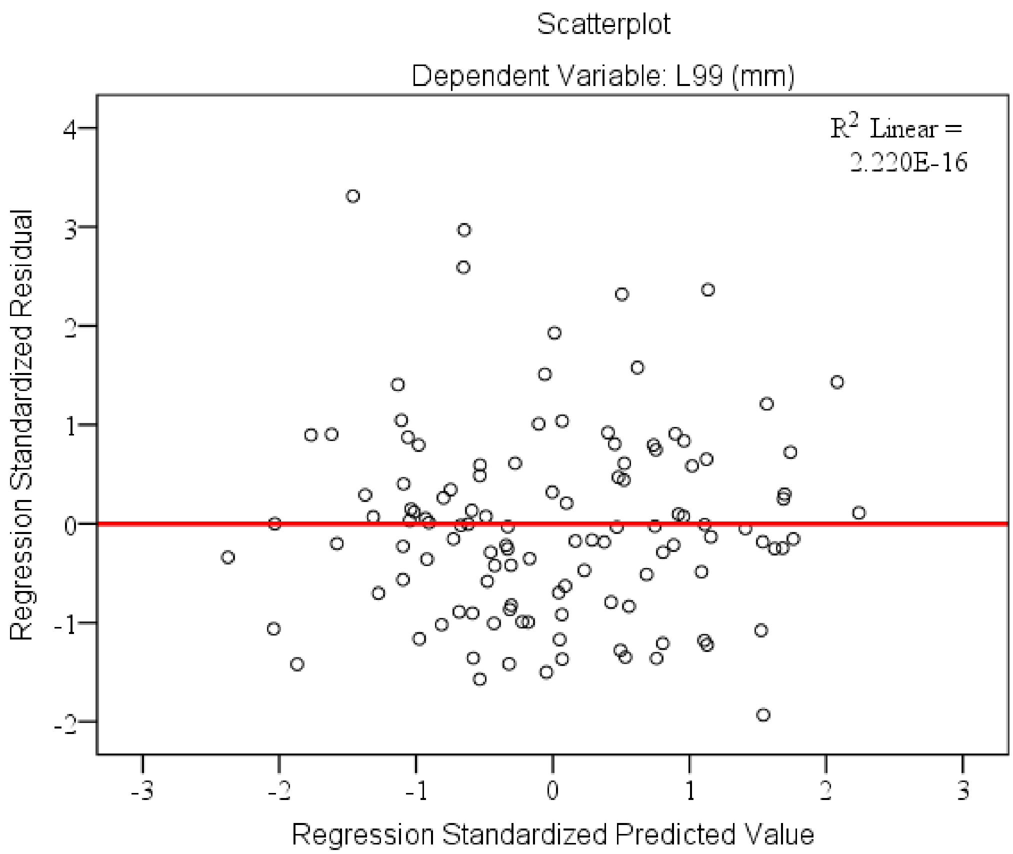


Figure 70. Plot of the standardized predicted (ZPred) values against the standardized residual values (ZResid).

Bootstrapped hierarchical linear regression model.

Because no bias was found in the predictor variables for the previous model, a fourth hierarchical linear regression model was conducted in order to improve the robustness of the linear regression. Improved robustness was accomplished by bootstrapping the data with 2,000 bootstrap samples and a 95% bias corrected and accelerated (BCa) confidence interval. The two most common methods of bootstrapping are the percentile interval and BCa methods. The percentile interval method uses the user-specified percentile level to select the percentiles from the bootstrap histogram to generate the corresponding confidence interval (Efron & Tibshirani, 1993; IBM Corp., 2013). The percentile interval method does not control the bootstrap sampling for any type of bias and can lead to a biased confidence interval. The BCa method also uses the user-specified percentile level; however, BCa has a bias correction and acceleration parameter to steer the shape of the bootstrapped histogram and minimize any amount of bias (DiCiccio & Efron, 1996). The result of the corrections factors leads the BCa to a second order increase in accuracy and correctness over the percentile interval method (Efron & Tibshirani, 1993). The main disadvantage of the BCa method is the substantial number of required samples which exhausts computational resources (Wright, London, & Field, 2011). Because computational resources are not a concern and the increase accuracy of the confidence interval is desired, the BCa method is used for this dissertation.

The summary of the hierarchical linear regression models is presented below in Table 57. Model 1 from Table 57 is the baseline summary statistics for the predictor variables used in the SAE J4004 recommended practice shown above in Equation 17. This model is based on the previous research from Flannagan et al. (1998), Flannagan et al. (1996), and Philippart et al. (1984); therefore, the associated variables have been accepted by this researcher as making significant contributions to the linear regression model, and the hypothesized improvements pertain to the additional age predictor variable in model 2.

Model 2 in Table 57 is the summary statistics for the linear regression once the age group predictor variable is added to the model. See Equation 19. The addition of the age group predictor variable showed a significant change in the F-ratio ($\Delta F(6, 110) = 5.07$, $p =$ 0.026) and showed an 0.025 increase in the fit of the regression model. Therefore, the age group predictor variable demonstrated a significant contribution to the SAE J4004 recommended practice.

Table 57

Hierarchical Model Summary

			Change Statistics					
Model	R	R^2	R^2 Change	F Change	df_1	df_2	Sig. F Change	Durbin-Watson
1. SAE J4004	0.652	0.426	0.426	16.44	5	111	0.000	
2. Age Group	0.671	0.451	0.025	5.07	1	110	0.026	1.564

Note. Change in F-ratio considered significant at $p < 0.05$.

As a result of the significant age group predictor variable to improve the SAE J4004 recommended practice, Table 58 presents the bootstrapped coefficients for both the original SAE J4004 recommended practice as regressed in this hierarchical linear regression model, followed by the linear regression inclusive of the age group predictor variable.

It is interesting to note that in both layers of the hierarchical regression model the seat base angle and the transmission type did not show a significant *p*-value. The difference in significant finding for seat base angle is most likely that Flannagan et al. (1996) used two discrete values for the seat base angle (11 deg and 18 deg), and this research used the continuous range allowed by each participant's vehicle. The non-significant result of transmission type is certain to be due to the low sample size of the manual transmission (n = 6) compared to the automatic transmission (n = 111) feature in the participants' vehicles. Equation 20 is the linear regression coefficients for model 2 in Table 58 with the associated predictor variables.

Table 58

Hierarchical Linear Model of Predictors for measured BOFRP to H-point

			Bootstrap				
			BCa 95% Confidence Interval				
Model		Coefficients	Lower	Upper	*SE*	*p*-value	ß
1	Constant	279.026	92.103	462.233	103.824	0.009	
	Stature	0.285	0.174	0.397	0.056	0.001	0.492
	H30	-0.211	-0.404	0.016	0.107	0.042	-0.147
	A27	0.339	-1.260	1.959	0.814	0.682	0.031
	L6	0.320	0.190	0.473	0.074	0.001	0.361
	Transmission Type	0.961	-23.529	31.063	14.445	0.942	0.004
2	Constant	278.709	93.514	465.797	102.455	0.009	
	Stature	0.293	0.179	0.402	0.056	0.001	0.505
	H30	-0.265	-0.466	-0.037	0.112	0.015	-0.184
	A27	0.387	-1.128	2.014	0.788	0.629	0.035
	L6	0.288	0.163	0.435	0.072	0.001	0.325
	Transmission Type	7.925	-17.416	33.618	12.908	0.526	0.033
	Age Group	24.280	7.380	41.356	9.138	0.006	0.171

$$X = 278.709 + 0.293 \cdot Stature - 0.265 \cdot H30 + 0.387 \cdot A27 + 0.288 \cdot L6 + 7.925 \cdot t + 24.280 \cdot Age \quad \text{Equation 20}$$

Where,

Stature is the standing height of the individual in millimeters.

H30 is the vertical height of the H-point above the vehicle floor.

A27 is the cushion angle.

L6 is the BOFRP to steering wheel center, and

t is the transmission type (1 if manual and 0 is automatic).

Age is the age group of the driver (1 if driver is 60 years of age or greater and 0 if under 60 years of age).

The new regression data computed from Equation 20 were plotted in Figure 71. Because gender was not regressed in Equation 20 the gender segmentation was omitted in the scatterplot. In order to show the mean values for the SAE J4004 model, the L99 measurements, and the new regression model, Figure 72 adjusts the scale of both BOFRP to H-point and vehicle floor to H-point axes for better resolution. It can be seen in Figure 72 that the mean value for the new regression model more closely matches the mean value for the measured L99 values compared to the mean value for the SAE J4004 model.

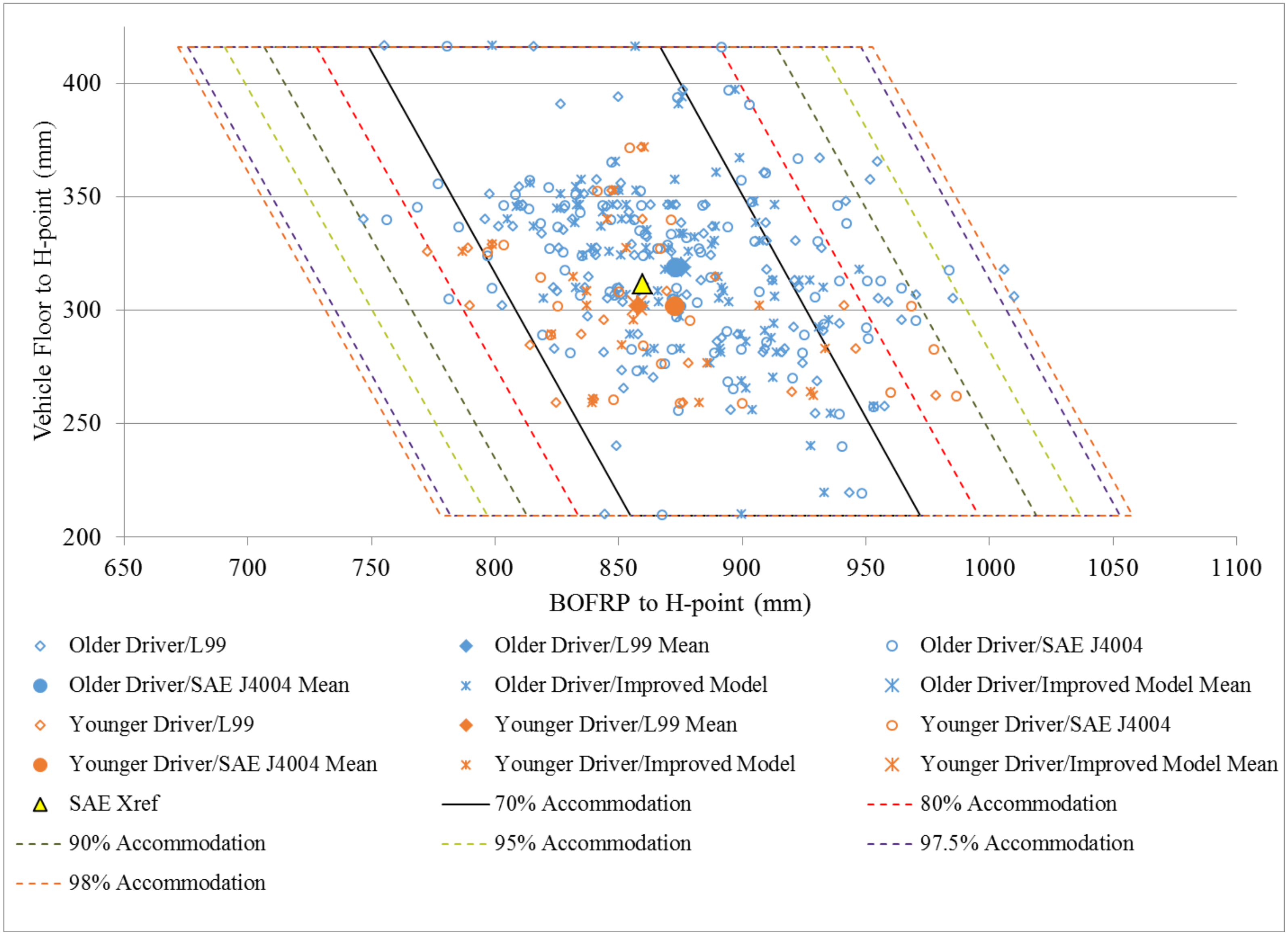


Figure 71. Scatter plot of vehicle floor to H-point by BOFRP to H-point in millimeters (mm).

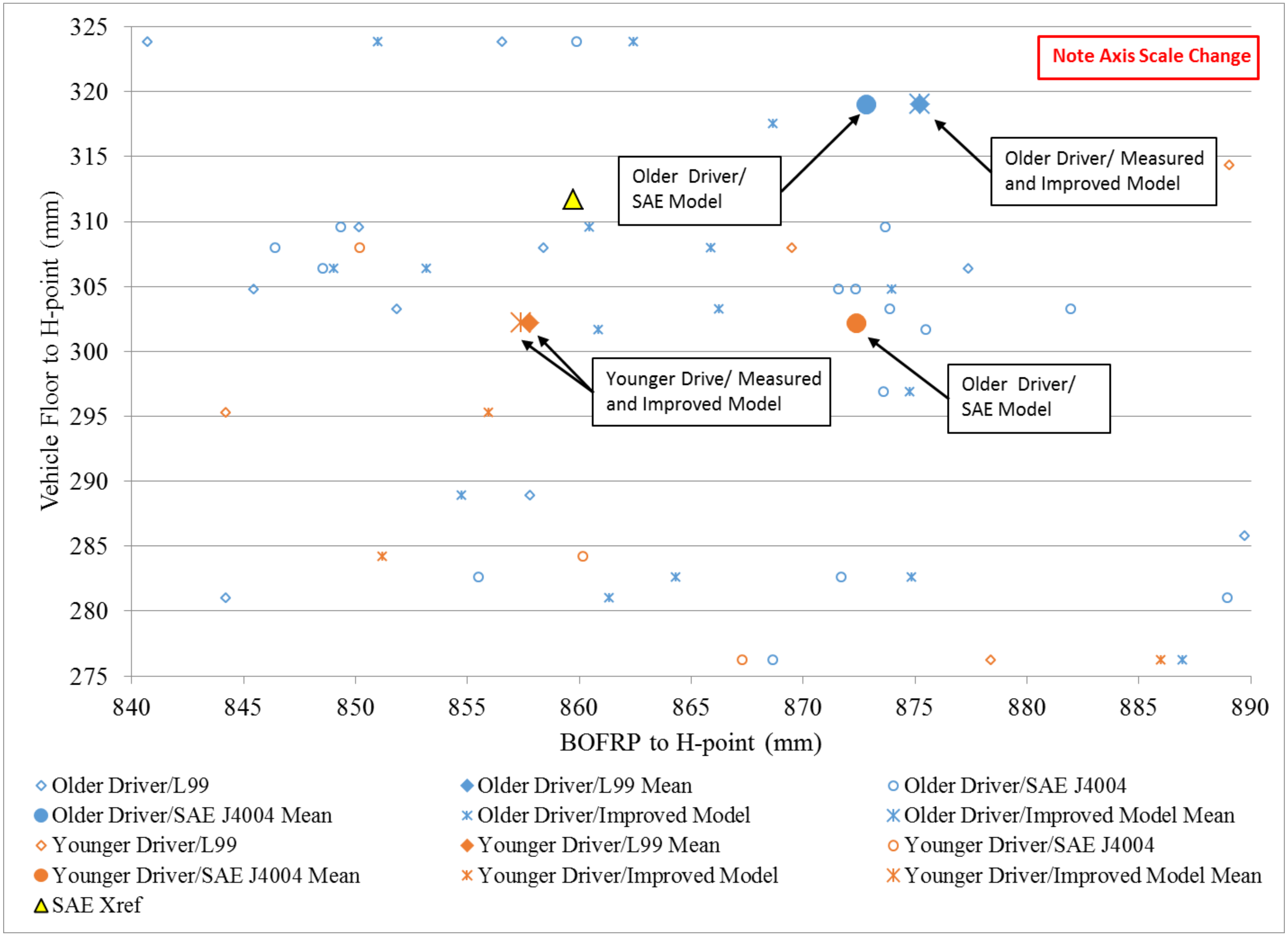


Figure 72. Adjusted scale of the scatter plot of vehicle floor to H-point by BOFRP to H-point in millimeters (mm).

Table 59 shows that there is no difference between the mean values of the improved model and the L99 measurement for older drivers, whereas there is a marginal difference of 2 mm between the mean value of the SAE J4004 and the measured L99. Younger drivers showed only a 1 mm difference between the improved model and the L99 model, but showed a more substantial 14 mm difference between the SAE J4004 model and the L99 measurement.

Table 59

Mean and Standard Error for Measured BOFRP to H-point SAE J4004 Model and Improved Model in Millimeter (mm)

	L99 (mm)		SAE J4004 (mm)		Improved Model (mm)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Older Drivers	875	5	873	5	875	4
Younger Drivers	858	13	872	13	857	10

Individual deviation of the models from the measured L99 is calculated as shown in Equation 21. In addition, the standard deviation and standard error of the models from the measured value are calculated as shown in Equation 22 and Equation 23, respectively. Figure 73 shows the mean deviation values for the SAE J4004 and the improved model, which shows that on average the improved model does not deviate from the measured L99 for either older or younger drivers. The same cannot be said for the SAE J4004 model's deviation. Table 60 shows the tabulation of the deviations from Figure 73 with the associated SE_{model}.

$$deviance_i = L99_i - Model_i \qquad \text{Equation 21}$$

$$s_{model} = \sqrt{\frac{\sum_{i=1}^{n}(L99_i - Model_i)^2}{N-1}} \qquad \text{Equation 22}$$

$$SE_{model} = \frac{s_{model}}{\sqrt{N}} \qquad \text{Equation 23}$$

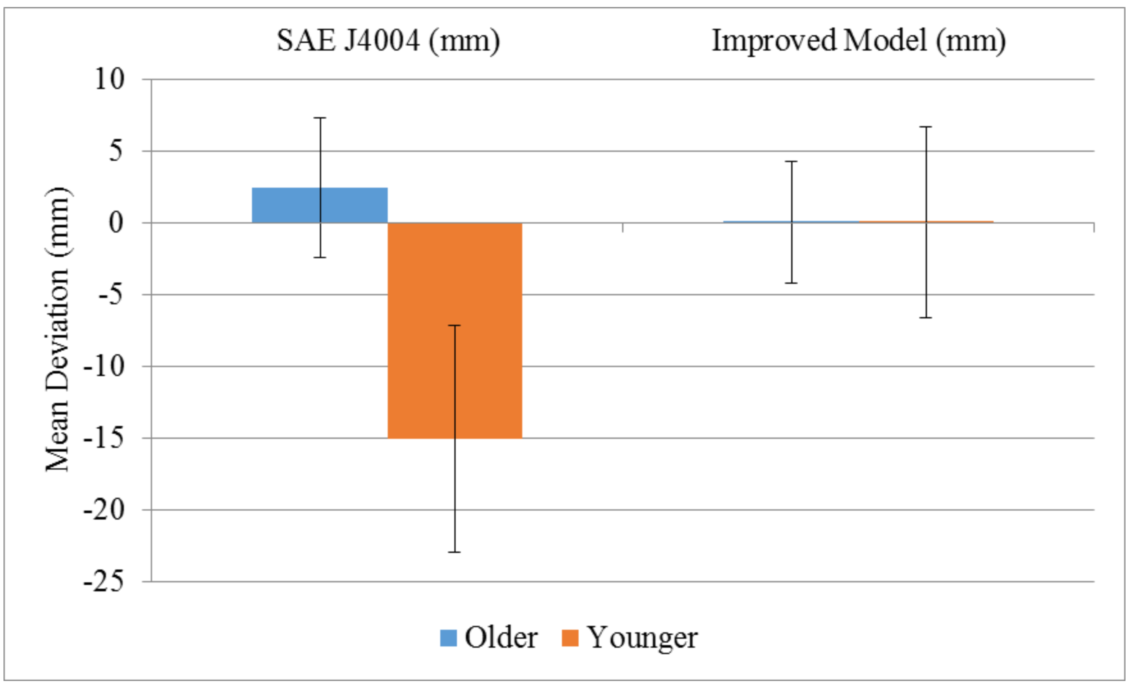


Figure 73. Mean deviation of the SAE J4004 recommended practice and improved model from the measured value by age.

Table 60

SAE J4004 and Improved Model Deviation from Measured BOFRP to H-point in Millimeters (mm)

	SAE J4004 (mm)		Improved Model (mm)	
	M	*SE*	*M*	*SE*
Older	2	5	0	4
Younger	-15	8	0	7

Last, the deviation of the models was compared using a mixed-model ANCOVA with variables age, stature and model deviation. The SAE J4004 deviation and the improved model deviation were a within subject variable, while age was a between subject variable, and stature was the covariate. The boxplot in Figure 74 summarizes the participants' deviation for both the SAE J4004 model and the improved model.

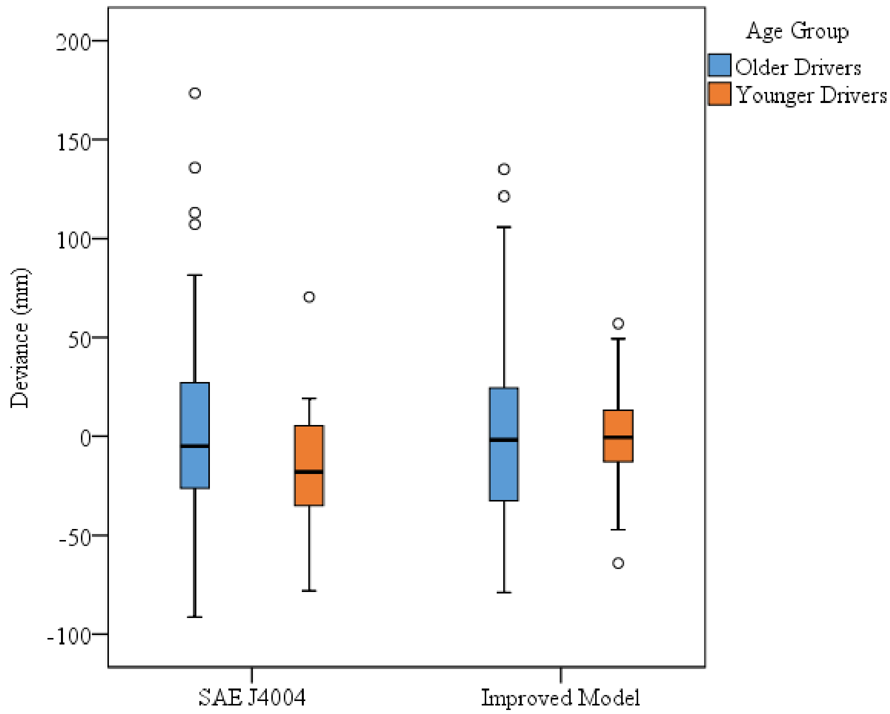


Figure 74. Boxplot diagram comparing the deviation of the SAE J4004 model and the improved model.

The assumption of homogeneity of regression slopes is not maintained for this ANCOVA; therefore, the covariate stature is allowed to interact with the main effects of the ANCOVA. In summary, the ANCOVA revealed an interaction effect between the deviation and the covariate stature ($F(1, 113) = 30.096$, $p < 0.001$, $r = 0.459$) and a main effect of deviation ($F(1, 113) = 27.899$, $p < 0.001$, $r = 0.445$). The complete ANCOVA table can be found in Appendix D. The results of the ANCOVA are shown below in Figure 75, which indicate that the SAE J4004 (M = -5.4 mm, SE = 6 mm) is 4.9 mm further from the L99 measurement than the improved model (M = -0.5 mm, SE = 5 mm) when evaluated at the sample mean for the covariate stature (stature = 1695 mm).

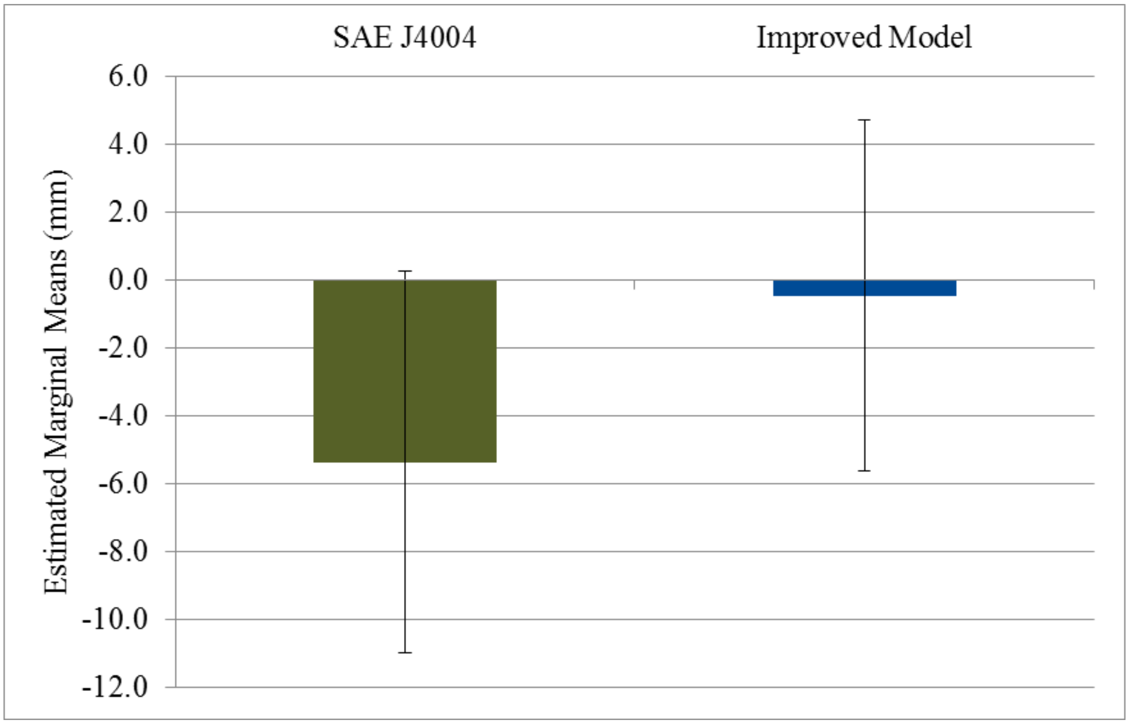


Figure 75. Estimated marginal means for the interaction of deviation with the stature covariate evaluated at 1695 mm.

The assumption of homogeneity of regression slopes was not met, so the stature covariate was allowed to interact with the main effects. Figure 76 shows the estimated marginal mean (EMM) for deviation by stature, while Table 61 is a tabulation of these values with the associated *SE*. Important features of Figure 76 are the following:

- The slope for the improved model deviation is quite small and positive, showing a change 1.8 mm over 151 mm of stature (slope = 0.01).
- The slope for the SAE J4004 deviation is nearly 10 times steeper and negative, with a change of 17.7 mm over 151 mm of stature (slope = -0.12).

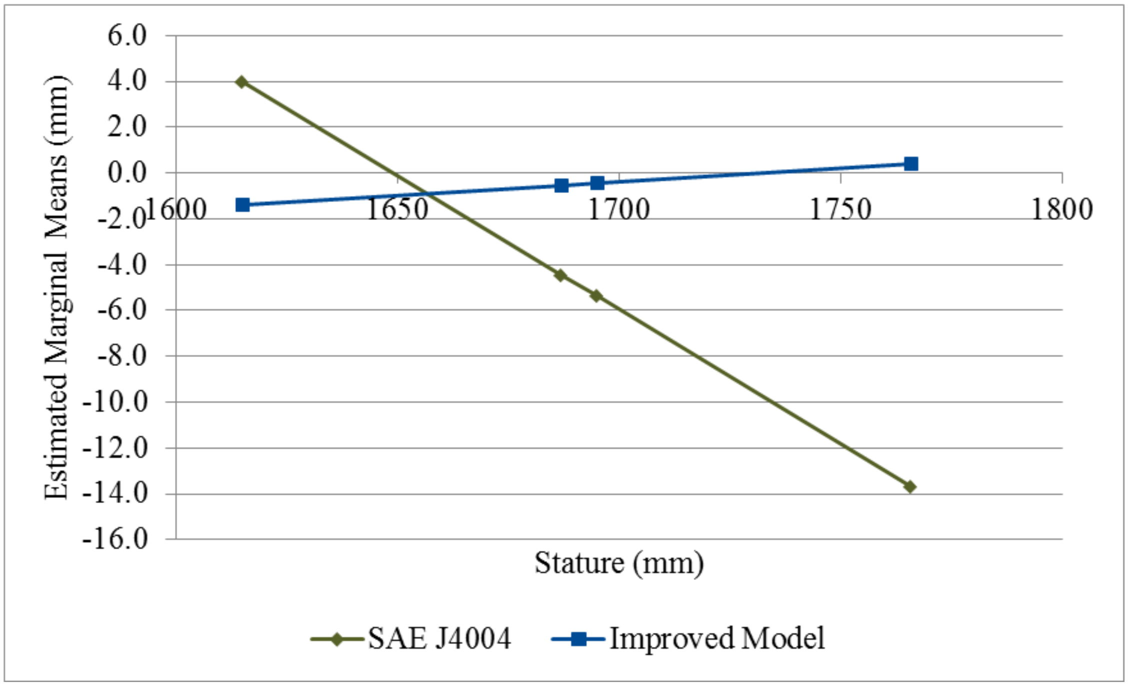


Figure 76. Estimated marginal means for the 3-way interaction of difference, age, and stature.

Table 61

Estimated Marginal Means by Difference, Age, and Stature in Millimeters (mm)

Stature (%)	25th Percentile		50th Percentile		Sample Mean		75th Percentile	
Stature (mm)	1615		1687		1695		1766	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
SAE J4004	4.0	8	-4.5	6	-5.4	6	-13.7	6
Improved Model	-1.4	7	-0.6	5	-0.5	5	0.4	6

Note. Percentiles are based on the NHANES 2007-2010 data sets (Parkinson, 2015).

The findings of this ANCOVA suggest that there is a significant difference between the two models. In addition, this ANCOVA suggests that the deviation of the improved model is not only significantly different from the SAE J4004 but also shows smaller deviation from the measure L99 values. The lack of an age-related effect appearing in deviation ANCOVA suggests that the improved model appropriately addressed the need to include an age predictor variable in the model to predict driver selected seat position of any driver.

7.5 Summary of the Improved Driver Selected Seat Position Model

The goal of this chapter was to demonstrate that a separate linear regression to include gender and age variables will provide a more accurate model to predict seat track position of older drivers.

To accomplish this task, four hierarchical linear regressions were performed. The first two regressions addressed the contributions of age and gender and the improved fit of the linear regression. The result of these regressions was that there were no hierarchical order effects when regressing the age and gender predictor variables, and that gender did not make a significant contribution to the fit of the regression model. The third regression was to assess bias in the linear regression model, and no bias was detected. Last, a bootstrapped hierarchical linear regression model was run to improve the robustness of the regression. As a result, the findings of this chapter suggest that the improved model provides a more accurate model to predict driver selected seat position of any driver when compared to the current SAE J4004 recommended practice. The improvement was shown as follows:

- Pearson correlation coefficient showed a statistically significant increase with the addition of age group as a predictor variable to the SAE J4004 model (R = 0.019, ΔR^2 = 0.025, ΔF(6, 110) = 5.074, p = 0.026).
- On average, there was zero deviation of the improved model from the measured L99 value for both older and younger drivers, whereas the SAE J4004 model showed an average deviation of 2 mm and 15 mm for older and younger drivers, respectively.
- A mixed-model ANCOVA showed an interaction effect with deviation and stature (F(1, 113) = 30.096, p < 0.001, r = 0.459), indicating a difference between the improved model deviation and the SAE J4004 deviation from the L99 measurement.

It was hypothesized that the addition of both age and gender as predictor variables would improve the accuracy of the SAE J4004 model; however, only age proved to significantly improve the linear regression model. Referencing back to the L99 and SAE J4004 ANCOVA in Chapter Six section 6.4, age showed an interaction effect with L99, SAE J4004 and the covariate stature (F(1, 109) = 5.950, p = 0.016, r = 0.228), and gender showed an interaction effect with L99 and the covariate stature (F(1, 109) = 4.775, p = 0.031, r = 0.205). These significant effects show that age was more likely to contribute to the improved model because age already showed an interaction with both L99 and SAE J4004, whereas gender only interacted with L99. The inclusion of the SAE J4004 in the interaction effect shows that age is already statistically related to the five established terms of the original equation and gender was not. In addition, this outcome is likely because stature accounts for a large portion of the driver selected seat position variances. Because stature is normally distributed across the population as well as within gender (Parkinson, 2015), the differences as a result of gender are likely to be accounted for by the stature term in the linear regression. However, because stature has been shown to decrease with age, stature cannot account for the age-related differences, and therefore, an age term is required for greater accuracy (Borkan et al., 1983; Chandler & Bock, 1991; Friedlaender et al., 1977; Noppa et al., 1980).

CHAPTER EIGHT

EVALUATION OF CARFIT© CRITERIA COMPLIANCE AND KNOWLEDGE OF SEAT ADJUSTMENT

8.1 Introduction

The goal of this chapter is to test Hypotheses 5, 6, and 7. Hypothesis 5 states that the likelihood of noncompliance with CarFit© criteria will increase with respect to age, and Hypothesis 6 states that the likelihood of noncompliance with CarFit© criteria will increase with decreasing stature. Lastly, Hypothesis 7 states that the majority of older drivers do not know how to demonstrate a number of seat adjustments, and that when compared to a younger driver population, the portion of older drivers that cannot demonstrate the adjustments will be significantly larger than the younger population.

During a CarFit© event, drivers are evaluated as to whether they meet the CarFit© criteria. If the participant meets the criteria, the appropriate box is marked on the evaluation sheet, and the CarFit© instructor continues with the evaluation; however, if the participant does not meet the criteria, then the CarFit© instructor provides training and the participant makes seat adjustments to accommodate an optimal seating position. The CarFit© education program thereby uses binary logic to assess driver selected seat position.

In addition, as described in Chapter Three, section 3.7 Lessons Learned, this researcher noticed that many of the older drivers were unfamiliar with the controls to adjust the seat and steering wheel. Therefore, in the remaining data collection sessions described in Chapters Four and Five, the participants were asked to demonstrate the seat and steering wheel adjustments prior to the CarFit© training. The participants were then given a binary value of *yes* or *no* as to whether the participant could or could not demonstrate the seat adjustment. The noncompliance of a CarFit© criterion and knowledge of a seat adjustment are therefore considered binary data. In order to test the three hypotheses, binary logistic regression will be used to assess statistical significance and provide the probability of a *yes* or *no* event occurring.

The remainder of this chapter presents the technique used to assess the CarFit© noncompliance and knowledge of seat adjustments as well as the results and discussion. The chapter sections that follow are section 8.2, which discusses how the collected data are used for this analysis; Section 8.3, which describes the binary logistic regression technique; Section 8.4, which is the results and discussion of the CarFit© binary logistic regressions; Section 8.5, which is the results and discussion of the knowledge of seat adjustment binary logistic regressions; and Section 8.6, which is the chapter summary.

8.2 Data Sets

There are three data sets for the CarFit© criteria compliance and knowledge of seat adjustment portion of this dissertation. They are the older drivers from the community setting, older drivers from the clinical setting, and younger drivers. The data sets for the CarFit© criterion analysis will be managed similarly to the previous chapters, where the younger drivers remain unchanged, and the older drivers from the two time periods and locations will be combined to make one large data set. Figure 77 shows the generic data structure for a nondescript measurement.

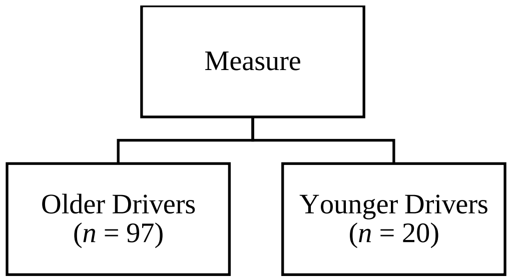


Figure 77. Structure of available data for binary logistic regression for CarFit© criterion.

However, the knowledge of seat adjustments data points were added after the lessons learned in Section 3.7; therefore, the older driver data set will refer to the data collected during the clinical setting alone, shown in green in Figure 78. The younger drivers for this analysis will remain unchanged and is also shown in green in Figure 78. The final data set arrangement for the knowledge of seat adjustments can be seen in Figure 84.

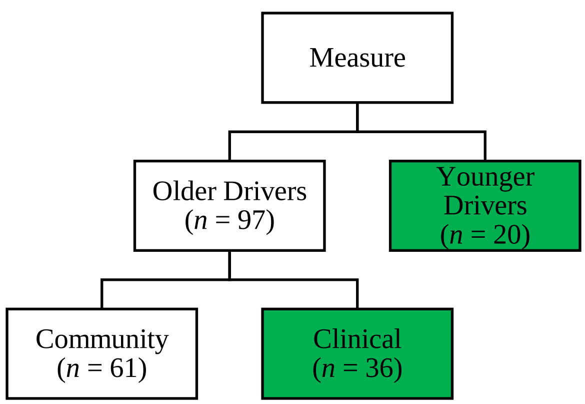


Figure 78. Structure of available data for binary logistic regression for knowledge of seat adjustments.

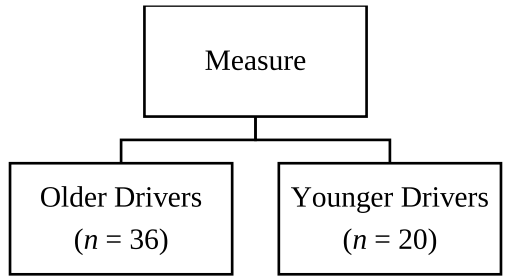


Figure 79. Final structure of available data for binary logistic regression for knowledge of seat adjustments.

8.3 Logistic Regression Technique

Binary logistic regressions are used to assess the probability of CarFit© criteria noncompliance and knowledge of seat adjustments. First, the CarFit© measurements are transformed into binary data. The binary transformation was accomplished with a logic statement, where if the participant's measurement met the CarFit© requirement, then a value of 1 was entered for the participant. Conversely, if the participant did not meet the CarFit© criterion, then a value of 0 was entered for the participant. Table 62 repeats the CarFit© measurements with the associated requirements.

Table 62

Logic for Binary Transformation of CarFit© Measurements

Measurement	CarFit© Criteria
Center of steering wheel to sternum	≥ 254 mm (≥ 10 in)
Backset	≤ 51 mm (≤ 2 in)
Top of head to ceiling	≥ 102 mm (≥ 4 in)
Top of leg to bottom of steering wheel	≥ 51 mm (≥ 2 in)
Line of sight above the steering wheel	≥ 76 mm (≥ 3 in)

After the CarFit© measurements were transformed, then two separate binary logistic regressions for each of the five CarFit© criteria were performed using a dichotomous value of age (age group) and stature as separate predictor variables. Age was transformed into a dichotomous variable, where participants ages 60 and over were grouped into the older driver category, and participants ages 30 to 39 were grouped into the younger driver category. Older drivers were assigned a value of 1 and younger drivers were assigned a value of 0 for the dichotomous groupings.

Similarly, the participant's knowledge of seat adjustment was coded with binary values at the time of data collection. The participants were asked to demonstrate each available seat adjustment option. If the participant was able to demonstrate each individual seat adjustment when asked and without instruction, then a *yes* was recorded for that particular seat adjustment; otherwise, a *no* was recorded. Upon entering the datasheets into the computer, a *yes* was given a value of 1 and a *no* was given a value of zero. Finally, for each of the seat adjustments demonstrated, a binary logistic regression was performed, using age group as the predictor variable.

8.4 Examination of CarFit© Criteria Compliance

Hypothesis 5 states that the likelihood of noncompliance with CarFit© criteria will increase with respect to age, and Hypothesis 6 states that the likelihood of noncompliance with CarFit© criteria will increase with decreasing stature. The CarFit© criteria is a binary value of either *yes, the driver met the requirement* or *no, the driver did not meet the requirement*. Therefore, binary logistic regressions will be conducted to test these hypotheses and examine the likelihood of a driver meeting the CarFit© criteria by age group and by stature. Given that all participants met the criterion for the center of steering wheel to sternum distance, the binary logistic regression cannot be computed for this measure because the model lacks the *no* data value for all participants. See Table 63 and Table 64. This is the only assumption violated for these binary regression analyses. Last, the dispersion parameter for all significant results was found to be greater than 1; therefore, no over dispersion was detected.

The results of the age group binary logistic regression, shown in Table 63, revealed that age group was only a predictor for the initial line of sight above the steering wheel (LoS), $B = 1.625$, Wald $\chi^2(1) = 4.402$, $p = 0.013$. The probability of an older driver meeting the CarFit© criterion for LoS prior to training is 0.900, whereas the probability of a younger driver meeting the CarFit© criterion for LoS prior to training is 0.639. These probabilities produce an odd ratio (OR) that indicates that older drivers are 5 times more likely to meet the LoS CarFit© criterion than younger drivers. The binary regression model accurately predicted 68% of the participant outcomes. The binary regression model to assess the probability that a driver will meet the initial LoS measurement is shown in Equation 24.

$$P(CarFit©) = \frac{1}{1 + e^{-(0.572+1.625 \cdot Age)}} \quad \text{Equation 24}$$

The fact that the LoS measurement is the only measurement that showed statistical relevance for binary logistic regression for age group is especially interesting, given that the CDRSs emphasized that the LoS measurement is the top priority when they are providing CarFit© education (as described in Chapter Six section 6.6). The binary regression result provides further evidence to support the CDRSs' awareness of the importance of the LoS measurement. The binary regression result shows a trend that older drivers are more likely than younger drivers to meet the CarFit© criteria. Given this trend provided by the binary regression result, CDRSs can now direct a higher level of attention to this measurement when educating younger drivers.

Table 63

Binary Logistic Regression to Predict Meeting CarFit© Criteria by Age Group

Variable	B0	95% CI	B	95% CI	*SE*	OR	Wald statistic	*p-value*
Initial (before CarFit©)								
Center of steering wheel to sternum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Backset	-0.397	[-0.792, -0.019]	-0.009	[-1.041, 0.976]	0.501	0.991	0.000	0.986
Top of head to ceiling	0.803	[0.378, 1.285]	0.044	[-1.035, 1.518]	0.535	1.045	0.007	0.935
Top of leg to bottom of steering wheel	-0.440	[0.022, 0.867]	-0.845	[-1.953, 0.062]	0.502	0.429	2.841	0.090
Line of sight above the steering wheel	0.572	[0.147, 1.015]	1.625	[0.185, 20.948]	6.285	5.081	4.402	0.007
Final (after CarFit©)								
Center of steering wheel to sternum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Backset	0.062	[-0.322, 0.481]	-0.263	[-1.328, 0.689]	0.493	0.769	0.283	0.595
Top of head to ceiling	0.852	[0.435, 1.316]	-0.005	[-1.156, 1.442]	0.536	0.995	0.000	0.993
Top of leg to bottom of steering wheel	0.483	[0.079, 0.932]	-0.283	[-1.268, 0.782]	0.496	0.754	0.325	0.568
Line of sight above the steering wheel	0.354	[-0.037, 0.740]	0.493	[-0.530, 1.951]	1.155	1.637	0.866	0.352

Note. N/A means model lacks data and not able to be computed; B0 = estimated intercept; B = estimated slope; OR = odds ratio.

Stature showed to significantly predict more of the CarFit© criteria than age group. In fact, as shown in Table 64, all of the initial measurements except center of steering wheel to sternum showed a significant model for the predictor variable stature. In addition, the final top of head to ceiling (Head) and LoS showed stature as a significant predictor variable for the final seat position as well. The OR for all of the measurements except LoS showed a value of less than 1. This indicates that as stature increases, the likelihood of a driver meeting the CarFit© criteria decreases for initial backset, initial Head, initial Leg2SW, and final Head; however, for both initial and final LoS, as stature increases, the likelihood of meeting the CarFit© criteria increases. Although the OR only slightly deviates from the neutral value of 1, this is the OR per unit of change in the predictor variable. The initial and final Head as well as the initial backset and Leg2SW CarFit© measurements show that a decrease in stature will increase the likelihood of meeting the CarFit© criteria. A short-statured individual will naturally have more headroom when compared to the headroom of a tall-statured individual. Also, given the same seat back angle, a short-statured individual is likely to have a smaller backset measurement. For example, in order for a backset measurement to exist, the torso must diverge from the seat back at some point. Given the same seat back angle, a tall-statured individual will diverge from the seat for a greater distance and thereby create a larger backset as compared to the backset of a small-statured individual. The Leg2SW measure is easier to obtain because there is less leg to package into approximately the same space. Last, the LoS measurement is naturally obtainable for tall-statured individuals because the eye height of a seated individual is on average 0.452 times the individual's stature; therefore a tall-statured individual should have a greater probability to pass the LoS criteria than a small-statured individual (Fromuth & Parkinson, 2008). The binary logistic regression models to assess the probability of meeting the CarFit© criterion are listed below in Equation 25 through Equation 30.

Initial backset

$$P(CarFit©) = \frac{1}{1 + e^{-(8.338 - 0.005 \cdot Stature)}} \qquad \text{Equation 25}$$

Initial top of head to ceiling

$$P(CarFit©) = \frac{1}{1 + e^{-(23.235 - 0.013 \cdot Stature)}} \qquad \text{Equation 26}$$

Initial top of leg to bottom of steering wheel

$$P(CarFit©) = \frac{1}{1 + e^{-(12.232 - 0.007 \cdot Stature)}} \qquad \text{Equation 27}$$

Initial line of sight above the steering wheel

$$P(CarFit©) = \frac{1}{1 + e^{-(-13.887 + 0.009 \cdot Stature)}} \qquad \text{Equation 28}$$

Final top of head to ceiling

$$P(CarFit©) = \frac{1}{1 + e^{-(18.209 - 0.010 \cdot Stature)}} \qquad \text{Equation 29}$$

Final line of sight above the steering wheel

$$P(CarFit©) = \frac{1}{1 + e^{-(-9.782 + 0.006 \cdot Stature)}} \qquad \text{Equation 30}$$

Table 64

Binary Logistic Regression to Predict Meeting CarFit© Criteria by Stature

Variable	B0	95% CI	B	95% CI	*SE*	OR	Wald statistic	*p-value*
Initial (before CarFit©)								
Center of steering wheel to sternum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Backset	8.338	[1.455, 16.951]	-0.005	[0.010, -0.001]	0.002	0.995	5.591	0.018
Top of head to ceiling	23.235	[11.475, 40.602]	-0.013	[-0.021, -0.008]	0.003	0.987	20.405	0.000
Top of leg to bottom of steering wheel	12.232	[4.029, 22.318]	-0.007	[-0.012, -0.003]	0.002	0.993	9.696	0.002
Line of sight above the steering wheel	-13.887	[-23.537, -6.982]	0.009	[0.003, 0.017]	0.003	1.009	11.521	0.001
Final (after CarFit©)								
Center of steering wheel to sternum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Backset	5.316	[-1.823, 12.928]	-0.003	[-0.008, 0.001]	0.002	0.997	2.316	0.127
Top of head to ceiling	18.209	[7.615, 32.514]	-0.010	[-0.017, -0.005]	0.003	0.990	14.752	0.000
Top of leg to bottom of steering wheel	7.433	[-0.235, 16.061]	-0.004	[-0.009, 0.000]	0.002	0.996	3.726	0.054
Line of sight above the steering wheel	-9.782	[-18.870, -3.158]	0.006	[0.001, 0.012]	0.003	1.006	7.260	0.007

Note. N/A means model lacks data and not able to be computed; B0 = estimated intercept; B = estimated slope; OR = odds ratio.

8.5 Examination of Knowledge of Seat Adjustment Controls

Hypothesis 7 states that the majority of older drivers do not know how to demonstrate a number of seat adjustments, and that when compared to a younger driver population, the portion of older drivers that cannot demonstrate the adjustments will be significantly larger than the younger population. This hypothesis is the direct result of the lessons learned during the pilot study with older adults from the community discussed in Chapter Three section 3.7. As a result, prior to CarFit© training, the participants were asked to demonstrate each available seat adjustment individually. As the participant demonstrated each individual seat option, the binary value of *yes* or *no* indicated that either the driver could demonstrate the adjustment or the driver could not demonstrate the seat adjustment. Therefore, binary logistic regressions will be conducted to test Hypothesis 7 and to examine the likelihood of a driver being able to demonstrate each seat adjustment by age group.

None of the binary logistic regressions revealed a significant model. The results of the age group binary logistic regression are listed below in Table 65. The seat belt, fore/aft seat track, head restraint tilt, and pedal adjustment binary logistic regressions could not be computed because these models violate the complete information assumption. For example, all participants were able to demonstrate seat belt placement, so this model lacks the *no* data value for all participants. The frequency for each demonstrated adjustment can be seen in Table 66. The binary regression for seat adjustment knowledge shows that an increased likelihood of knowledge about seat adjustment controls does not exist between age groups; nonetheless, a substantial number of participants were unable to demonstrate the seat height, steering wheel telescope, and seat base angle adjustments available within their vehicle. This suggests that these adjustments go unused in the vehicle. Table 66 shows that 14 of 34 older driver participants and 4 of 15 younger driver participants could not demonstrate the seat height adjustment. This means that for those individuals the seat height adjustment is neglected when selecting their seat position, thereby potentially compromising an optimal position for the LoS, Head, and Leg2SW measurements. In addition, the majority of both older and younger drivers were unable to demonstrate the adjustment of the steering wheel telescope. The steering wheel telescope adjustment, although not always present in more basic vehicle models, accommodates the tradeoffs between proper reach of the vehicle controls and safe seating with regards to the driver's relative position to the steering wheel airbag. All drivers met the CarFit© recommended distance from the steering wheel, suggesting that individuals who are unaware of their steering wheel telescope option are potentially forgoing proper reach of the accelerator and brake pedal to accommodate for the center of steering wheel to chest distance. Both the reach of the accelerator and brake pedals, and the center of steering wheel to chest distance have serious safety implications if not met. Knowledge of the seat base angle adjustment does not have direct safety implications; however, Flannagan et al. (1996) showed that seat base angle affects driver selected seat position. The SAE J4004 recommended practice currently indicates that as seat base angle increases, the distance from the BoFRP to H-point decreases. Therefore, drivers that are unable to adjust the seat base angle may alter their selected seat position to a less optimal position.

Table 65

Binary Logistic Regression to Predict Ability to Demonstrate Seat Position Adjustment by Age Group

Variable	B0	95% CI	B	95% CI	*SE*	OR	Wald statistic	*p-value*
Seat Belt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Upward/Downward Seat Height	0.357	[-0.353, 1.145]	0.965	[-0.305, 3.115]	0.662	2.625	2.146	0.145
Fore/Aft Seat Track	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seat Back Recline	2.398	[1.288, 21.203]	0.547	[-18.869, 19.656]	1.190	1.727	0.211	0.646
Seat Base Angle	0.182	[-0.693, 1.099]	2.120	[0.127, 21.832]	1.133	8.333	3.503	0.061
Head Restraint Height	1.253	[0.470, 2.398]	1.692	[-0.310, 20.664]	1.102	5.429	2.359	0.125
Head Restraint Tilt	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Steering Wheel Angle	1.386	[0.560, 2.741]	-0.767	[-2.181, 0.583]	0.631	0.464	1.478	0.224
Steering Wheel Telescope	-0.251	[-1.386, 0.693]	-0.624	[-2.334, 0.847]	0.733	0.536	0.725	0.394
Pedal Adjustment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note. N/A means model lacks data and not able to be computed; B0 = estimated intercept; B = estimated slope; OR = odds ratio.

Table 66

Frequency for Knowledge of Seat Adjustment Controls

Variable	Older Drivers (n = 36)			Younger Drivers (n = 20)		
	Demonstrated adjustment	Could not demonstrate adjustment	Option not present	Demonstrated adjustment	Could not demonstrate adjustment	Option not present
Seat Belt	36	0	0	20	0	0
Upward/Downward Seat Height	20	14	2	15	4	1
Fore/Aft Seat Track	36	0	0	20	0	0
Seat Back Recline	33	3	0	19	1	0
Seat Base Angle	12	10	14	10	1	9
Head Restraint Height	28	8	0	19	1	0
Head Restraint Tilt	1	1	34	3	0	17
Steering Wheel Angle	28	7	1	13	7	0
Steering Wheel Telescope	7	9	20	5	12	3
Pedal Adjustment	1	0	35	0	0	20

A likely source for driver unfamiliarity with seat height, steering wheel telescope and seat base angle adjustments is that the adjustment controls are often combined with other adjustments. For example, the seat base angle and seat height adjustment are often adjusted with the same switch, as are the steering wheel telescope and the steering wheel angle. Figure 80 shows a common, 8-way seat adjustment configuration. Note that the horizontal bar adjusts the seat height, seat base angle, and the seat track position. The seat track adjustment is accomplished by pushing the bar forward or rearward, and all participants were able to demonstrate this adjustment. The seat height adjustment is accomplished by pulling the back-side of the horizontal bar up or down, whereas the seat base angle is accomplished by pulling the front-side of the horizontal bar up or down. The text boxes in Figure 80 indicate the adjustment location for the seat base angle and seat height adjustment on a typical multifunction seat adjustment switch. This is the same switch and the same motion in order to control different adjustments.

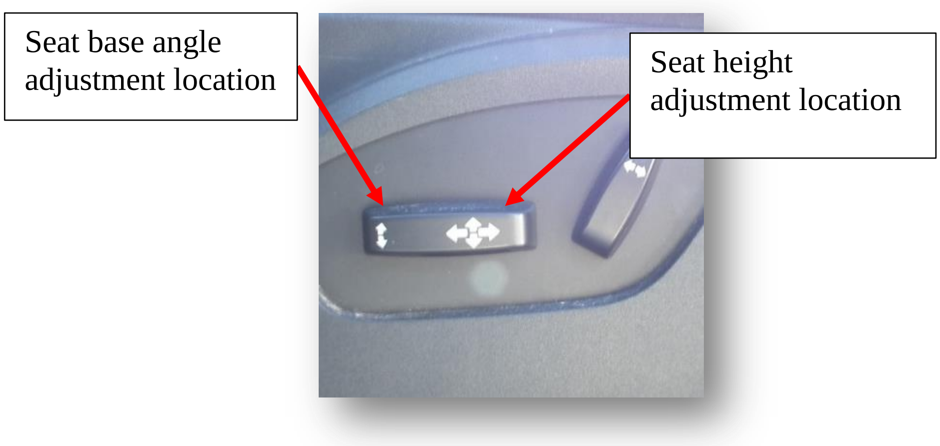


Figure 80. Common 8-way seat adjustor for passenger vehicles.

Similarly, Figure 81 shows a common release mechanism to allow for the steering wheel telescope and steering wheel angle adjustment. This mechanism has one lever that is pulled downward to release both the steering wheel telescope and the steering wheel angle adjustments simultaneously. A large majority of the participants were familiar with the adjustment for the steering wheel angle adjustment; however, most were often surprised when informed of the steering wheel telescope feature available.

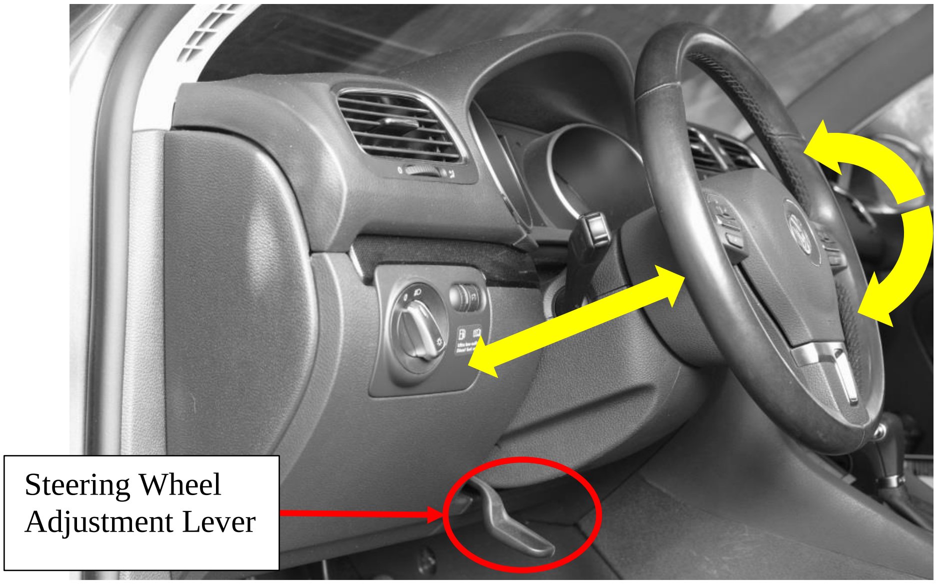


Figure 81. Common steering wheel telescope and steering wheel angle adjustor in the unlocked position to allow for steering wheel adjustment.

8.6 Summary of CarFit© Criteria Compliance and Seat Adjustment Knowledge

The goal of this chapter was to assess the likelihood of CarFit© compliance by age and stature, as well as the knowledge of the seat adjustments by age. Because both of these outcomes are binary values, either *yes* or *no,* a binary logistic regression for each measurement was performed to accomplish the analyses.

The findings show that only the initial LoS measurement, which is prior to any CarFit© training, was statistically significant for CarFit© compliance by age. The binary logistic regression showed that older drivers are 5 times more likely to meet the LoS CarFit© requirement of more than or equal to 76 mm (3 in). Age was not a significant predictor of any of the other measures for either before or after CarFit© training. Hypothesis 5 states that older drivers would not likely comply with the CarFit© criteria; however, the evidence is contradictory to this hypothesis. The binary logistic regression for the majority of the measurements lacks statistical significance, and the one significant measurement shows that younger drivers are more likely not to comply with the LoS CarFit©, rather than older drivers. Nonetheless, the findings show that the stature variable was a better predictor variable for CarFit© compliance rather than age. This is especially true for predicting CarFit© compliance prior to any training. Four of the five initial measurements showed that stature was a statistically significant predictor variable for CarFit© compliance; for the fifth variable, center of steering wheel to sternum, the CarFit© requirement was satisfied by all participants, so it was not able to be tested using binary logistic regression. In addition, after CarFit© training, stature was a statistically significant predictor variable for the Head and LoS measurements. All of the measurements except the initial and final LoS measurement had OR less than the neutral value of 1. This indicates that small-statured individuals are more likely to comply with the initial backset, Head, Leg2SW and Final Head measurement. Conversely, the initial and final LoS measurement had an OR ratio greater than the neutral value of 1; therefore, tall-statured individuals are more likely to comply with the LoS measurement.

Knowledge of the predictor variables as they relate to CarFit© criteria is especially important for CDRSs and other CarFit© instructors because it allows attention to be shifted to the area of need. For example, because CDRSs emphasize the LoS measurement, knowledge that a small-statured individual will have greater difficulty meeting the LoS criteria compared to a tall-statured individual, the CDRS will be able to shift their attention on an individual basis. From the researcher's experience, CarFit© training should use knowledge of the predictor variables to focus on the least likely criteria at the beginning of seat position training, and then iterate on the measurements throughout the training. Focusing on the least likely criteria first would provide the most relevant information to the participant while the participant's interest is at its greatest level. In addition, because the measurements compete with one another, iteration assures that one adjustment is not compromised by another adjustment and allows for repetition of the individual's least likely criteria, thereby enhancing the individual's retention of the training process. See Section 8.7 for new proposed CarFit© procedures.

Last, age was not shown as a statistically significant predictor for knowledge of any of the available seat adjustments; however, the seat height, steering wheel telescope, and seat base angle adjustments had a substantial number of both older and younger drivers that could not demonstrate the adjustments. The primary safety implications for the unfamiliarity of these seat adjustments may result in improper line of sight above steering wheel, inadequate reach of the accelerator and brake pedal, and a less than optimal selected seat position. It is likely that the unfamiliarity with the adjustments is a result of multifunction adjustors. These adjustors are advantageous for manufacturers because they reduce the number or required parts, and theoretically, the cost of the vehicle. Ideally, the multifunction adjustors could be made more visible, so that the user can actually see the available adjustments, and whenever increased visibility is not possible, minimize the number of adjustments available through a single control device.

The purpose of CarFit© training is to increase the safety of older drivers. The CarFit© program is designed to help individuals fit better in their vehicle. The findings of this chapter are most beneficial to those who routinely assess a driver's selected seat position, namely those involved in CarFit© events and CDRSs. For example, knowing that younger drivers are less likely to meet the LoS measurement allows an instructor to direct extra focus on this measurement when working with this particular age group. Currently, the CarFit© education program targets the older driver, but the safety criteria used is applicable to *all* drivers. This research shows that younger drivers could benefit from a similar, if not the same, training program. For example, seat position education program could be included in defensive driving courses such as the Alive at 25© education programs used by school districts to permit students to park on campus or in private safe-driving courses in order to facilitate optimal seating position for younger drivers.

The LoS measurement has shown to be a highly salient measurement, for it has been shown to be statistically significant throughout the data analysis of this dissertation. First, the LoS measurement was shown statistically significant when computing the variance between drivers in Chapter Six. Next, while interviewing CDRSs for this dissertation, there was an emphasis on drivers meeting the CarFit© criterion for the LoS measurement in order to facilitate a better view of the roadway and afford better visual search and scanning patterns. Last, in this chapter both age and stature act predicted meeting the CarFit© criterion for the LoS measurement. Given all the statistical and allegorical occurrences of the LoS measurement, it would stand to reason that the LoS measurement take priority during a CarFit© evaluation, and that instructors should check this measurement multiple times during the evaluation of a driver.

8.7 CarFit© Recommended Changes

This section describes the proposed changes to the CarFit© data sheet. These changes focus on the order that the seat adjustments are made to meet the CarFit© safe seating guidelines. In addition, the changes include "double checks" of the CarFit© safe seating guidelines as different seat adjustments are made to competing criteria, such as the line of sight above the steering wheel and the top of leg to the bottom of the steering wheel measurements. Last, a change in the assessment of the driver's fit from a measured value, typically in inches, to a *fit* or *does not fit* criteria is proposed. This change would reduce the time and effort of the CarFit© volunteers as they "double check" to reaffirm the CarFit© safe seating guidelines. Table 67 compares the current CarFit© procedures to the proposed changes to the CarFit© procedures. The first two line items of Table 67 are the same for both the current procedure and the proposed changes. The reordered changes begin on line three of Table 67.

Table 67

Current and Proposed Changes for CarFit© Procedures

	Current Procedures	Proposed Changes
1	Shared vehicle status	Shared vehicle status (no change)
2	Safety belt use	Safety belt use (no change)
3	Steering wheel angle and position to airbag	Positioning to accelerator pedal and brake pedal
4	Head restraint adjustment	Line of sight above the steering wheel
5	Distance between chest and steering wheel	Head restraint adjustment
6	Line of sight above steering wheel	Seat back angle adjustment for backset measurement
7	Positioning to accelerator pedal and brake pedal	Steering wheel telescope
8		Vehicle rollover protection
9		Line of sight above the steering wheel
10		Final confirmation

The current adjustment procedure begins with steering wheel adjustments on line item three, and ends with position to the accelerator and brake pedal on line item seven. The steering wheel adjustments have the most limited range of motion, whereas the positioning to the accelerator and brake pedal, typically accomplished by fore/aft seat travel, has the greatest range of motion. Therefore, it is suggested that the order be changed to begin the CarFit© procedure with the adjustments that have the largest range of motion and end with the adjustments that have the smallest range of motion. As a result, the reach to the accelerator and brake pedals has been moved to the beginning and the steering wheel telescope to the end. This methodology allows for the smaller range of motion adjustments to be used to make minor adjustments of the individual’s position while utilizing the maximum range of motion available in all of the vehicle adjustments.

The proposed reordering also compensates for seat adjustments that change in multiple directions simultaneously. For example, the fore/aft seat adjustment is typically on a ramp, and as the seat moves closer to the steering wheel, the seat also moves in the upward direction. Similarly, the vertical adjustment of the seat will typically move the seat towards the steering wheel as the seat base moves in the upward direction. Reordering the CarFit© procedure to address the larger range of motion adjustments first will minimize the effects of the multidirectional adjustments.

The second proposed change is to add reaffirmation of a CarFit© safe seating guideline after a competing measure is accommodated. For example, in the proposed changes column of Table 67, line item nine reaffirms the line of sight above the steering wheel measurement after the competing guideline, line item eight for vehicle rollover protection, is adjusted. Similarly, line item 10 is implemented so that at the end of the adjustment period all of the guidelines are confirmed.

Because more measurements have been added to the procedure, the last proposed change is to use a 3 in x 2 in x 10 in folded tool as a *fit* or *does not fit* measurement device. The suggested tool is shown in Figure 82. The tool is made of folded cardboard which could be manufactured and included in the required CarFit© materials. Note that there is also an additional 2 inch extension door that can be opened to test the 4 inch CarFit© criteria for the top of head to ceiling requirement if the vehicle is manufactured prior to 2008.

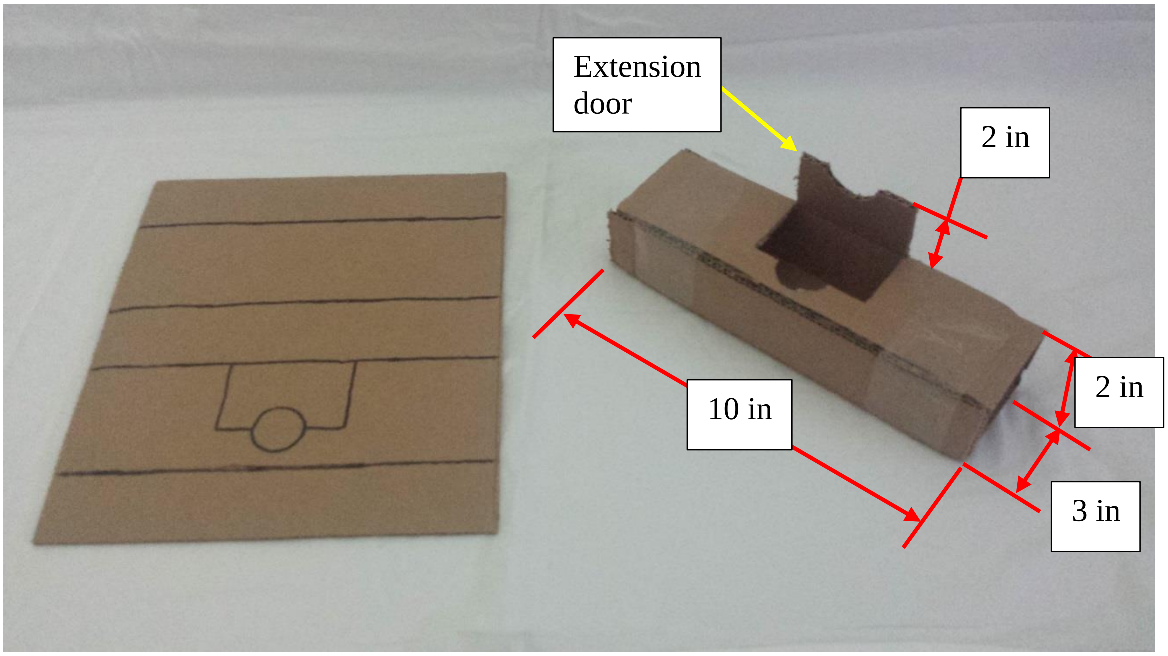


Figure 82. Flattened and formed prototype of the *fit*/*does not fit* tool.

The *fit* or *does not fit* measurement device will assist with the timing of a CarFit© assessment because the CarFit© instructors will no longer have to read precise measurements from a ruler. In addition, the device will provide visual feedback to the participant as to how well he or she fits in the vehicle.

The following list is the detailed changes to the CarFit© data sheet with the directions for how to perform each step in italics.

1	**"Are you the only driver?"**	Yes	No	
2	**Is the driver using the vehicle's seat belt?**	Yes	No	
	Does the driver use it all the time? If no, why?	Yes	No	
	Is the belt being used correctly?	Yes	No	
	Is the driver able to unbuckle/buckle and reach the belt without a problem?	Yes	No	
	Is the driver able to use the belt without discomfort?	Yes	No	
3	**Brake and Accelerator Pedal Reach**			
	Adjust the seat forward or rearward so that the participant can completely depress the brake pedal without reaching with his/her toes or locking his/her knee.			
	Is the driver able to reach and completely depress the brake pedal without reaching with his/her toes?	Yes	No	
	Is the driver able to reach and completely depress the brake pedal without locking his/her knee?	Yes	No	
	Is the driver able to reach and completely depress the accelerator pedal without reaching with his/her toes?	Yes	No	
	Is the driver able to reach and completely depress the clutch pedal without reaching with his/her toes?	Yes	No	N/A
	Can the driver reach the steering wheel without leaning forward?	Yes	No	
	Can the driver reach the steering wheel without locking his/her elbows?	Yes	No	
	Is the driver's sternum at least 10 inches away from the center of the steering wheel?	Fits	Does not fit	✓

4 Line of Sight Above the Steering Wheel

Adjust the seat height up or down to obtain the proper line of sight above the steering wheel.

Is the driver's straight line of vision at least 3 inches above the top of the steering wheel?	Fits	Does not fit	✓
Can the driver still reach the accelerator and brake pedal without locking his/her knee or reaching with his/her toes? *If no, adjust the seat forward or rearward to accommodate.*		Yes No	

5 Head Restraint Adjustment for Backset Measurement

Adjust the head restraint up or down so that the center of the head is at the center of the head restraint.

Is the back of the driver's head less than 2 inches from the head restraint?	Fits	Does not fit	✓

6 Seat Back Angle Adjustment for Backset Measurement

If the back of the driver's head is more than 2 inches from the head restraint, then adjust the seat back angle forward to decrease the distance.

Is the driver pitched too far forward, reclined too far rearward, or mentions being uncomfortable?		Yes No	
Is the back of the driver's head less than 2 inches from the head restraint? *If no, adjust seat back angle as necessary.*	Fits	Does not fit	✓

7 Steering Wheel Telescope Reach

If steering wheel telescope option is available, adjust the telescope of the steering wheel for proper reach of the steering wheel and a safe seating distance of at least 10 inches.

Can the driver reach the steering wheel without leaning forward?		Yes No	
Can the driver reach the steering wheel without locking his/her elbows?		Yes No	
Is the driver's sternum at least 10 inches away from the center of the steering wheel?	Fits	Does not fit	✓

8 Vehicle Rollover Protection

Ask the driver, "What is the model year of the vehicle?" If vehicle is older than 2008, then adjust the seat height up or down so that the top of the head to the ceiling measurement is greater than 4 inches.

What is the vehicle model year?	Year ________		
Does the driver have at least 4 inches of space between the top of his/her head and the ceiling? *If no, adjust seat height downward.*	Fits	Does not fit	✓
Is the driver's straight line of vision at least 3 inches above the top of the steering wheel?	Fits	Does not fit	✓

9 Line of Sight Above the Steering Wheel

Adjust the steering wheel angle to accommodate view of the instrument panel, straight line of vision above the steering wheel, and for at least 2 inches between the top of the leg and the bottom of the steering wheel.

Does the driver have at least 2 inches of space between the top of the leg and the bottom of the steering wheel?	Fits	Does not fit	✓
Is the driver's straight line of vision is at least 3 inches above the top of the steering wheel?	Fits	Does not fit	✓

10 Final measurements

Repeat any steps as necessary.

Is the driver's straight line of vision is at least 3 inches above the top of the steering wheel?	Fits	Does not fit	✓
Is the back of the driver's head less than 2 inches from the head restraint?	Fits	Does not fit	✓
Is the driver's sternum at least 10 inches away from the center of the steering wheel?	Fits	Does not fit	✓
Does the driver have at least 2 inches of space between the top of the leg and the bottom of the steering?	Fits	Does not fit	✓
Does the driver have at least 4 inches of space between the top of his/her head and the ceiling?	Fits	Does not fit	✓

CHAPTER NINE

CONCLUSIONS

9.1 Conclusions

The objective of this research was to measure and understand the preferred seat position and posture of older drivers and younger drivers within their personal vehicles to influence recommended practices for meeting the increased safety needs of drivers.

The five major tasks to complete the objective of this dissertation were to

- compare the measured seat position of older drivers to the measured seat position of younger drivers to discern whether differences exist between the two groups;
- compare the driver selected seat position of older and younger drivers to the theoretical values calculated from the SAE's recommended practices to assess the accuracy of their model;
- compare posture measurements of older drivers' and younger drivers' selected seat positions to the recommended seating guidelines written in the CarFit© education program;
- propose improvements to SAE's recommended practices in order to accommodate the needs of the older driver; and
- quantify older drivers' and younger drivers' ability to demonstrate the seat adjustments available within their personal vehicle.

Chapter Six compared the driver selected seat position measurements of older drivers to younger drivers, older drivers to the SAE J4004 model, and younger drivers to the SAE

J4004 model. The comparison of driver selected seat position measurements were compared using mixed-model analysis of covariance (ANCOVA) with variables age, gender, stature and the initial/final seat position measurements. The initial/final seat position measurements were each within subject variables, while age and gender were between subject variables, and stature was the covariate. The results of the ANCOVAs showed that there was a significant interaction effect with the measured BoFRP to H-point (L99), calculated BoFRP to H-point (SAE J4004), age, and stature ($F(1, 109) = 5.950$, $p = 0.016$, $r = 0.228$). This finding indicates that age does in fact contribute to the variance of the fore/aft position for driver selected seat position; however, the directionality of driver fore/aft position was opposite of the hypothesized direction. It was hypothesized that older drivers would sit in a more forward position than younger drivers, but the difference in the L99 estimated marginal mean (EMM) evaluated at the sample mean for stature show that older drivers initially sat 30 mm behind younger drivers, and after CarFit© training this difference was reduced to 18 mm behind younger drivers. In addition, it was hypothesized that age would contribute to a vertical height of the H-point (H30) and erectness of the seat back angle, but age was not shown to contribute to either of these measurements. The H30 measure only showed a significant main effect with stature ($F(1, 109) = 4.132$, $p = 0.044$, $r = 0.191$), and the seat back angle was non-significant altogether. The age effect between the theoretical SAE J4004 model and the L99 value was evaluated using an ANCOVA for the difference between the SAE J4004 model and the L99 measurement (*Difference*), age, gender, and stature. The ANCOVA result for *Difference* did show a significant interaction effect between age and stature (F(1, 109) = 5.950, p = 0.016, r =0.228). The EMM for both older and younger driver *Difference* was a positive value, indicating that the calculated value was larger than the measured value, therefore showing that both older and younger drivers sit more forward than the SAE J4004 model predicts. As a result, Hypothesis 1 was fully supported. However, this finding goes against Hypothesis 2, which states that younger drivers will not differ from the SAE J4004 recommended practice. With regard to the CarFit© measurements, there was a significant interaction effect between the center of steering wheel to sternum distance, age, and stature, F(1,109) = 13.577, p = 0.001, r = 0.333. In addition, the top of leg to bottom of steering wheel measurement had an interaction effect between age and stature, F(1,109) = 7.023, p = 0.009, r = 0.246. Because CarFit© is an educational program designed to help older drivers learn about safe seating positions, it was expected that more of the measurements would show significant age effects. However, the lack of significance does not show a lack importance for the measurement, only that an age-related difference was not detected. The measurements still relate to driver safety, and there were plenty of individuals, both older and younger drivers alike, who did not meet all of the CarFit© requirements; therefore, lack of significance only shows that the role of CarFit© as an educational program is as applicable to younger drivers as it is to older drivers.

Given the measurements that showed significant effects in Chapter Six, the finding agreed with the Hypothesis 4 which suggested that the model in the SAE J4004 recommended practice would be improved by including an age and gender term in conjunction with the existing terms. However, in Chapter Seven a hierarchical linear regression showed that a gender term did not significantly contribute to the regression model ($p = 0.926$), whereas age did provide significant contribution to the regression model ($p = 0.026$). The fact that gender did not show statistically significant in the regressed equation is likely due to the stature term already incorporated in the equation. Stature is known to be normally distributed between gender as well as across the population; therefore, the stature term within the original SAE J4004 model most likely accounts for the gender differences. However, because stature has been shown to decrease with age, it is possible that stature does not account for the age-related differences, and therefore, an age term was shown to improve the accuracy of the model.

Chapter Eight examined both the likelihood of meeting the CarFit© criteria by age and stature and the likelihood of being able to demonstrate the available seat adjustments by age. The analysis was performed using binary logistic regression, and the results show that stature is a better predictor variable for meeting the CarFit© criteria than age. Age tested as significant predictor variable only for the initial line of sight above the steering wheel (LoS). The expected outcome was that older drivers would be less likely to meet the CarFit© criterion than younger drivers; however, for the one measurement that tested significant, the opposite result was found. The odds ratio from the binary linear regression showed that older drivers are 5 times more likely to meet the LoS measurement prior to any CarFit© training than younger drivers. As stated previously , stature was the better predictor variable and tested significant to predict the CarFit© criteria for initial backset, top of head to ceiling (Head), top of leg to bottom of steering wheel (Leg2SW), and LoS, as well as the final Head and LoS. It was expected that a decrease in stature would yield a higher likelihood of not meeting the CarFit© criteria; however, this was only true for the initial and final LoS measurements. Although the odds ratio for all of the measurements in which stature was a predictor variable deviated slightly from the neutral value of 1, the odds ratio is per unit change in the predictor variable, and stature is measured in millimeters. Last, it was expected that younger drivers would have been significantly more likely to be able demonstrate the available seat adjustment than older drives; however, age was not found to be a predictor variable for any of the seat adjustments.

9.2 Research Contributions

The contributions provided by this research are listed to show how the study results contribute to the SAE, CarFit© education program, and Original Equipment Manufacturers (OEMs). A summary table of the contributions is provided in Table 68.

SAE contributions:

- This research shows that both older and younger drivers select a different seat position than the SAE J4004 recommended practice predicts. In addition, this research shows that older and younger drivers select a different seat position from one another. These findings suggest that the SAE J4004 model to predict driver selected seat position of any driver be updated to consider the inclusion of an age term to the model.
- Age was shown to contribute significantly to the fit of the SAE J4004 model for predicting the L99 measurement for any driver. This finding suggests that for the

most accurate prediction of a driver's selected seat position, an age term be added in the SAE J4004 recommended practice. This addition in the SAE J4004 recommended practice will allow for the most accurate prediction to accommodate drivers better, for improved interior packaging models, and for finer tuning of safety devices, such as steering wheel airbags.

- Gender was not shown to contribute significantly to the fit of the SAE J4004 model for predicting the L99 measurement for any driver. Therefore, it is recommended to continue to omit this variable from the SAE J4004 model.

CarFit© contributions

- Age was shown to predict only the initial line of sight above the steering wheel measure from the CarFit© criteria. Because the CarFit© safety criteria are applicable to all drivers, the lack of significance for CarFit© criteria compliance with age group as a predictor variable indicates that both older and younger drivers can both benefit from seat position training. Therefore, the CarFit© program should be expanded to include all ages.
- Stature was shown as a statistically significant predictor variable for assessing the likelihood of meeting the CarFit© criteria for four of the five CarFit© measurements, prior to the individual receiving CarFit© training. The results showed that as stature increases, the likelihood of a driver meeting the CarFit© criteria decreases for backset, top of head to ceiling, and top of leg to bottom of steering wheel. For line of sight above the steering wheel, as stature increases, the

likelihood of meeting the CarFit© criteria increases. Knowledge of stature as a predictor variable will allow a CarFit© instructor or CDRS to direct extra focus on specific measurements to accommodate a tall-statured or a short-statured individual.

- CarFit© is traditionally performed using a sequential checklist and only confirms each measure one time during a training session. Given that the some of the measures have been shown to compete with one another, it is recommended that CarFit© training should be restructured to accommodate an iterative approach to the training and allow the measures to be confirmed at multiple points. See Appendix F for new proposed CarFit© procedures.
- There was no statistically significant, age-related difference regarding the ability to demonstrate available seat adjustments. This means that neither younger drivers nor older drivers were more likely to be able to demonstrate and adjust the seat position. Therefore, when seat position training (such as CarFit©) is being provided, all drivers should be instructed on how to make available seat adjustments within their personal vehicle.
- New federal legislation was passed in 2008 to increase the roof crush resistance of passenger vehicles. Consequently, the top of head to ceiling measurement will become obsolete, as a substantial number of new cars occupy the roadways; therefore, and the top of head to ceiling measurement should be phased out of the CarFit© education program.

- A substantial number of drivers were unable to demonstrate the steering wheel telescope, seat height, and seat base angle adjustments. This is likely related to the low visibility of the adjustment controls, combined with the fact that the controls are typically multifunction switches. It is important that CarFit© education program train instructors to identify this deficient so that CarFit© participants can optimize their driver selected seat position.
- Changes were proposed to the CarFit© education program to assist the instructor facilitate the optimum seat position. The changes included reordering the seat and steering wheel adjustments, the addition of “double checks” to the measurements, and a *fit/does not fit* tool to reduce the instructor’s effort.

OEM contributions

- This research showed that older and younger drivers select a different seat position than the SAE J4004 recommended practice predicts. This suggests that OEMs should consider age related differences for occupant packaging design in order to broaden their market appeal to the increasing older population.
- An age variable has been shown to improve significantly the fit of the SAE J4004 model to predict driver selected seat position of any driver. Therefore, when seat track accommodation ranges are established for a new vehicle platform, age would affect the desired accommodation range, and should be considered when designing the occupant space.

- Gender was not shown to contribute significantly to the fit of the SAE J4004 model for predicting the L99 measurement for any driver. Gender is accounted for in the SAE J4004 model primarily through differences in stature between gender. Therefore, it is still recommended to use female stature for the low side of the accommodation range and male stature for the high side of the accommodation ranges when designing the occupant space for new vehicle models.
- A substantial number of drivers were unable to demonstrate the steering wheel telescope, seat height, and seat base angle adjustments. This is likely related to the low visibility of the adjustment controls, combined with the fact that the controls are typically multifunction switches. Ideally, the multifunction adjustors could be made more visible to the user if positioned on the door, center console, or dashboard. Whenever increased visibility is not possible, minimizing the number of adjustments available through a single control device is recommended to draw attention to different functions.

Table 68

Summary of Contributions to CarFit©, OEM, and SAE

	Contribution	SAE	CarFit©	OEM
1	The selected seat position of older drivers differs from the selected seat position of younger drivers.	x		
2	The selected seat position of older drivers differs from the SAE J4004 recommended practice.	x		x
3	The selected seat position of younger drivers differs from the SAE J4004 recommended practice.	x		x
4	Age contributes significantly to the fit of the SAE J4004 recommended practice.	x		x
5	Gender did show a significant contribution to the SAE J4004 recommended practice.	x		x
6	Age was shown as a statistically significant predictor variable for initial line of sight above the steering wheel.		x	
7	Stature was shown as a statistically significant predictor variable for four of the five CarFit© criteria.		x	
8	The CarFit© education program should be restructured to iterate through the seat adjustments in order to meet competing criteria.		x	
9	The top of head to ceiling CarFit© criterion should be phased out for vehicles newer than 2008, due to new government legislation.		x	
10	Age was a non-significant predictor variable regarding knowledge of seat adjustment controls.		x	x
11	A larger number of drivers were unfamiliar with seat adjustments that were placed on a multifunction control switch or mechanisms, namely the seat height, seat base angle, and steering wheel telescope adjustors.		x	x

9.3 Future Work

Identified future work from this research is as follows:

- This research grouped the participants into dichotomous age categories of older drivers and younger drivers for analysis. Future research should examine broader age range to include teenage drivers as well as older drivers that are over 90 years of age and continuing to drive. In addition, the research should strive to collect enough of participants from the ages to treat the age variable as a continuous variable rather than a dichotomous variable.
- This research examines the selected seat position of drivers in their personal vehicles in the position that they arrived to the study site, assuming that any necessary changes would have been made prior to their arrival. A second measurement was collected after the driver went through CarFit© training; however, the driver did not drive the vehicle before the second measurement was collected. Potential future work would collect a third measure after the driver has had an opportunity to drive the vehicle. This would provide insight as to how and if the driver selected seat position changes after the driver has received CarFit© training, and driven the vehicle.
- Similarly, this research collects a snapshot of the driver's selected seat position. There is no insight regarding the driver's method for selecting a seat position. For example, did the driver move forward once and upward once and that was all, or was there iteration between the adjustments? Ideally, this would be demonstrated

in a seat buck instrumented with measurement equipment to capture the direction, magnitude and frequency of the adjustments in real time.

- Prior research states that the presence of a clutch pedal will cause a 18.2 mm forward shift in driver selected seat position (Flannagan et al., 1998; Flannagan et al., 1996). Future work should examine how other features such as a tall or deep dash console, steering wheel diameter variance, etc., would affect driver selected seat position.
- Last, this research examines the variance of driver selected seat position between stature, age, and gender; however, there is no indication of body mass. Therefore, future research should examine how body mass index affects driver selected seat position.

APPENDICES

APPENDIX A

MEASUREMENT MANUAL

The following appendix describes how the measurements were captured for this dissertation and the larger NHTSA study. As the three studies progressed, data points were added as necessary. The additional information is also annotated within this appendix.

A black box (☐) around the step(s) indicates that the measurement item was added during Part Two: 20 Younger Participants from the Community and measured in Part Three.

A green box (☐) around the step(s) indicates that the measurement item was added during Part Two: 20 Younger Participants from the Community, and the item was captured in Part Three: Older Adults in a Clinical Setting, under the larger research study and shared with this study.

No measurements were added to Part Three: Older Adults in a Clinical Setting that were not also in Part Two: 20 Younger Participants from the Community.

A black horizontal line (—) across the page indicates the start/stop of steps for a subroutine to setup specialized equipment in order to take the following measurements.

1. Study Identification Information

    A. Participant number

    B. Date of measurement

    C. Persons taking measurements

    D. Ask the participant, “Have you ever participated in this research before?”

II. Measurements with Participant Present

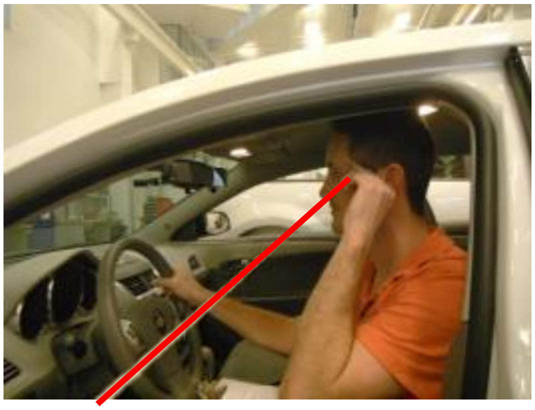
    A. Ground to eye level

        1. With the driver in a seated position, hands on the steering wheel, foot on the brake, and driver door in the open position

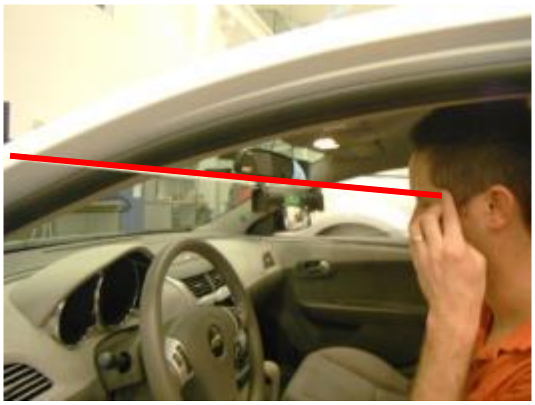
        2. Place the vertical jig next to the passenger

3. Using post level, insure that the vertical jig is level

4. Ask participant to hold the mason string to their temple



5. Using the other end of the mason string and a line level, draw the mason string level and across the vertical jig and take a reading



B. Top of leg to steering wheel bottom

1. With the driver in a seated position, hands on the steering wheel, foot on the brake, and driver door in the open position

2. Place ruler on the top of the leg and read the measurement to bottom of the steering wheel

C. Top of steering wheel to eye level

1. Ask participant to look at the horizon

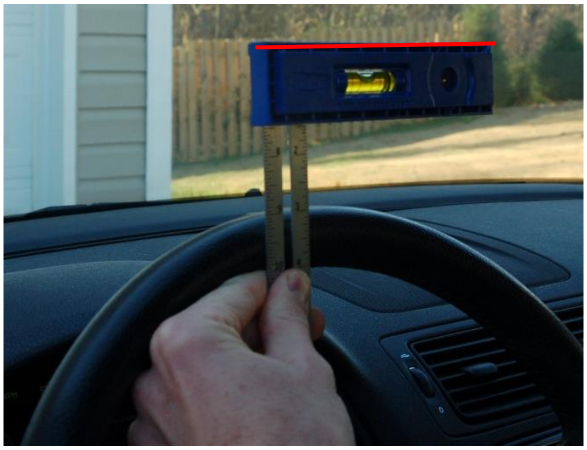
2. Place a ruler on the steering grip

Pilot study only

3. Ask the participant to notify you when the top of ruler is level with their vision

4. Slide the ruler up slowly and take measurement when notified

Pilot study only



D. Steering wheel to breast bone

1. Using the tailor's tape measure, ask the participant to hold one end to their breast bone

    a. If the participant is wearing bulky clothing, such as a winter jacket, ask the participant to place the tape on their base-layer of clothing (i.e. shirt or blouse).

2. Hold the free end of the tailor's tape measure to the center of the vehicle's badging on the steering wheel and record the reading

E. Top of head to roof

1. Hold one end of the tailor's tape measure to the top of the participant's head

2. Hold free end to the roof and record the vertical measurement

F. Back of head to head rest

1. Hold one end of the tailor's tape measure to the back of the participant's head

2. Hold free end to the front of the head rest and record the measurement

G. Participant stature

H. Length of upper right leg from the greater trochanter to the lateral epicondyle of the femur. In other words, the distance from the hip joint to the knee.

I. Length of lower right leg from the head to the lateral malleolus of the fibula. The distance from the knee to the ankle.

J. Ask participant shoe size

1. Ask whether participant's shoe size is in men or women (M or W)

K. Record participant's gender (M or F)

L. Ask if the participant is the only driver of the vehicle (Y or N)

1. If *no*, ask what is the percentage they drive the vehicle

M. Ask the participant if the car was purchased new or used

N. How many floor mats are present in the driver compartment: none(0), single (1), double(2)

    1. Are the floor mats original to the vehicle (Y or N)

O. Is there a presence of wear pattern in the floor mat or carpet (Y or N)

    1. Describe the location and severity of wear pattern(s)

P. Ask the participant, why did you select this seat position?

III. Vehicle Product Information:

A. Make

B. Model

C. Trim

D. Year

E. Odometer

F. VIN

G. Engine

    1. Gas or Diesel

H. Engine Displacement

I. Power Brakes

J. Driveline

K. Transmission type

L. Pedal mounting

1. Brakes

2. Accelerator

M. Is the head rest adjustable

1. Vertically (Y or N)

2. With tilt (Y or N)

N. Number of seat adjustments

O. Presence of aftermarket items

IV. Initial and Final Seat Position Measures

A. Initial position

1. Seat track length

a. Open driver door

b. Place painters tape along the inside of the door seal and on the seat.

c. Place a vertical reference mark on the painters tape stuck to the seat using the engineer's square

d. Mark on the tape the original position of the seat relative to the hard reference

2. Angle of seat base

a. Place inclinometer at the forward center of the seat base and record reading

3. Angle of seat back

a. Place inclinometer at the bottom center of the seat back and record reading

4. Brake pedal to seat

   a. Using the carpenter's tape measure, place the end at the center of the brake pedal

   b. Draw the tape measure to the top front and center of seat and record measurement

5. Telescoping steering wheel

    a. Locate fixed position that does not travel with the steering wheel and a fixed position that does travel with the steering wheel

    b. Measure between locations with ruler

6. Steering angle

    a. Place inclinometer at the center of the steering wheel and record reading

7. Ground to top of steering wheel

   a. Open door

   b. Place vertical jig next to steering wheel

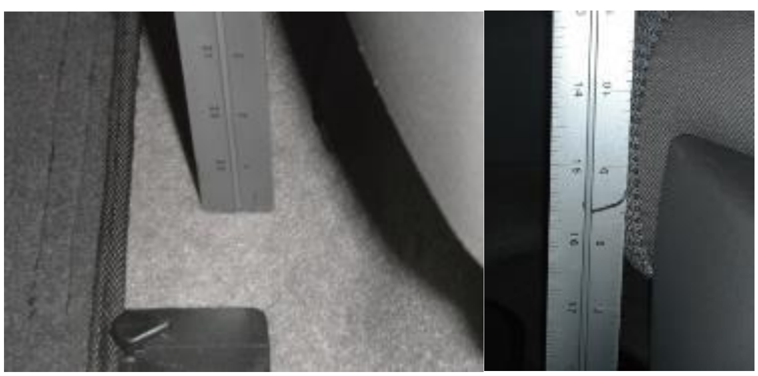
   c. Using post level, insure that the vertical jig is vertical

d. Hold one end of the mason string tangent to the top of the steering wheel

e. Using the other end of the mason string and a line level, draw the string level and across the vertical jig and take reading

8. Seat height

   a. Using the combination square, place ruler’s short edge on the vehicle floor with the floor mat(s) removed and long edge at the front-center of seat base



   b. Adjust square mechanism to be tangent to the top of the seat base and record the reading

9. H-point to ground

   a. Open door

   b. Place H-point jig in the center the seat

   c. Place vertical jig next to H-point jig

d. Using post level, insure that the vertical jig is vertical

e. Hold one end of the mason string to the H-point jig

f. Using the other end of the mason string and line level, draw the string level and across the vertical jig and take reading

10. H-point to brake

    a. Using the carpenter’s tape measure, place the end at the center of the brake pedal

    b. Draw the tape measure to the H-point and record measurement

B. Adjust each item separately to the Minimum Position and repeat steps IV.A.1 through IV.A.10

C. Adjust each item separately to the Maximum Position and repeat steps IV.A.1 through IV.A.10

V. Measurements of Vehicle Space

A. Ground to door seal

1. Using the combination square, place ruler's short edge on the ground and long edge at the original seat position of the door seal

2. Adjust square mechanism to be tangent to the top of the door seal

3. Record reading

B. Door seal to vehicle floor

1. Using the combination square, place ruler's short edge on the vehicle floor with the floor mat(s) removed and long edge at the original seat position of the door seal

2. Adjust square mechanism to be tangent to the top of the door seal

3. Record reading

C. Top of brake pedal to top of accelerator pedal

1. Place ruler along the top of the brake pedal and over the accelerator pedal

2. Depress the brake pedal until the ruler touches the accelerator pedal

3. Using a second ruler, measure the distance from the top of the ruler to the top of the accelerator pedal

D. Bottom of brake pedal to bottom of accelerator pedal

1. Place ruler along the bottom of the brake pedal and over the accelerator pedal

2. Depress the brake pedal until the ruler touches the accelerator pedal

3. Using a second ruler, measure the distance from the bottom of the ruler to the bottom of the accelerator pedal

E. Brake pedal height above accelerator pedal

1. Place ruler at center of the brake pedal and over the accelerator pedal

2. Using a second ruler, measure the “step up” distance of the accelerator pedal to the brake pedal

F. Accelerator pedal height

1. Using the combination square, place ruler’s short edge on the vehicle floor and flat face on the side of the accelerator pedal

2. Use the square to get the total height of the pedal from the vehicle floor with the floor mat(s) removed

G. Accelerator pedal length

1. Place a ruler on the face of the accelerator pedal and measure the length

H. Accelerator pedal angle

1. Place the inclinometer on the accelerator pedal and record the reading

I. Brake pedal height

1. Using the combination square, place ruler’s short edge on the vehicle floor and flat face on the side of the brake pedal

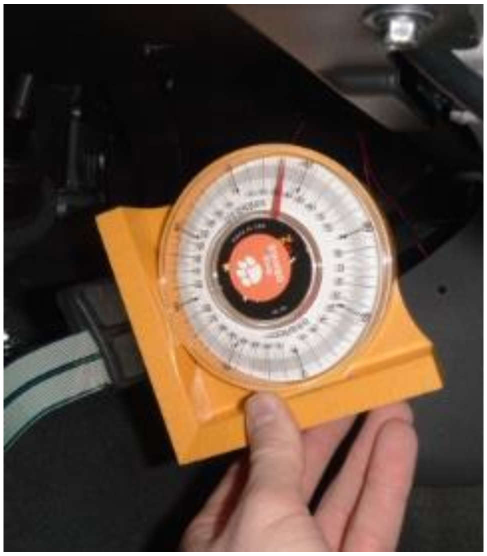
2. Use the square to get the total height of the pedal from the vehicle floor with the floor mat(s) removed

J. Brake pedal length

1. Place a ruler on the face of the brake pedal and measure the length

K. Brake pedal angle

1. Place the inclinometer on the accelerator pedal and record the reading



L. Brake pedal to left footwell wall

1. Using a ruler, place the long edge of the blade aligned with the top of the brake pedal

2. Slide the scale to the left until the edge of the ruler contacts the left footwell wall and record the reading from the left footwell wall to the top left corner of the brake pedal

M. Accelerator pedal to center console

1. Using a ruler, place the long edge of the blade aligned with the top of the brake pedal

2. Slide the scale to the right until the edge of the ruler contacts the center console and record the reading from the left footwell wall to the edge of the accelerator pedal at the height of the top of the brake pedal

VI. Measurement of the Adjustable Pedal Envelope

A. Does the vehicle have adjustable brakes?

1. If yes, proceed with step VI.A.2, if no proceed to next section (step VII)

2. Measure from top of seat base at centerline to the center of the brake pad:

a. Seat completely forward and pedals completely lowered

b. Seat completely forward and pedals completely raised

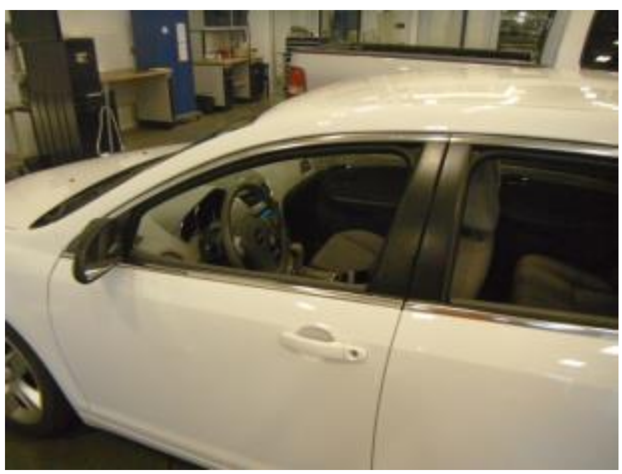
c. Seat completely rearward and pedals completely lowered

d. Seat completely rearward and pedals completely raised

VII. Measurements of Pedals with Laser

Laser Setup

- Set up the laser measuring instrument
    - Close all doors
    - Roll the driver and front passenger window to the fully open position



-
    - Place the window height gauge block so that the length is along the door and the width is along the B-pillar

- Separately, roll up both the driver and front-passenger window so that the top of the window glass aligns with the top of the window height gauge block

- Attach digital measuring device to I-beam with two thumbscrews


- Place I-beam through windows, insuring it is firmly against B pillar

- Clamp I-Beam to Window

- Attach laser and lower arm with thumbscrew

- Plug laser into portable battery pack

- Find Center of Steering Wheel
  - Turn laser on

  - Aim laser at the steering wheel

- Slide laser to the left most edge of the steering wheel

- Press the “zero” button on digital display

- Slide the laser to the right most edge of the steering wheel

- Divide diameter of steering wheel by two to obtain the radius

- Slide the laser to the value of the radius (center of steering wheel)

- Place tape on the steering wheel along the direction of the laser

- Trace the laser onto the tape

- Find Center of Seat
    - Slide the seat to the most rearward position
    - Aim laser at the seat

    - Slide laser to the left most edge of the seat

- Press the “zero” button on digital display

- Slide the laser to the right most edge of the seat

- Divide width of seat by two

- Slide the laser to value obtained in the previous step

- Press the “zero” button on digital display

- Place tape on the seat along the direction of the laser

- Trace the laser onto the tape

End of Laser Setup

A. Use laser to record data from center of seat

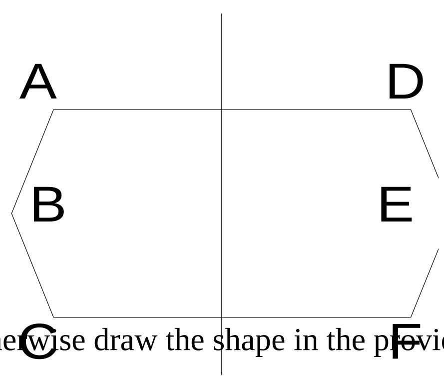
1. From center of seat, find brake pedal position (A-F)

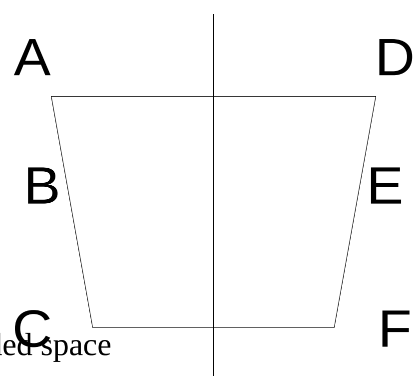
2. From center of seat, find gas pedal position (G-L)

3. From center of seat, find steering wheel positions

VIII. Appearance of Brake Pedal

A. Examine the brake pedal. If it resembles one of the two provided images, circle it.

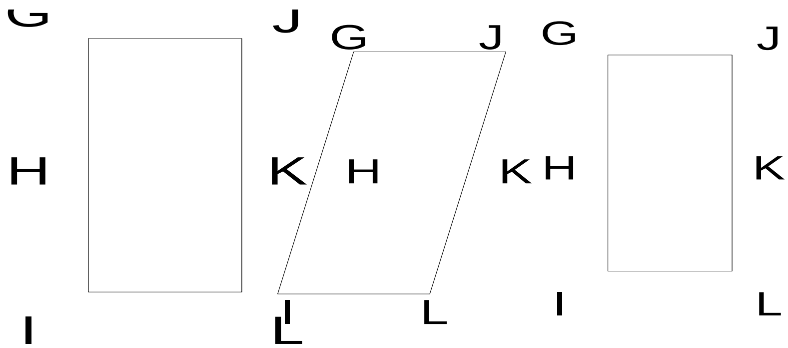




B. otherwise draw the shape in the provided space

IX. Appearance of Acceleration Pedal

A. Examine the accelerator pedal. If it resembles one of the three provided images, circle it.



B. Otherwise, draw the shape in the provided space.

X. CarFit©

A. Mark the available seat adjustment options for the particular vehicle.

B. Ask the participant sequentially to demonstrate their ability to operate the seat position adjustments and mark if they demonstrated adjustment correctly or need instruction.

1. “Please put on and then remove your seatbelt.”

2. “Please move your seat down.”

3. “Please move our seat up.”

4. “Please move your seat forward.”

5. “Please move your seat backward.”

6. “Please recline your seatback.”

7. “Please bring your seatback to an upright position.”

8. “Please adjust the tilt of your seat bottom.”

9. “Please tilt your steering wheel to a different position.”

10. “Please show me how the telescope feature of your steering wheel works.”

11. “Please adjust your pedals.”

12. “Please describe how you can adjust your head restraint up and down.”

13. “Please describe how you can tilt your head restraint.”

C. Read the CarFit© recommendations and mark that the participant was given the recommendations:

1. It is recommended that there is at least 2” of space between the top of the driver’s thighs and the bottom of the steering wheel.

2. It is recommended that the driver’s straight line of vision is at least 3” above the top of the steering wheel.

3. It is recommended that the driver is sitting at least 10” back from the steering wheel.

4. It is recommended that the head restraint should be positioned to allow only 2” between the back of the person’s head and the center of the head restraint.

5. It is recommended that the driver does not have to fully extend their leg or use their toes to press on the gas and brake pedals and push them to their full range.

XI. Photographs of Vehicle (Note: the participant will not be in the photos)

A. Cabin from driver side with the door open

B. Top down view of the pedals

XII. Post Test Measures repeat steps II.A through II.F

XIII. Measurements Requiring Calculations

A. Brake pedal width from laser data (D-A,E- B, and F-C)

B. Accelerator pedal width from laser data (J-G, K-H, and L-I)

C. Steering wheel diameter

D. Ground to floor

E. Floor to eye level

F. Gap between pedals from laser data (G-D, H-E, and I-F)

G. Range of pedals from laser data (J-A, K-B, and L-C)

H. Ground to top of steering wheel

I. Floor to H-Point

APPENDIX B

DATA SHEETS

B.1 Part One: Pilot Study with Older Adults from the Community Data Form

General Information

Participant Number : ____________ Date: ________ Collected by: ____________

Initial Seat Position *(Patient in Vehicle)*

Ground to Eye Level	
Top of Leg to Steering Wheel Bottom	
Top of Steering Wheel to Eye Level	
Steering Wheel to Breast Bone	
Top of Head to Roof	
Back of Head to Head Rest	

Patient Height: ____________ Shoe Size: ________ M or W Gender: M or F

Age: ________

Is the subject the only driver? Y or N *If no, what is the percentage they drive?* ____________

Was the car purchase new or used? ________

Vehicle Info

How many floor mats are present? None(0) Single (1) Double (2)

Are the floor mats original to the vehicle? Y or N

Is there a presence of wear pattern in the floor matt and/or carpet? Y or N

Describe location and severity: ____________

Make: ____________ Model: ____________

Trim: ____________ Year: ________ Odometer: ____________

VIN: ____________

Engine: L4 L5 L6 V4 V6 V8 V10 ( ) Gas ( ) Diesel Displacement: ________ L/CI

Power Brakes: Y or N ( ) Vacuum ( ) Hydroboost Driveline 2wd front 4wd 2wd rear Awd

Transmission type: Automatic or Manual

Are the Pedals Mounted to the Floor? Brake Y or N Accel. Y or N

Is the head rest adjustable? Vertical Y or N Tilt Y or N

Number of Seat adjustments ____________

Presence of aftermarket items :

(i.e. Seat Covers, Steering wheel Covers, Pedal Covers, Adaptive Equipment)

____

____

Initial Seat Position *(count.)*

	Mark Seat Track Fill in Measure Below
Seat Track Length	
Seat Height at Front	
Brake Pedal to Seat	
Angle of Seat Base	
Angle of Seat Back	
Steering Tilt	
Telescoping Steering Wheel	
Ground to Top of Steering Wheel	
H-point to Ground	
H-point to Brake	

Make Sure That you Have All Initial Data Before Continuing

Available Seat Positions

	Minimum Position	Maximum Position	Initial Seat Position
Seat Track Length	see below	see below	
Seat Height at Front	see below	see below	see above
Brake Pedal to Seat			see above
Angle of Seat Base			see above
Angle of Seat Back			see above
Steering Tilt			see above
Telescoping Steering Wheel	0		see above
Ground to Top of Steering Wheel	see below	see below	see above
H-point to Ground			see above
H-point to Brake			see above

Ground to Top of Steering Wheel

	Telescope Forward	Telescope Rearward
Steering Tilt Upward		
Steering Tilt Downward		

Seat Adjustment Height/ Track

	Forward Seat	Rearward Seat
Seat Tilted Upward Max Seat Height	0	
Seat Tilted downward Min Seat Height		

Initial Seat Position *(count.)*

	Mark Seat Track Fill in Measure Below
Seat Track Length	
Seat Height at Front	
Brake Pedal to Seat	
Angle of Seat Base	
Angle of Seat Back	
Steering Tilt	
Telescoping Steering Wheel	
Ground to Top of Steering Wheel	
H-point to Ground	
H-point to Brake	

Make Sure That you Have All Initial Data Before Continuing

Available Seat Positions

	Minimum Position	Maximum Position	Initial Seat Position
Seat Track Length	see below	see below	
Seat Height at Front	see below	see below	see above
Brake Pedal to Seat			see above
Angle of Seat Base			see above
Angle of Seat Back			see above
Steering Tilt			see above
Telescoping Steering Wheel	0		see above
Ground to Top of Steering Wheel	see below	see below	see above
H-point to Ground			see above
H-point to Brake			see above

Ground to Top of Steering Wheel

	Forward Telescope	Rearward Telescope
Steering Tilt Upward		
Steering Tilt Downward		

Seat Adjustment Height/ Track

	Forward Seat	Rearward Seat
Seat Tilted Upward Max Seat Height	0	
Seat Tilted downward Min Seat Height		

B.2 Part Two: 20 Younger Participants from the Community Data Form

Hello, are you here to participate in a study? Good, you've come to the right place. And what is your name? Welcome, _________, my name is, __________, and this is, ________, who will take some measurements today . Thank you for participating. We would like to take some measurements of you in your vehicle. Afterwards, we will be taking our engineering measurements of your vehicle. Then, we will have you move the seat and steering wheel before we make these measurements a second time. Do you have any questions before we get started? (Make sure driver has seatbelt on. If not, ask driver to put seatbelt on.)

Note: All measurements are in English units (Inches)

Have you ever been a participant in this study before? __________

General Information

Participant ID : __________ Date: __________ Collected by: ____________________

Initial Seat Position *(Patient in Vehicle)*

A1		Ground to Eye Level
A2		Top of Leg to Steering Wheel Bottom
A3		Top of Steering Wheel to Eye Level
A4		Steering Wheel to Breast Bone
A5		Top of Head to Roof
A6		Back of Head to Head Rest

A7 Patient Height: ____________________ Shoe Size: __________ M or F Gender: M or F

Lower Leg Length: ____________________ Upper Leg Length: ____________________

Age: __________

Is the subject the only driver? Y or N *If no, what is the percentage they drive?* __________

Was the car purchase new or used? __________

Why did you select this seat position? ____________________

A8 ***(Put tape on door seal bottom edge, seat (base, back, & next to adjustment controls), steering wheel, and steering column.)***

For the engineering measurements we'll need to move your seat forward and backward and move your windows up and down. If you want to go inside would you please leave your car key with me. We will not move or drive your vehicle. Is it ok to put painters tape on the seats and plastic of your car? Did you bring your drivers manual with you today? If so, please leave it on the seat.

Vehicle Info

How many floor mats are present? None(0) Single (1) Double (2)

Are the floor mats original to the vehicle? Y or N

Is there a presence of wear pattern in the floor matt and/or carpet? Y or N

Describe location and severity: ____________________

Make: ____________________ Model: ____________________

Trim: ____________________ Year: __________ Odometer: ____________________

VIN: ____________________

Engine: L4 L5 L6 V4 V6 V8 V10 Displacement: __________ L/CI

( ) Gas ( ) Diesel Driveline: 2wd front 4wd

2wd rear Awd

Brakes: ( ) Vacuum ( ) Hydroboost Power Brakes: Y or N

Transmission type: Automatic or Manual

Are the Pedals Mounted to the Floor? Brake: Y or N Accel.: Y or N

Is the head rest adjustable? Vertical: Y or N Tilt: Y or N

Presence of aftermarket items : ____________________

(i.e. Seat Covers, Steering wheel Covers, Pedal Covers, Adaptive Equipment)

Initial Seat Position (*cont.*)

(Mark Initial Seat Track Position Now)

	Mark Seat Track Fill in Measure Below	
B1		Seat Height at Front
B2		Brake Pedal to Seat
B3		Angle of Seat Base *(mark location on tape on seat base)*
B4		Angle of Seat Back *(mark location on tape on seat back)*
B5		Steering Tilt *(mark initial position on tape on steering wheel)*
B6		Telescoping Steering Wheel *(mark initial position on steering column)*
B7		Ground to Top of Steering Wheel
B9		H-point to Brake
B8		H-point to Ground

Make Sure That you Have All Initial Data Before Continuing

Available Seat Positions

(Be sure to mark the position on the tape)

= seat all the way back

(Roll back floor mat; measure from floorboard)

** Mark max and min seat positions on tape on door seal*

	Minimum Position*	Maximum Position*	Initial Position*	
	see to right	see below		Seat Track Length
	see below	see below	see above	Seat Height at Front
B10			see above	Brake Pedal to Seat
B11			see above	Angle of Seat Base
B12			see above	Angle of Seat Back
B14			see above	H-point to Brake
B13			see above	H-point to Ground

Seat Adjustment Height (Y)/Track Length (X)

B15 & B16	Seat Forward	Rearward Seat
Tilted Upward (Y=ht.) / Min. Seat Track Position (X=horiz. Dist.)	(y) (x=0)	(y) (x)
TiltedDownward (Y=ht.) / Max. Seat Track Position (X=horiz. Dist.)	(y) (x)	(y) (x)

*Mark initial position

B18	0		see above	Telescoping Steering Wheel
B17			see above	Steering Tilt
--	see below	see below	see above	Ground to Top of Steering Wheel

Ground to Top of Steering Wheel

		Telescope Forward	Telescope Rearward
B19	Steering Tilt Upward	Push, Up	Pull, Up
B20	Steering Tilt Downward	Push, Down	Pull, Down

Adjustable Pedals: ( ) Yes ( ) No
(look for switch on door or dash)

If yes:			Brake Pedals Lowered	Brake Pedal Raised
	B21	Seat Forward		
	B22	Seat Rearward		

Non-Laser Vehicle Measures

B21 Ground to Door Seal: ____________

B22 Door Seal to Vehicle Floor: ____________

B23 Top of brake pedal to top of accel.: ____________

B24 Bottom of brake to bottom of accel.: ____________

B25 Brake Pedal Height above accel. Pedal: ____________

B26 Accel. Pedal Height *(from floorboard)* : ____________

B27 Accel. Pedal Length: ____________

B28 Accel. Pedal angle: ____________

B29 Brake Pedal Height *(from floorboard)* : ____________

B30 Brake Pedal Length: ____________

B31 Brake pedal angle: ____________

B32 Accel. Pedal to center console: ____________

B33 Brake Pedal to Left Footwell Wall: ____________

Number of Seat adjustments:

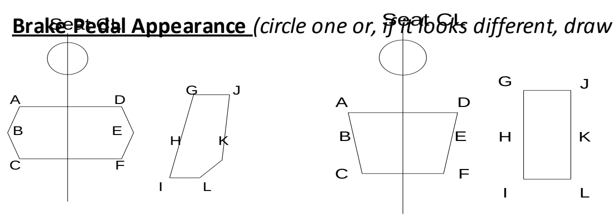
(Clear all hand tools out of vehicle at this time and roll down windows.)

	Seat CL to Steering Wheel	
B34	Left	
B35	Center	
B36	Right	

	Seat CL to Brake Pedal	
B36	A	
B37	B	
B38	C	
B39	D	
B40	E	
B41	F	

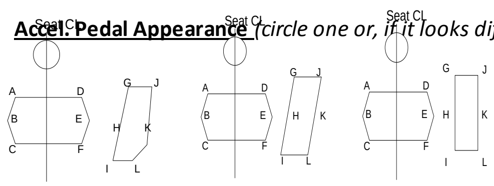
	Seat CL to Accel. Pedal	
B41	G	
B42	H	
B43	I	
B44	J	
B45	K	
B46	L	

Brake Pedal Appearance *(circle one or, if it looks different, draw shape)*



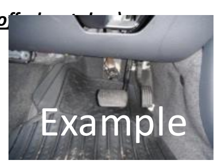
Other:

Accel. Pedal Appearance *(circle one or, if it looks different, draw shape)*



Other:

B47



Move tools, mat, & tee away from door so participant can get into vehicle. Put Towel Down

Welcome back. Please sit in the driver's seat and demonstrate the following tasks:		
Questions	Experimentor indicates if Option is Present Before Participant Comes Outside (Y/N) (if no, put 'X' in next column)	Patient Demonstrated Correctly (PDC) or Patient Needed Instructions (PNI)
Please put on and then remove your seatbelt.		
Please move your seat down.		
Please move your seat up.		
Please move your seat forward.		
Please move your seat backward.		
Please recline your seatback.		
Please bring your seatback to an upright position.		
Please adjust the tilt of your seat bottom.		
Please tilt your steering wheel to a different position.		
Please show me how the telescope feature of your steering wheel works.		
Please adjust your pedals.		
For the next two items, please describe the following:		
Please describe how you can adjust your headrest up and down.		
Please describe how you can tilt your headrest.		

Please adjust the position of your seat and steering wheel until you are comfortable. Let me know when you're ready to proceed. Before we proceed, I'm going to read a list of recommendations for your consideration.

Recommendations to Participant	*Check After Recommendations Read to Participant*
It is recommended that there is at least 2" of space between the top of the driver's thighs and the bottom of the steering wheel.	
It is recommended that the driver's straight line of vision is at least 3" above the top of the steering wheel.	
It is recommended that the driver is sitting at least 10" back from the steering wheel.	
It is recommended that the head restraint should be positioned to allow only 2" between the back of the person's head and the center of the head restraint.	
It is recommended that the driver does not have to fully extend their leg or use their toes to press on the gas and brake pedals and push them to their full range.	

Do you have any questions?

	Measurements	
C1	Top of Leg to Steering Wheel Bottom	
C2	Top of Steering Wheel to Eye Level	
C3	Steering Wheel to Breast Bone	
C4	Back of Head to Head Rest	

I have two more measurments I need to take and then I will ask you to step out of the car.

C5	Top of Head to Roof	
C6	Ground to Eye Level	

Move tools and mat out of the way for the patient

Please get out of your vehicle so we can take a few last measurments. You are welcome to sit in this chair.

Patient out vehicle

C7		Seat Track Length	**C12**		Steering Tilt
C8		Seat Height at Front	**C13**		Telescoping Steering Wheel
C9		Brake Pedal to Seat			
C10		Angle of Seat Base	**C14**		H-point to Brake
C11		Angle of Seat Back	**C15**		Top of Steering Wheel to Ground
			C16		H-point to Ground

	Average	Min	Max
Brake Pedal Width			
Accel. Pedal Width			
Steering Wheel Dia.			
Ground to Floor			
Floor to Eye Level			

Floor to H-Point: ____________

	Min	Max
Gap Between Pedals		
Range of Pedals		

Floor to Top of Steering Wheel: ________

B.3 Part Three: Older Adults in a Clinical Setting Data Form

Hello, are you here to participate in a study? Good, you've come to the right place. And what is your name? Welcome, _________, my name is, __________, and this is, ________, who will take some measurements today . Thank you for participating. Before you go inside to work with the CDRS, we would like to take some measurements of you in your vehicle. While you are inside, we will be taking our engineering measurements of your vehicle. When the CDRS brings you back outside, we will have you move the seat and steering wheel before we make these measurements a second time. This will take about 15 minutes. Do you have any questions before we get started? (Make sure driver has seatbelt on. If not, ask driver to put seatbelt on.)

Note: All measurements are in English units (Inches)

Have you ever been a participant in this study before? __________

General Information

Participant ID : __________ Date: __________ Collected by: ____________________

Initial Seat Position *(Patient in Vehicle)*

A1		Ground to Eye Level
A2		Top of Leg to Steering Wheel Bottom
A3		Top of Steering Wheel to Eye Level
A4		Steering Wheel to Breast Bone
A5		Top of Head to Roof
A6		Back of Head to Head Rest

A7 Patient Height: ____________________ Shoe Size: __________ M or F Gender: M or F

Age: __________

Is the subject the only driver? Y or N *If no, what is the percentage they drive?* __________

Was the car purchase new or used? __________

Why did you select this seat position? ______________________________

A8 ***(Put tape on door seal bottom edge, seat (base, back, & next to adjustment controls), steering wheel, and steering column.)***

(Text the CDRS to meet us). We are now going to take you inside to meet the CDRS. While you're inside, we'll need to move your seat forward and backward and move your windows up and down. Please leave your car key with me. We will not move or drive your vehicle. Is it ok to put painters tape on the seats and plastic of your car? Did you bring your drivers manual with you today? If so, please leave it on the seat.

Vehicle Info

How many floor mats are present? None(0) Single (1) Double (2)

Are the floor mats original to the vehicle? Y or N

Is there a presence of wear pattern in the floor matt and/or carpet? Y or N

Describe location and severity: ______________________________

Make: ____________________ Model: ____________________

Trim: ____________________ Year: __________ Odometer: __________

VIN: ____________________

Engine: L4 L5 L6 V4 V6 V8 V10 Displacement: __________ L/CI

( ) Gas ( ) Diesel Driveline: 2wd front 4wd

2wd rear Awd

Brakes: ( ) Vacuum ( ) Hydroboost Power Brakes: Y or N

Transmission type: Automatic or Manual

Are the Pedals Mounted to the Floor? Brake: Y or N Accel.: Y or N

Is the head rest adjustable? Vertical: Y or N Tilt: Y or N

Presence of aftermarket items : ______________________________

(i.e. Seat Covers, Steering wheel Covers, Pedal Covers, Adaptive Equipment)

Initial Seat Position (*cont.*)

(Mark Initial Seat Track Position Now)

	Mark Seat Track Fill in Measure Below	
B1		Seat Height at Front
B2		Brake Pedal to Seat
B3		Angle of Seat Base *(mark location on tape on seat base)*
B4		Angle of Seat Back *(mark location on tape on seat back)*
B5		Steering Tilt *(mark initial position on tape on steering wheel)*
B6		Telescoping Steering Wheel *(mark initial position on steering column)*
B7		Ground to Top of Steering Wheel
B9		H-point to Brake
B8		H-point to Ground

Make Sure That you Have All Initial Data Before Continuing

Available Seat Positions

(Be sure to mark the position on the tape)

= *seat all the way back*

(Roll back floor mat; measure from floorboard)

** Mark max and min seat positions on tape on door seal*

	Minimum Position*	Maximum Position*	Initial Position*	
	see to right	see below		Seat Track Length
	see below	see below	see above	Seat Height at Front
B10			see above	Brake Pedal to Seat
B11			see above	Angle of Seat Base
B12			see above	Angle of Seat Back
B14			see above	H-point to Brake
B13			see above	H-point to Ground

Seat Adjustment Height (Y)/Track Length (X)

B15 & B16	Seat Forward	Rearward Seat
Tilted Upward (Y=ht.) / Min. Seat Track Position (X=horiz. Dist.)	(y) (x=0)	(y) (x)
TiltedDownward (Y=ht.) / Max. Seat Track Position (X=horiz. Dist.)	(y) (x)	(y) (x)

*Mark initial position

B18	0		see above	Telescoping Steering Wheel
B17			see above	Steering Tilt
--	see below	see below	see above	Ground to Top of Steering Wheel

Ground to Top of Steering Wheel

		Telescope Forward	Telescope Rearward
B19	Steering Tilt Upward	Push, Up	Pull, Up
B20	Steering Tilt Downward	Push, Down	Pull, Down

Adjustable Pedals: ( ) Yes ( ) No

(look for switch on door or dash)

If yes:			Brake Pedals Lowered	Brake Pedal Raised
	B21	Seat Forward		
	B22	Seat Rearward		

Non-Laser Vehicle Measures

B21 Ground to Door Seal: ______

B22 Door Seal to Vehicle Floor: ______

B23 Top of brake pedal to top of accel.: ______

B24 Bottom of brake to bottom of accel.: ______

B25 Brake Pedal Height above accel. Pedal: ______

B26 Accel. Pedal Height *(from floorboard)* : ______

B27 Accel. Pedal Length: ______

B28 Accel. Pedal angle: ______

B29 Brake Pedal Height *(from floorboard)* : ______

B30 Brake Pedal Length: ______

B31 Brake pedal angle: ______

B32 Accel. Pedal to center console: ______

B33 Brake Pedal to Left Footwell Wall: ______

Number of Seat adjustments:

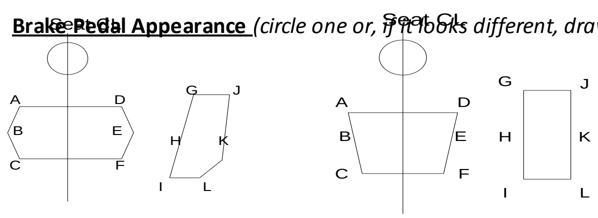
(Clear all hand tools out of vehicle at this time and roll down windows.)

	Seat CL to Steering Wheel	
B34	Left	
B35	Center	
B36	Right	

	Seat CL to Brake Pedal	
B36	A	
B37	B	
B38	C	
B39	D	
B40	E	
B41	F	

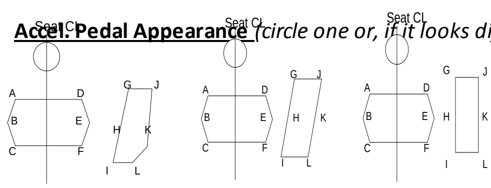
	Seat CL to Accel. Pedal	
B41	G	
B42	H	
B43	I	
B44	J	
B45	K	
B46	L	

Brake Pedal Appearance *(circle one or, if it looks different, draw shape)*



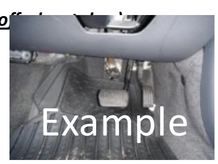
Other:

Accel. Pedal Appearance *(circle one or, if it looks different, draw shape)*



Other:

B47



Move tools, mat, & tee away from door so participant can get into vehicle. Put Towel Down

Welcome back. Please sit in the driver's seat and demonstrate the following tasks:

Questions	Experimentor indicates if Option is Present Before Participant Comes Outside (Y/N) (if no, put 'X' in next column)	Patient Demonstrated Correctly (PDC) or Patient Needed Instructions (PNI)
Please put on and then remove your seatbelt.		
Please move your seat down.		
Please move your seat up.		
Please move your seat forward.		
Please move your seat backward.		
Please recline your seatback.		
Please bring your seatback to an upright position.		
Please adjust the tilt of your seat bottom.		
Please tilt your steering wheel to a different position.		
Please show me how the telescope feature of your steering wheel works.		
Please adjust your pedals.		
For the next two items, please describe the following:		
Please describe how you can adjust your headrest up and down.		
Please describe how you can tilt your headrest.		

Please adjust the position of your seat and steering wheel until you are comfortable. Let me know when you're ready to proceed. Before we proceed, I'm going to read a list of recommendations for your consideration. In the next section, a CDRS will go over these recommendations in detail.

Recommendations to Participant	*Check After Recommendations Read to Participant*
It is recommended that there is at least 2" of space between the top of the driver's thighs and the bottom of the steering wheel.	
It is recommended that the driver's straight line of vision is at least 3" above the top of the steering wheel.	
It is recommended that the driver is sitting at least 10" back from the steering wheel.	
It is recommended that the head restraint should be positioned to allow only 2" between the back of the person's head and the center of the head restraint.	
It is recommended that the driver does not have to fully extend their leg or use their toes to press on the gas and brake pedals and push them to their full range.	

A CDRS will go over this in detail in your next session. Please save questions for the CDRS.

	Measurements	
C1	Top of Leg to Steering Wheel Bottom	
C2	Top of Steering Wheel to Eye Level	
C3	Steering Wheel to Breast Bone	
C4	Back of Head to Head Rest	

I have two more measurments I need to take and then I will ask you to step out of the car.

C5	Top of Head to Roof	
C6	Ground to Eye Level	

Move tools and mat out of the way for the patient

Please get out of your vehicle so we can take a few last measurments. You are welcome to sit in this chair.

Patient out vehicle

C7		Seat Track Length	**C12**		Steering Tilt
C8		Seat Height at Front	**C13**		Telescoping Steering Wheel
C9		Brake Pedal to Seat			
C10		Angle of Seat Base	**C14**		H-point to Brake
C11		Angle of Seat Back	**C15**		Top of Steering Wheel to Ground
			C16		H-point to Ground

	Average	Min	Max
Brake Pedal Width			
Accel. Pedal Width			
Steering Wheel Dia.			
Ground to Floor			
Floor to Eye Level			

Floor to H-Point: ____________

	Min	Max
Gap Between Pedals		
Range of Pedals		

Floor to Top of Steering Wheel: ________

APPENDIX C

APPARATUS

C.1 Tools Purchased for the Study

Standard tools used to obtain the measurements for the data capture were the following:

- A 6, 12, and 24 inch Starrett© stainless steel ruler with 4R graduation type and graduations of 8ths, 16ths, 32nds, and 64ths. See Figure 83.

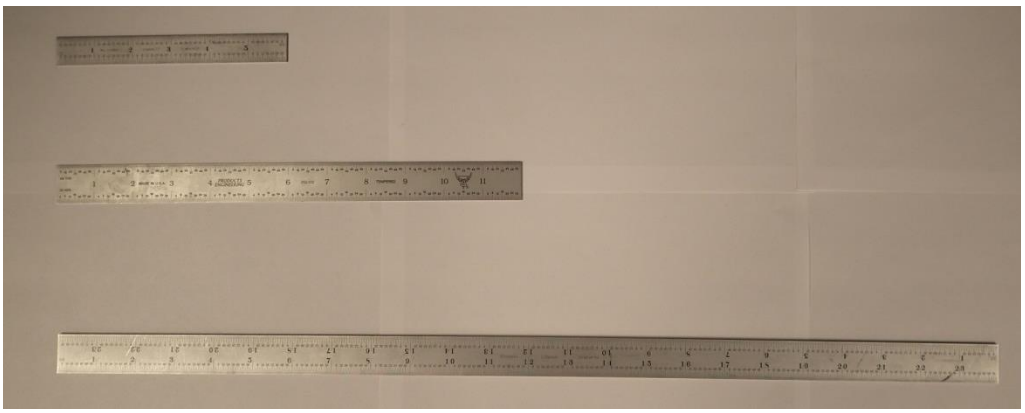


Figure 83. 6, 12, and 24 inch steel rulers.

- A 12, 18, and 24 inch Starrett© combination square. The blade is stainless steel with 4R graduation type and graduations of 8ths, 16ths, 32nds, and 64ths. The head is made of cast iron and contains a spirit level to ensure level or plumb measurements. See Figure 84.

Figure 84. 12 and 18 inch combination square with a 24-inch combination blade.

- A 25 foot Stanley© PowerLock® carpenter’s measuring tape. Graduations are in feet and inches with the smallest graduations every 1/16th of an inch. See Figure 85.

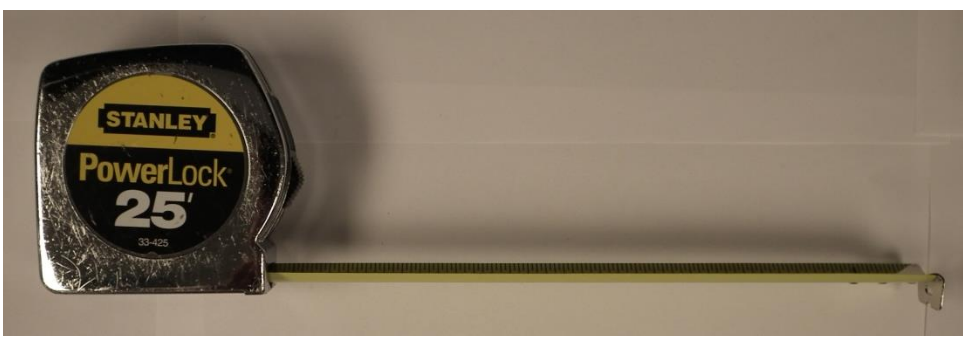


Figure 85. Carpenter’s measuring tape.

- A tailor’s measuring tape. The tailor’s tape has graduations of 1/8th inch. See Figure 86.

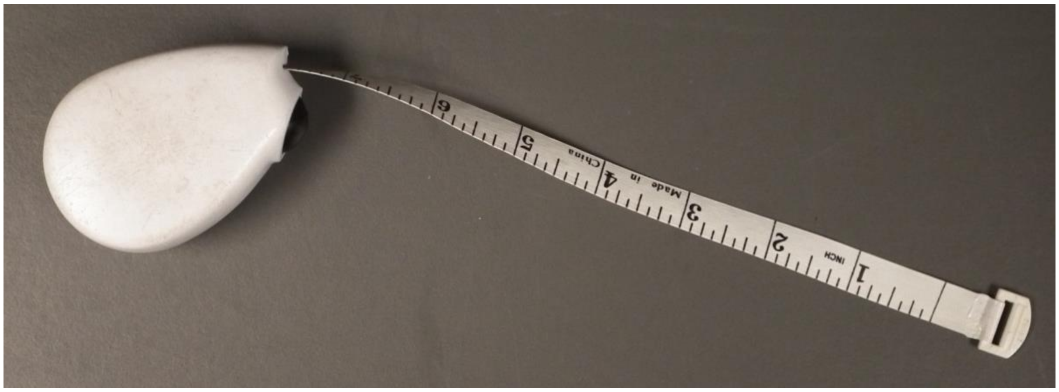


Figure 86. Tailor's measuring tape.

- A Dasco Pro© inclinometer. The inclinometer measures 0 to 90 degrees in each quadrant with an accuracy of 0.5 deg. See Figure 87.

Figure 87. Inclinometer.

- A 6 inch Starrett© precision steel square. There are no graduations on the precision square; however, this tool had a squareness of 0.00063 inches. See Figure 88.

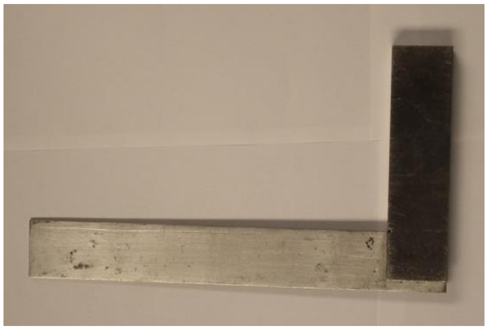


Figure 88. Precision steel square.

- A Kreg® Multi-Mark™. The Kreg® Multi-Mark™ blade is made of stainless steel and the head is made of plastic. The head contains a spirit level and guides to place the blade in specific positions. The blade measures in inches with 1/16th inch graduations. See Figure 89.

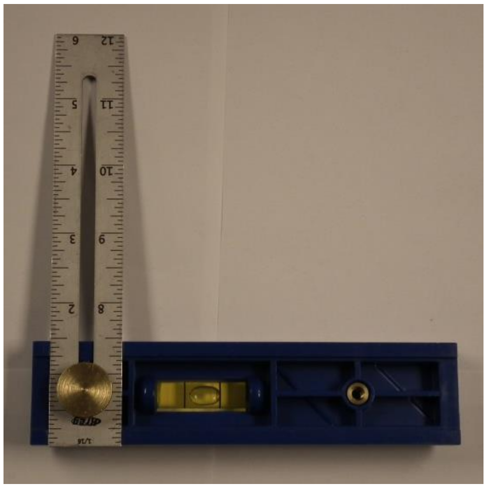


Figure 89. Kreg® Multi Mark™.

C.2 Tools Created for the Study.

Tools created to obtain the measurements for the data capture were the following:

- A jig was constructed to measure the location of the H-point as described in Chapter Three. The H-point jig simulates the location of the hip joint for the 95th percentile person. The jig was made to lessen investigators' physical contact with the participant. The jig, made from wood, reflects the Society of Automotive Engineering (SAE) standard J826, "Devices for Use in Defining and Measuring Vehicle Seating Accommodation". The H-point jig is shown below in Figure 90.

Figure 90. H-point jig to measure the location of the H-point. H-point Jig located in a vehicle seat (left) and laid flat (right).

- The Vertical Post Rule was made to capture vertical position of eye-level, steering wheel height, and H-point height, see Table 14. The device is a PVC pipe mounted over a tee ball stand and a Kreg® self-adhesive measuring tape placed along the length of the pipe. The Kreg® self-adhesive measuring tape has graduations in feet and inches with the smallest graduation every 1/16th of an inch. A post level was used to ensure that the device was vertical, and a mason's string with a line level was drawn from the item to be measured to across the Kreg® ruler. The Vertical Post Rule is shown in Figure 91.

Figure 91. Vertical post rule to capture vertical position of eye-level, steering wheel height, and H-point height.

- A Vernier laser position gauge, on loan from NHTSA, was used to find lateral position of the steering wheel, brake pedal, and accelerator pedal within the occupant cabin, relative to the centerline of the driver's seat. See Table 14 and Figure 25, 26, and 27 for further detail.

- The Vernier laser position gauge consists of a laser, I-beam, and digital Vernier height gauge. The digital Vernier height gauge was accurate to ±0.0005 inches. The Vernier laser position gauge is shown in Figure 92.

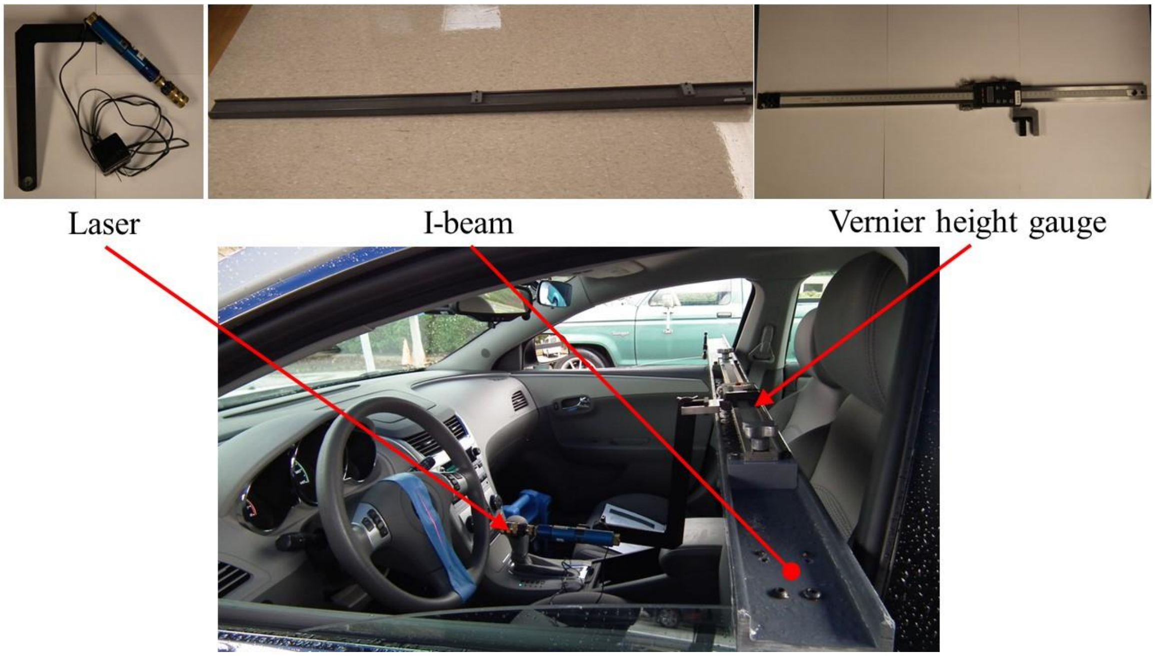


Figure 92. Vernier laser position gauge constructed to determine lateral position of items in the occupant cabin.

APPENDIX D

ANCOVA TABLES

D.1 Custom Mixed-Model ANCOVA Tables

Table 69

Mixed-Model ANCOVA for Effects of Measured BOFRP to H-point (L99), Calculated BOFRP to H-point (SAE J4004), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
L99 x SAE J4004 x Age x Gender x Stature	0.043	0.836	-
L99 x Age x Gender x Stature	0.415	0.521	-
SAE J4004 x Age x Gender x Stature	0.440	0.509	-
L99 x SAE J4004 x Age x Gender	0.079	0.780	-
L99 x SAE J4004 x Age x Stature	5.950	0.016	0.228
L99 x SAE J4004 x Gender x Stature	3.680	0.058	0.181
L99 x Age x Gender	0.365	0.547	-
L99 x Age x Stature	0.771	0.382	-
L99 x Gender x Stature	4.775	0.031	0.205
SAE J4004 x Age x Gender	0.414	0.521	-
SAE J4004 x Gender x Stature	2.821	0.096	-
SAE J4004 x Age x Stature	0.000	0.986	-
L99 x SAE J4004 x Age	5.771	0.018	0.224
L99 x SAE J4004 x Gender	3.606	0.600	-
L99 x SAE J4004 x Stature	0.375	0.541	-
Age x Gender x Stature	0.072	0.789	-

Table 69 *continued*

Mixed-Model ANCOVA for Effects of Measured BOFRP to H-point (L99), Calculated BOFRP to H-point (SAE J4004), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
L99 x Age	0.787	0.377	-
L99 x Gender	4.755	0.031	0.204
L99 x Stature	0.891	0.347	-
L99 x SAE J4004	0.275	0.601	-
SAE J4004 x Age	0.005	0.945	-
SAE J4004 x Gender	2.774	0.099	-
SAE J4004 x Stature	0.260	0.611	-
Age x Gender	0.038	0.846	-
Age x Stature	3.075	0.082	-
Gender x Stature	0.726	0.396	-
L99	0.639	0.426	-
SAE J4004	0.365	0.547	-
Age	3.349	0.070	-
Gender	0.876	0.351	-
Stature (covariate)	72.005	0.000	0.631

Note. $df_1 = 1$ and $df_2 = 109$.

Table 70

Mixed-Model ANCOVA for Effects of Difference between Measured and Calculated BOFRP and H-point (Difference), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Difference x Age x Gender x Stature	0.043	0.836	-
Difference x Age x Gender	0.079	0.780	-
Difference x Age x Stature	5.950	0.016	0.228
Difference x Gender x Stature	3.680	0.058	0.181
Age x Gender x Stature	0.415	0.521	-
Difference x Age	5.771	0.018	0.224
Difference x Gender	3.606	0.060	0.179
Difference x Stature	0.375	0.541	-
Age x Gender	0.365	0.547	-
Age x Stature	0.771	0.382	-
Gender x Stature	4.775	0.031	0.205
Difference	0.275	0.601	-
Age	0.787	0.377	-
Gender	4.755	0.031	0.204
Stature (covariate)	0.891	0.347	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 71

Mixed-Model ANCOVA for Effects of Vehicle Floor to H-point, Age (H30), Gender and Their Interactions

Factor	*F*	*p*-value	*r*
H30 x Age x Gender x Stature	1.015	0.316	-
H30 x Age x Gender	1.138	0.288	-
H30 x Age x Stature	1.428	0.235	-
H30 x Gender x Stature	1.786	0.184	-
Age x Gender x Stature	0.389	0.534	-
H30 x Age	1.420	0.236	-
H30 x Gender	1.862	0.175	-
H30 x Stature	0.952	0.331	-
Age x Gender	0.466	0.496	-
Age x Stature	0.063	0.803	-
Gender x Stature	0.076	0.784	-
H30	1.003	0.319	-
Age	0.037	0.847	-
Gender	0.022	0.884	-
Stature (covariate)	4.132	0.044	0.191

Note. $df_1 = 1$ and $df_2 = 109$.

Table 72

Mixed-Model ANCOVA for Effects of BOFRP to Center of Steering Wheel (L6), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
L6 x Age x Gender x Stature	0.414	0.521	-
L6 x Age x Gender	0.524	0.471	-
L6 x Age x Stature	4.355	0.039	0.196
L6 x Gender x Stature	0.080	0.778	-
Age x Gender x Stature	0.020	0.888	-
L6 x Age	4.406	0.038	0.197
L6 x Gender	0.103	0.749	-
L6 x Stature	1.236	0.269	-
Age x Gender	0.036	0.849	-
Age x Stature	3.362	0.069	-
Gender x Stature	0.093	0.761	-
L6	1.213	0.273	-
Age	3.700	0.057	0.181
Gender	0.055	0.815	-
Stature (covariate)	2.552	0.113	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 73

Mixed-Model ANCOVA for Effects of Seat Base Angle (A27), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A27 x Age x Gender x Stature	4.306	0.040	0.195
A27 x Age x Gender	4.129	0.045	0.191
A27 x Age x Stature	2.298	0.132	-
A27 x Gender x Stature	3.503	0.064	-
Age x Gender x Stature	0.426	0.515	-
A27 x Age	1.822	0.180	-
A27 x Gender	3.259	0.074	-
A27 x Stature	1.199	0.276	-
Age x Gender	0.528	0.469	-
Age x Stature	1.555	0.215	-
Gender x Stature	0.857	0.357	-
A27	0.994	0.321	-
Age	1.545	0.217	-
Gender	0.990	0.322	-
Stature (covariate)	1.663	0.200	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 74

Mixed-Model ANCOVA for Effects of Seat Back Angle (A40), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A40 x Age x Gender x Stature	0.468	0.495	-
A40 x Age x Gender	0.492	0.485	-
A40 x Age x Stature	0.038	0.846	-
A40 x Gender x Stature	0.376	0.541	-
Age x Gender x Stature	0.033	0.856	-
A40 x Age	0.036	0.850	-
A40 x Gender	0.336	0.563	-
A40 x Stature	0.183	0.669	-
Age x Gender	0.019	0.892	-
Age x Stature	1.930	0.167	-
Gender x Stature	0.723	0.397	-
A40	0.254	0.615	-
Age	1.805	0.182	-
Gender	0.564	0.454	-
Stature (covariate)	4.888	0.029	0.207

Note. $df_1 = 1$ and $df_2 = 109$.

Table 75

Mixed-Model ANCOVA for Effects of Hip Angle (A42), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A42 x Age x Gender x Stature	2.541	0.114	-
A42 x Age x Gender	2.515	0.116	-
A42 x Age x Stature	0.852	0.358	-
A42 x Gender x Stature	0.215	0.644	-
Age x Gender x Stature	0.233	0.630	-
A42 x Age	0.697	0.406	-
A42 x Gender	0.208	0.649	-
A42 x Stature	0.800	0.373	-
Age x Gender	0.236	0.628	-
Age x Stature	0.184	0.669	-
Gender x Stature	1.312	0.255	-
A42	0.818	0.368	-
Age	0.155	0.695	-
Gender	1.219	0.272	-
Stature (covariate)	1.088	0.299	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 76

Mixed-Model ANCOVA for Effects of Steering Wheel Angle (A18), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A18 x Age x Gender x Stature	0.180	0.672	-
A18 x Age x Gender	0.185	0.668	-
A18 x Age x Stature	1.697	0.195	-
A18 x Gender x Stature	0.839	0.362	-
Age x Gender x Stature	0.208	0.649	-
A18 x Age	1.593	0.210	-
A18 x Gender	0.822	0.367	-
A18 x Stature	8.351	0.005	0.267
Age x Gender	0.182	0.670	-
Age x Stature	0.000	0.999	-
Gender x Stature	0.394	0.532	-
A18	8.512	0.004	0.269
Age	0.018	0.893	-
Gender	0.491	0.485	-
Stature (covariate)	0.570	0.452	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 77

Mixed-Model ANCOVA for Effects of Vehicle Floor to Top of Steering Wheel (VF2SW), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
VF2SW x Age x Gender x Stature	0.746	0.390	-
VF2SW x Age x Gender	0.651	0.422	-
VF2SW x Age x Stature	0.048	0.826	-
VF2SW x Gender x Stature	0.089	0.766	-
Age x Gender x Stature	0.085	0.771	-
VF2SW x Age	0.014	0.907	-
VF2SW x Gender	0.074	0.787	-
VF2SW x Stature	0.105	0.746	-
Age x Gender	0.111	0.739	-
Age x Stature	0.431	0.513	-
Gender x Stature	1.037	0.311	-
VF2SW	0.059	0.808	-
Age	0.352	0.554	-
Gender	0.948	0.332	-
Stature (covariate)	0.074	0.787	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 78

Mixed-Model ANCOVA for Effects of Center of Steering Wheel to Sternum (Chest2SW), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Chest2SW x Age x Gender x Stature	0.082	0.776	-
Chest2SW x Age x Gender	0.019	0.889	-
Chest2SW x Age x Stature	13.577	0.000	0.333
Chest2SW x Gender x Stature	0.477	0.491	-
Age x Gender x Stature	1.159	0.284	-
Chest2SW x Age	12.996	0.000	0.326
Chest2SW x Gender	0.409	0.524	-
Chest2SW x Stature	3.709	0.057	0.181
Age x Gender	1.038	0.311	-
Age x Stature	0.285	0.594	-
Gender x Stature	1.791	0.180	-
Chest2SW	3.482	0.065	-
Age	0.157	0.693	-
Gender	2.017	0.158	-
Stature (covariate)	43.855	0.000	0.536

Note. $df_1 = 1$ and $df_2 = 109$.

Table 79

Mixed-Model ANCOVA for Effects of Backset, Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Backset x Age x Gender x Stature	0.209	0.648	-
Backset x Age x Gender	2.227	0.635	-
Backset x Age x Stature	1.152	0.286	-
Backset x Gender x Stature	0.075	0.785	-
Age x Gender x Stature	0.123	0.727	-
Backset x Age	1.141	0.288	-
Backset x Gender	0.137	0.712	-
Backset x Stature	2.024	0.158	-
Age x Gender	0.118	0.073	0.033
Age x Stature	0.315	0.576	-
Gender x Stature	0.796	0.374	-
Backset	2.264	0.135	-
Age	0.330	0.567	-
Gender	0.792	0.375	-
Stature (covariate)	4.062	0.046	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 80

Mixed-Model ANCOVA for Effects of Top of Head to Ceiling (Head), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Head x Age x Gender x Stature	0.181	0.672	-
Head x Age x Gender	0.188	0.666	-
Head x Age x Stature	0.273	0.603	-
Head x Gender x Stature	2.882	0.092	-
Age x Gender x Stature	2.916	0.091	-
Head x Age	0.221	0.640	-
Head x Gender	2.856	0.094	-
Head x Stature	0.003	0.954	-
Age x Gender	2.739	0.101	-
Age x Stature	0.055	0.815	-
Gender x Stature	1.986	0.162	-
Head	0.016	0.899	-
Age	0.890	0.766	-
Gender	2.245	0.137	-
Stature (covariate)	1.323	0.253	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 81

Mixed-Model ANCOVA for Effects of Top of Leg to Bottom of Steering Wheel (Leg2SW), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Leg2SW x Age x Gender x Stature	0.001	0.975	-
Leg2SW x Age x Gender	0.002	0.956	-
Leg2SW x Age x Stature	0.173	0.678	-
Leg2SW x Gender x Stature	0.880	0.350	-
Age x Gender x Stature	1.026	0.313	-
Leg2SW x Age	0.129	0.720	-
Leg2SW x Gender	0.754	0.387	-
Leg2SW x Stature	0.239	0.626	-
Age x Gender	0.822	0.367	-
Age x Stature	7.023	0.009	0.246
Gender x Stature	1.353	0.247	-
Leg2SW	0.217	0.642	-
Age	6.403	0.013	0.236
Gender	1.362	0.246	-
Stature (covariate)	10.361	0.002	0.295

Note. $df_1 = 1$ and $df_2 = 109$.

Table 82

Mixed-Model ANCOVA for Effects of Line of Sight above the Steering Wheel (LoS), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
LoS x Age x Gender x Stature	0.522	0.471	-
LoS x Age x Gender	0.526	0.470	-
LoS x Age x Stature	0.359	0.550	-
LoS x Gender x Stature	0.022	0.881	-
Age x Gender x Stature	2.104	0.150	-
LoS x Age	0.415	0.521	-
LoS x Gender	0.008	0.927	-
LoS x Stature	0.001	0.978	-
Age x Gender	2.106	0.150	-
Age x Stature	0.000	0.986	-
Gender x Stature	0.512	0.476	-
LoS	0.010	0.920	-
Age	0.020	0.888	-
Gender	0.735	0.393	-
Stature (covariate)	0.131	0.718	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 83

Mixed-Model ANCOVA for Effects of Vehicle Floor to Eye Level (VF2Eye), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
VF2Eye x Age x Gender x Stature	0.019	0.890	-
VF2Eye x Age x Gender	0.020	0.887	-
VF2Eye x Age x Stature	1.032	0.312	-
VF2Eye x Gender x Stature	0.325	0.570	-
Age x Gender x Stature	2.765	0.099	-
VF2Eye x Age	1.035	0.311	-
VF2Eye x Gender	0.268	0.606	-
VF2Eye x Stature	2.271	0.135	-
Age x Gender	2.705	0.103	-
Age x Stature	0.012	0.913	-
Gender x Stature	0.023	0.880	-
VF2Eye	2.085	0.152	-
Age	0.001	0.988	-
Gender	0.105	0.747	-
Stature (covariate)	0.069	0.793	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 84

Mixed-Model ANCOVA for Effects of Top of Steering Wheel to Eye Level (SW2Eye), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
SW2Eye x Age x Gender x Stature	0.470	0.495	-
SW2Eye x Age x Gender	0.423	0.517	-
SW2Eye x Age x Stature	0.519	0.473	-
SW2Eye x Gender x Stature	0.084	0.773	-
Age x Gender x Stature	3.079	0.082	-
SW2Eye x Age	0.623	0.432	-
SW2Eye x Gender	0.069	0.794	-
SW2Eye x Stature	1.145	0.287	-
Age x Gender	2.870	0.093	-
Age x Stature	0.537	0.465	-
Gender x Stature	1.242	0.268	-
SW2Eye	1.144	0.287	-
Age	0.099	0.568	-
Gender	1.648	0.202	-
Stature (covariate)	0.323	0.571	-

Note. $df_1 = 1$ and $df_2 = 109$.

Table 85

Mixed-Model ANCOVA for Effects of Deviation between the SAE J4004 Model and the Improved Model from the Measured BoFRP to the H-point, Age, Gender and Their Interactions

Factor	*F*	*p*-value	*R*
Deviation x Age x Stature	0.069	0.794	-
Deviation x Age	0.175	0.677	-
Deviation x Stature	30.096	0.000	0.459
Age x Stature	0.147	0.702	-
Deviation	27.899	0.000	0.445
Age	0.174	0.678	-
Stature (covariate)	0.909	0.342	-

Note. For all tests, $df_1 = 1$ and $df_2 = 113$.

D.2 Full Factorial Mixed-Model ANCOVA Tables

Table 86

Mixed-Model ANCOVA for Effects of Seat Back Angle (A40), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A40 x Age x Gender	0.964	0.328	-
A40 x Age	0.358	0.551	-
A40 x Gender	0.424	0.516	-
A40 x Stature	0.047	0.829	-
Age x Gender	0.002	0.962	-
A40	0.080	0.777	-
Age	0.956	0.330	-
Gender	1.868	0.174	-
Stature (covariate)	3.331	0.071	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 87

Mixed-Model ANCOVA for Effects of Hip Angle (A42), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
A42 x Age x Gender	1.015	0.316	-
A42 x Stature	0.085	0.772	-
A42 x Age	0.408	0.524	-
A42 x Gender	0.022	0.883	-
Age x Gender	0.139	0.71	-
A42	0.105	0.747	-
Age	0.174	0.677	-
Gender	0.368	0.545	-
Stature (covariate)	1.202	0.275	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 88

Mixed-Model ANCOVA for Effects of Vehicle Floor to Top of Steering Wheel (VF2SW), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
VF2SW x Age x Gender	1.448	0.231	-
VF2SW x Age	3.548	0.062	-
VF2SW x Gender	0.280	0.598	-
VF2SW x Stature	0.031	0.860	-
Age x Gender	0.582	0.447	-
VF2SW	0.008	0.930	-
Age	3.801	0.054	0.181
Gender	0.250	0.618	-
Stature (covariate)	0.001	0.977	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 89

Mixed-Model ANCOVA for Effects of Backset, Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Backset x Age x Gender	0.319	0.573	-
Backset x Age	0.256	0.614	-
Backset x Gender	2.219	0.139	-
Backset x Stature	1.002	0.319	-
Age x Gender	0.504	0.479	-
Backset	1.200	0.276	-
Age	0.623	0.432	-
Gender	0.037	0.849	-
Stature (covariate)	3.753	0.055	0.180

Note. $df_1 = 1$ and $df_2 = 112$.

Table 90

Mixed-Model ANCOVA for Effects of Top of Head to Ceiling (Head), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
Head x Age x Gender	0.217	0.642	-
Head x Stature	0.076	0.784	-
Head x Age	0.893	0.347	-
Head x Gender	0.037	0.847	-
Age x Gender	2.607	0.109	-
Head	0.082	0.776	-
Age	0.000	1.000	-
Gender	2.869	0.093	-
Stature (covariate)	2.580	0.111	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 91

Mixed-Model ANCOVA for Effects of Line of Sight above the Steering Wheel (LoS), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
LoS x Age x Gender	0.127	0.722	-
LoS x Age	0.267	0.606	-
LoS x Gender	0.698	0.405	-
LoS x Stature	0.142	0.707	-
Age x Gender	0.031	0.860	-
LoS	0.045	0.833	-
Age	3.376	0.069	-
Gender	8.212	0.005	0.261
Stature (covariate)	0.152	0.697	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 92

Mixed-Model ANCOVA for Effects of Vehicle Floor to Eye Level (VF2Eye), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
VF2Eye x Age x Gender	0.676	0.413	-
VF2Eye x Age	0.000	0.983	-
VF2Eye x Gender	0.315	0.576	-
VF2Eye x Stature	1.516	0.221	-
Age x Gender	0.001	0.980	-
VF2Eye	1.402	0.239	-
Age	0.286	0.594	-
Gender	12.027	0.001	0.311
Stature (covariate)	0.004	0.952	-

Note. $df_1 = 1$ and $df_2 = 112$.

Table 93

Mixed-Model ANCOVA for Effects of Top of Steering Wheel to Eye Level (SW2Eye), Age, Gender and Their Interactions

Factor	*F*	*p*-value	*r*
SW2Eye x Age x Gender	2.212	0.140	-
SW2Eye x Age	1.474	0.227	-
SW2Eye x Gender	0.017	0.896	-
SW2Eye x Stature	0.869	0.353	-
Age x Gender	0.524	0.471	-
SW2Eye	0.903	0.344	-
Age	5.871	0.017	0.223
Gender	14.165	0.000	0.335
Stature (covariate)	0.010	0.921	-

Note. $df_1 = 1$ and $df_2 = 112$.

APPENDIX E

FIGURES USED TO INSPECT LINEAR MODEL ASSUMPTIONS

E.1 Q-Q Plots

The following Q-Q plots for this section were used to assess the normality of the measurements collected. These plots show the quartiles of the measured variable on the x-axis against the expected quartiles of normal distribution on the y-axis. The solid line in each plot represents a normal distribution. Therefore, if the plotted quartiles fall on the solid line, then the collected measurements are represented by a normal distribution. Conversely, deviation from the line shows a deviation from the distribution.

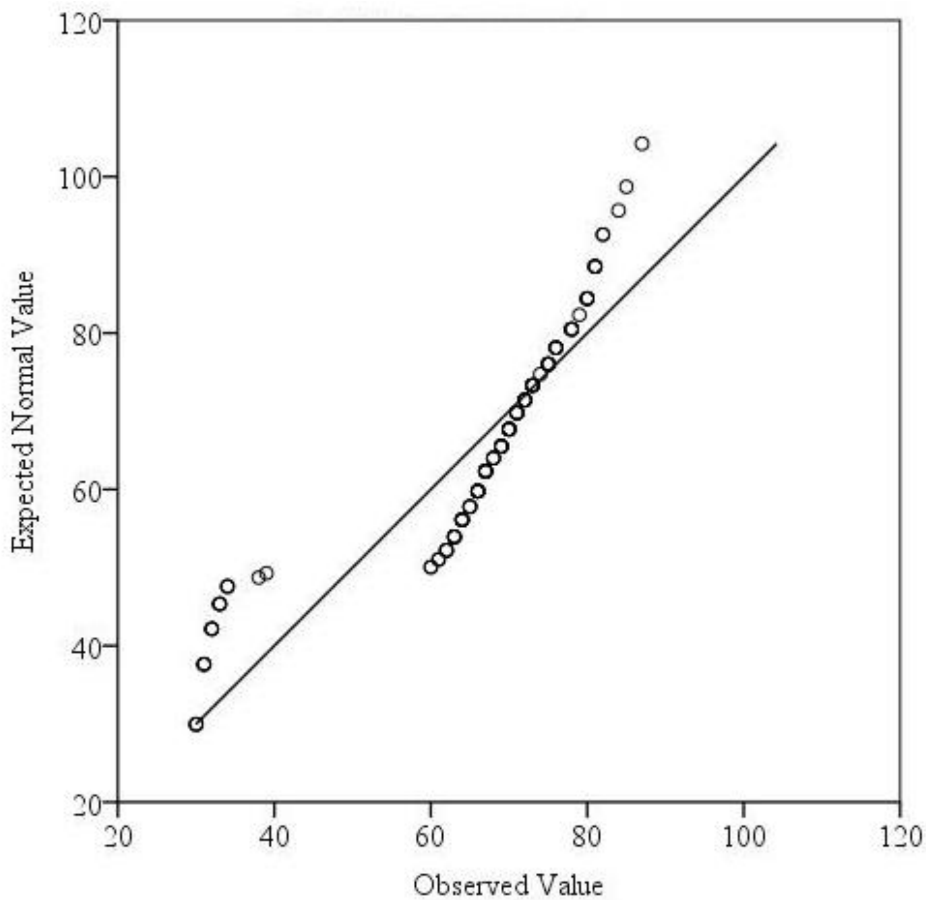


Figure 93. Normal Q-Q plot of the participant's age in years.

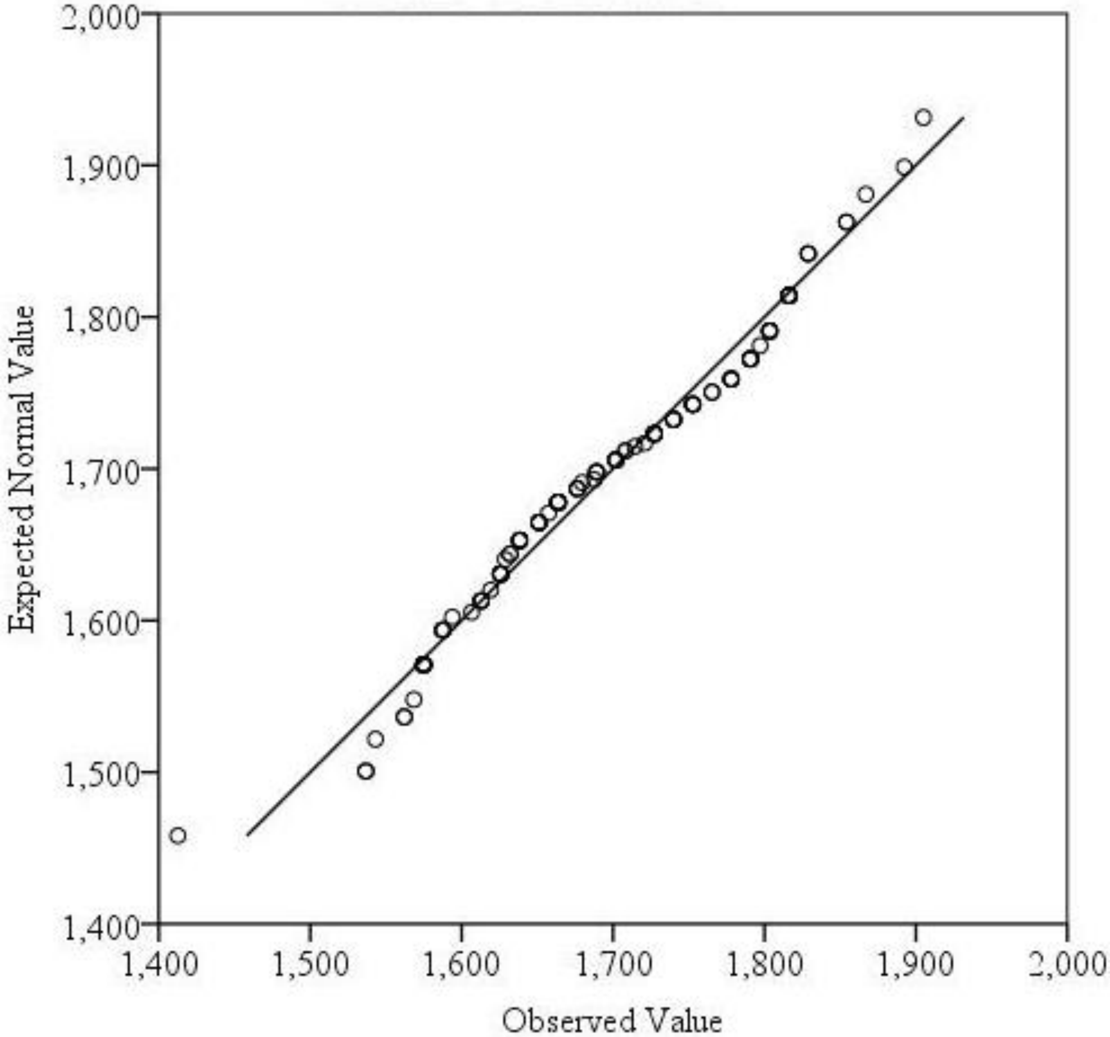


Figure 94. Normal Q-Q plot of participant's stature in millimeters.

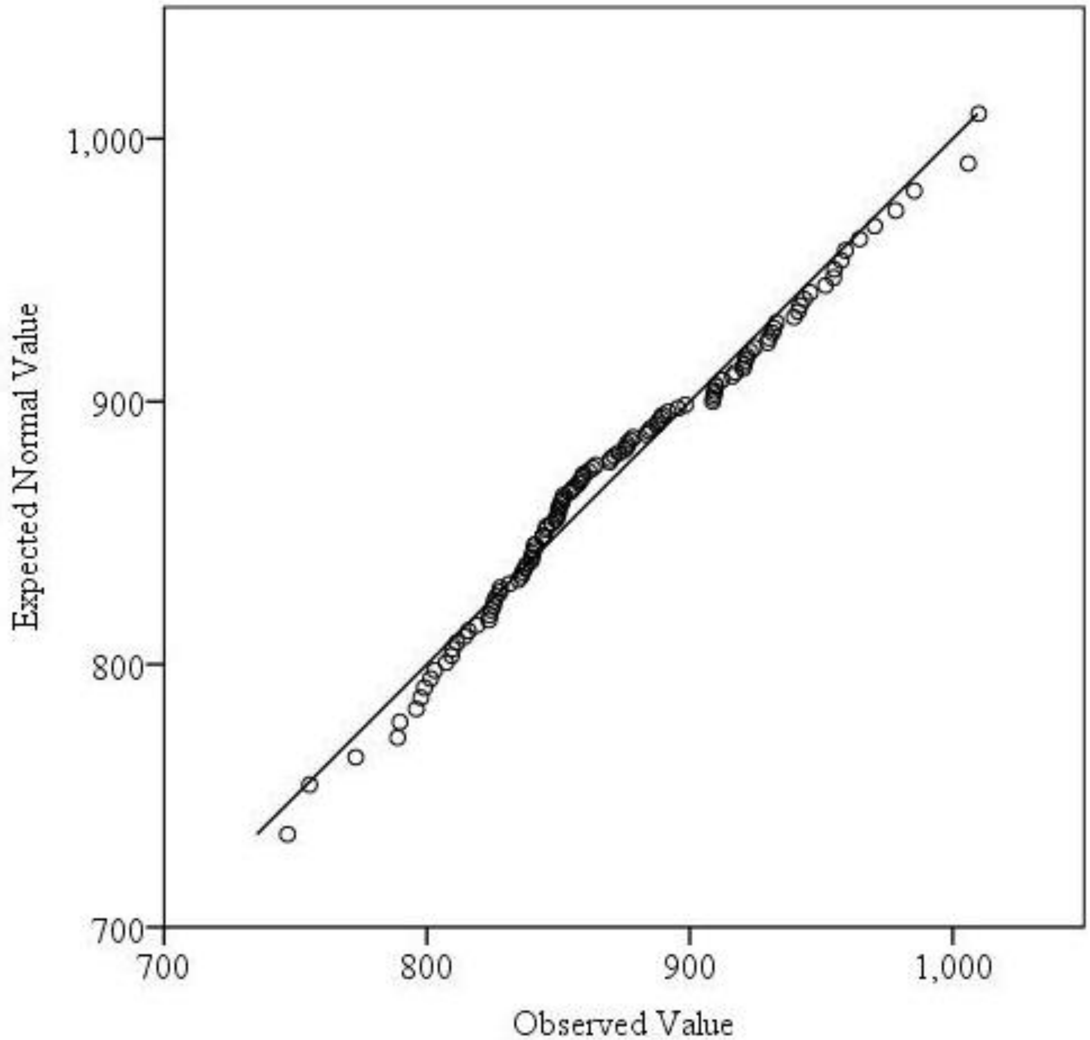


Figure 95. Normal Q-Q plot of the initial measured BoFRP to H-point in millimeters.

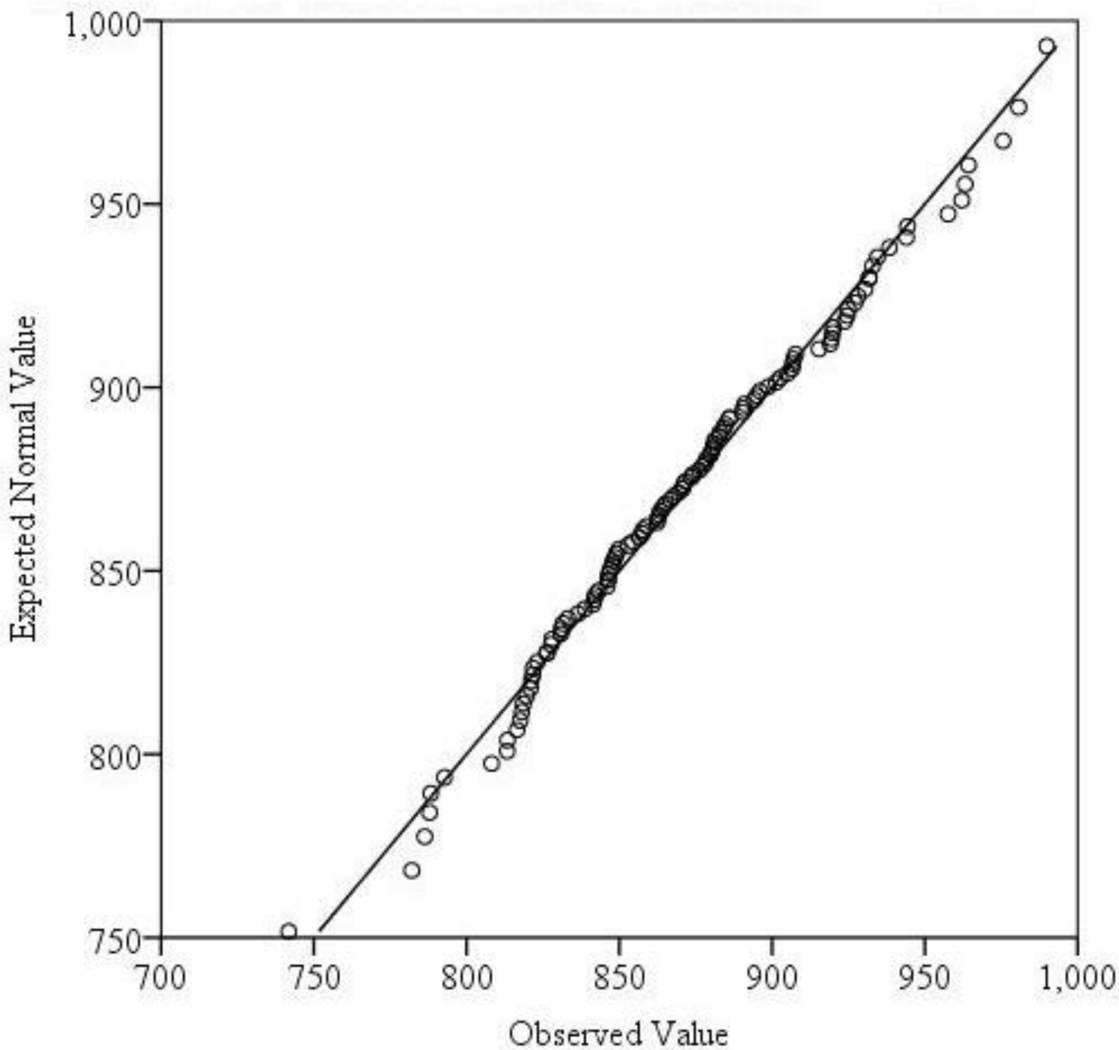


Figure 96. Normal Q-Q plot of the final measured BoFRP to H-point in millimeters.

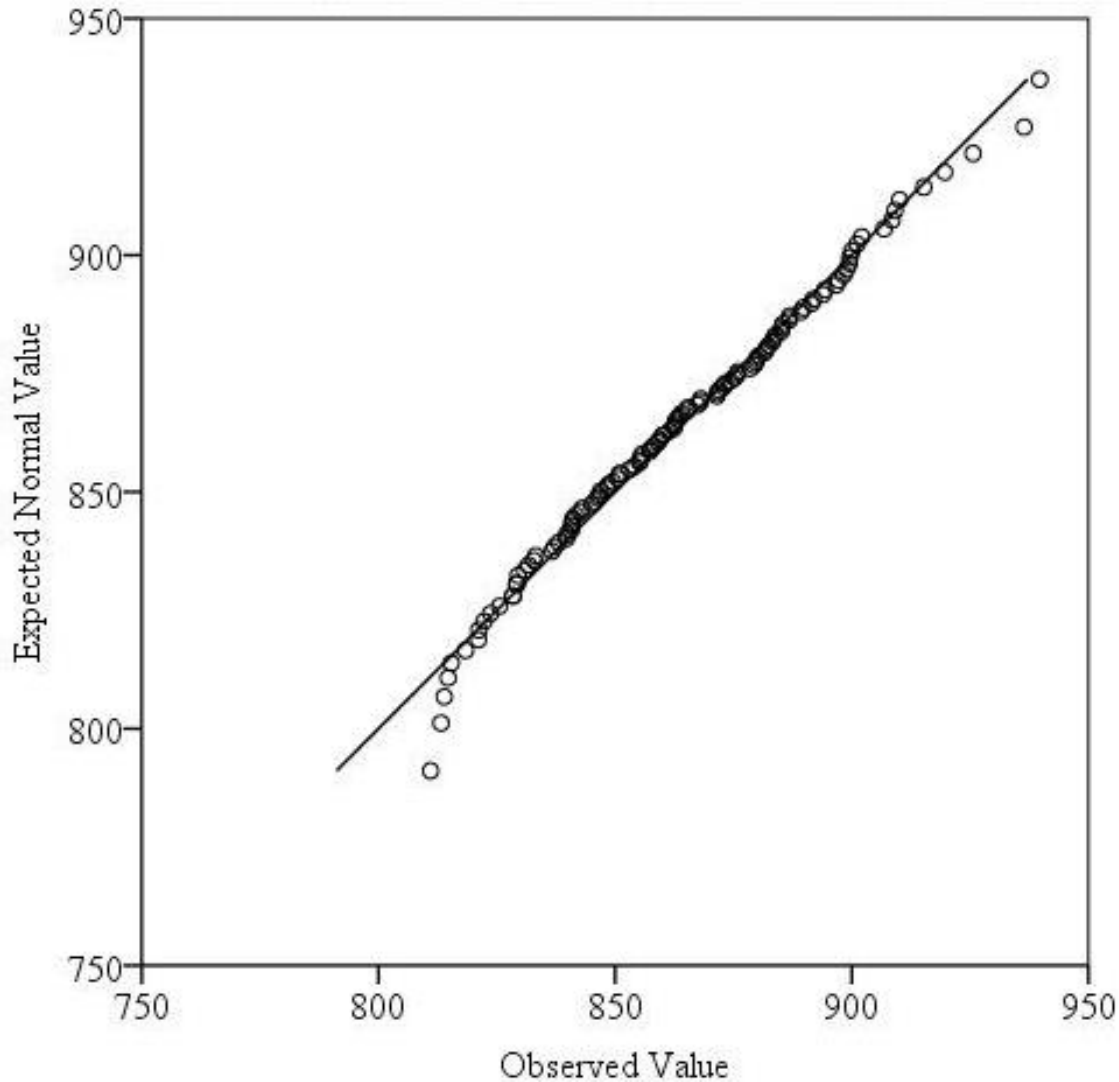


Figure 97. Normal Q-Q plot of the initial calculated BoFRP to H-point in millimeters.

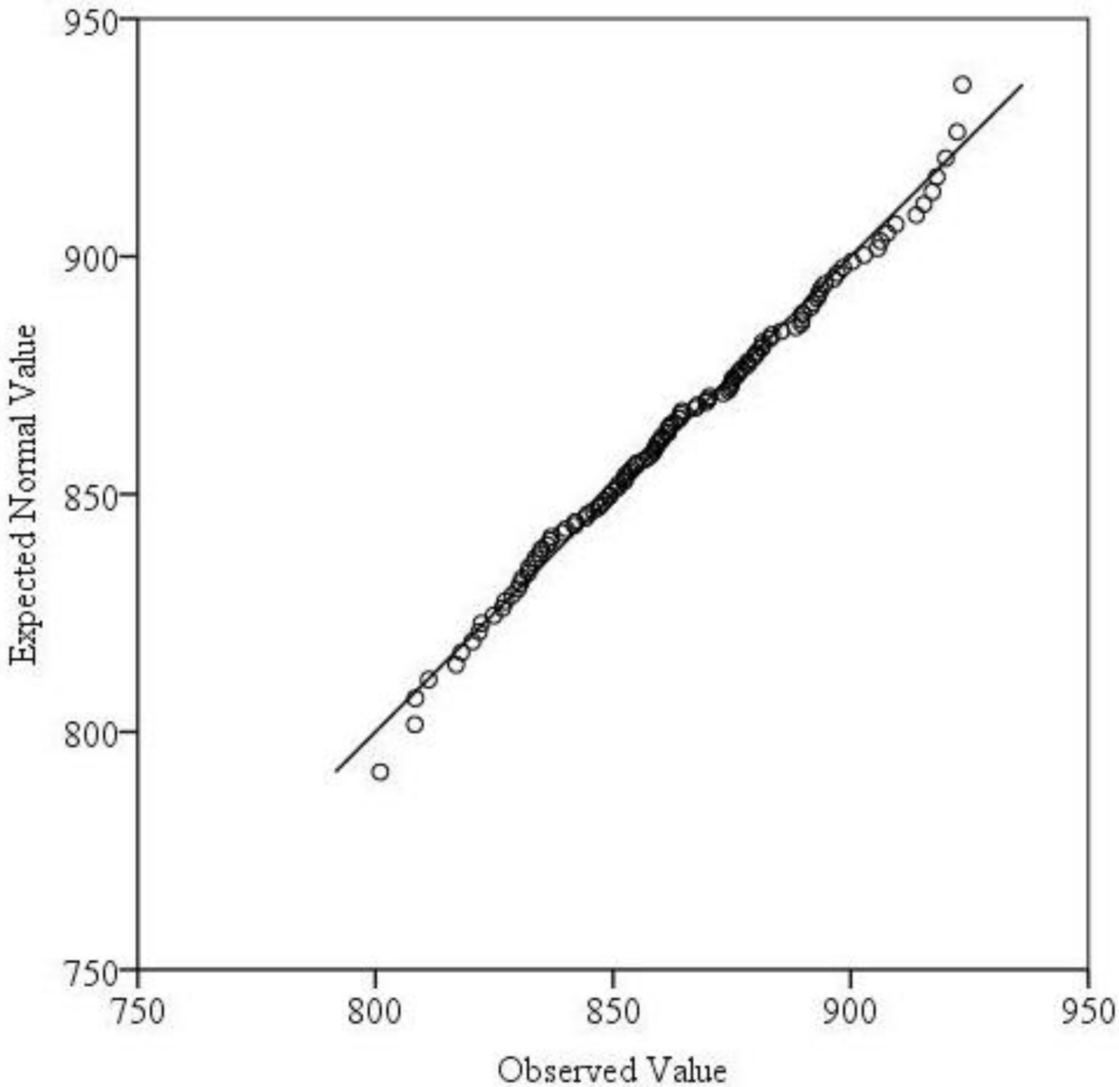


Figure 98. Normal Q-Q plot of the final calculated BoFRP to H-point in millimeters.

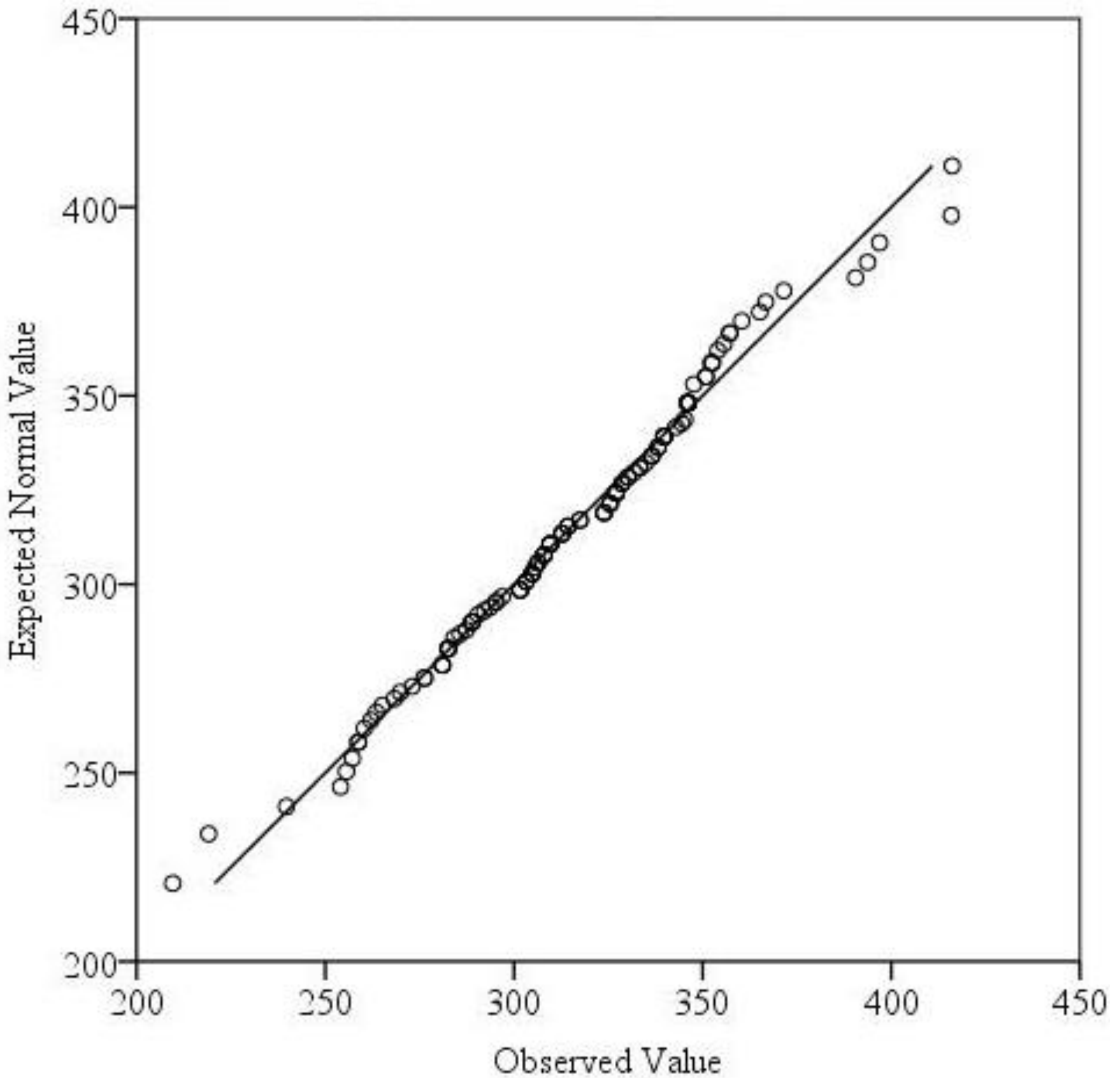


Figure 99. Normal Q-Q plot of the initial vehicle floor to H-point in millimeters.

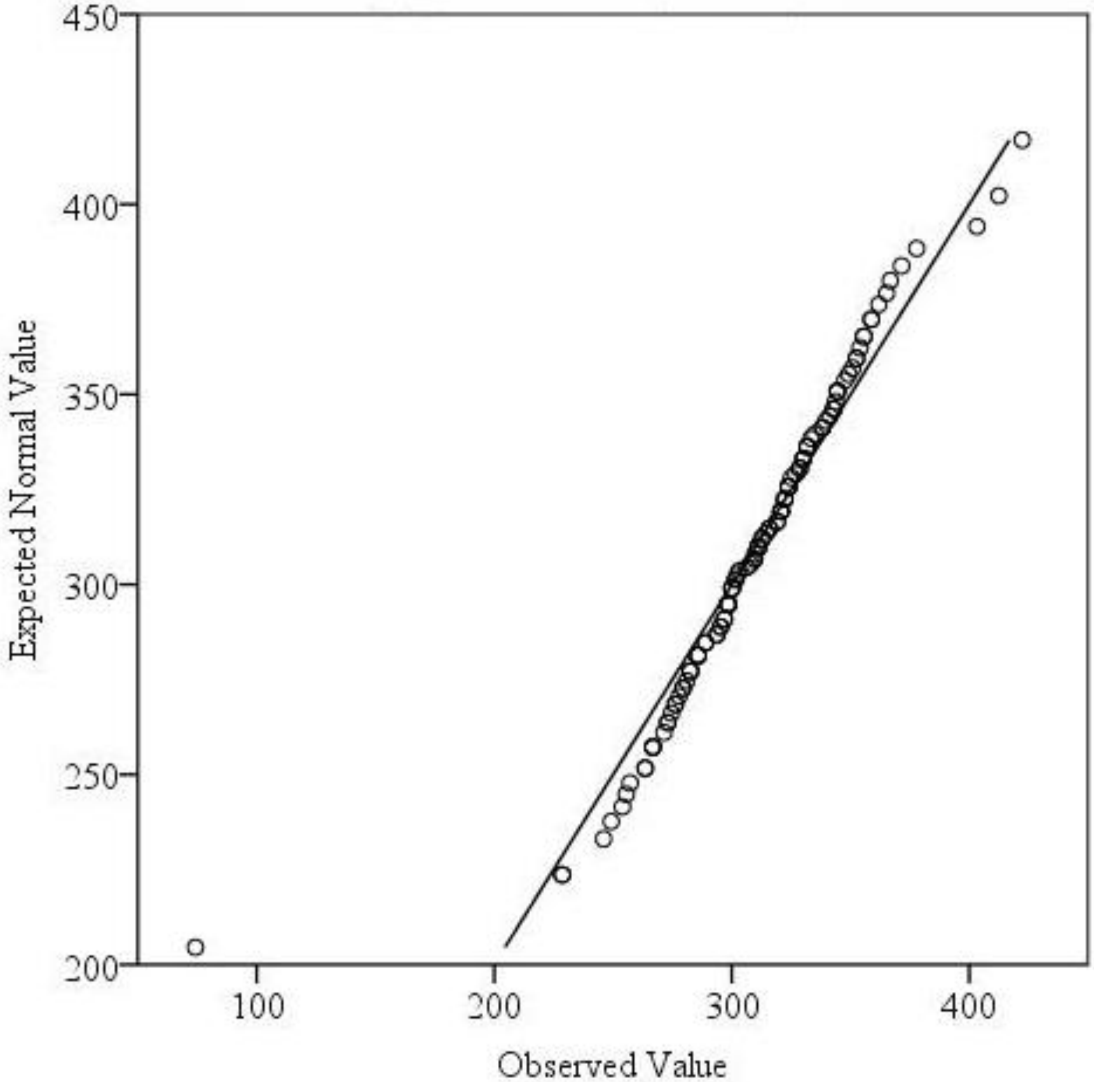


Figure 100. Normal Q-Q plot of the final vehicle floor to H-point in millimeters.

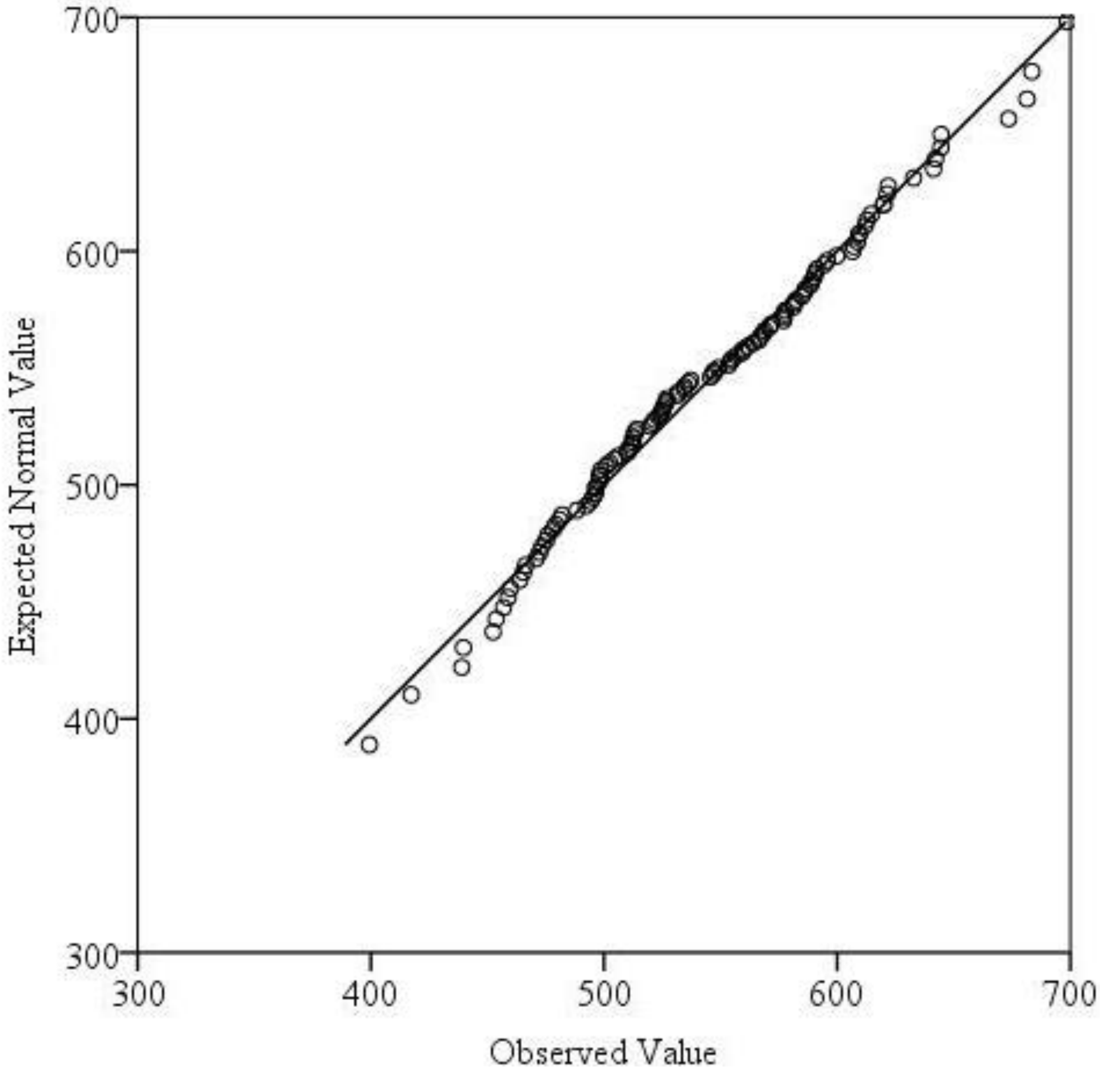


Figure 101. Normal Q-Q plot of the initial BoFRP to steering wheel center in millimeters.

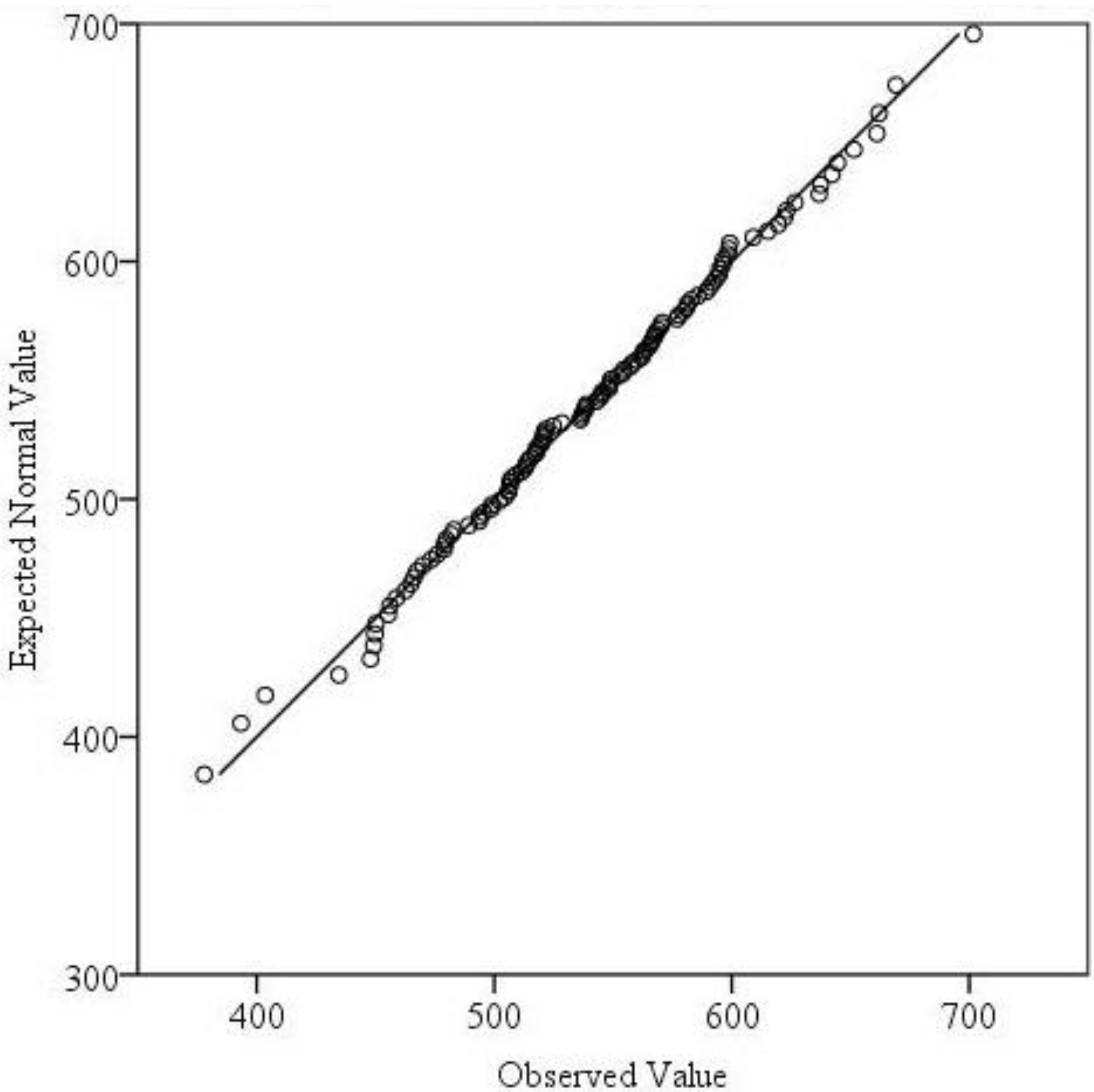


Figure 102. Normal Q-Q plot of the final BoFRP to steering wheel center in millimeters.

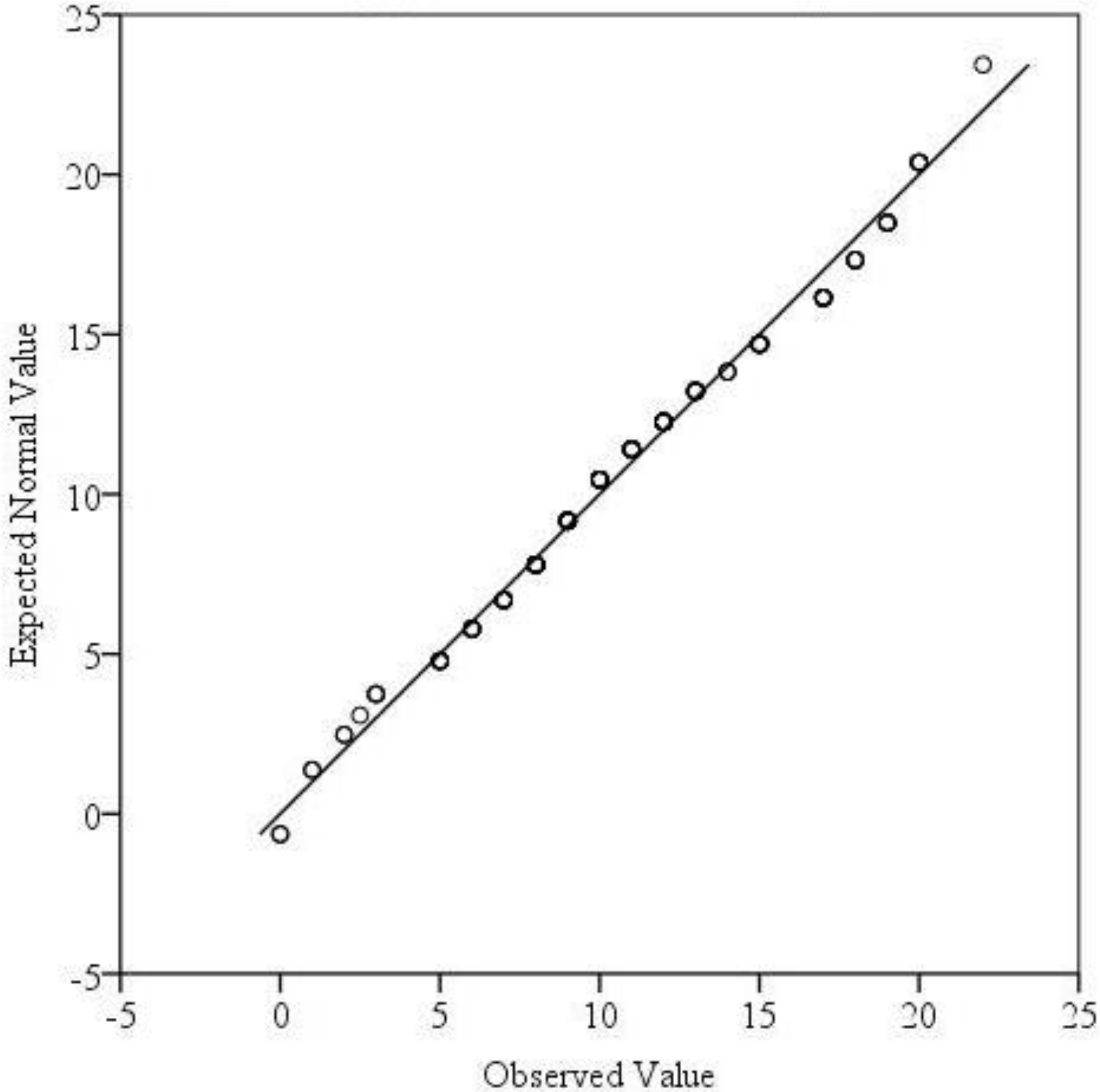


Figure 103. Normal Q-Q plot of theinitial seat base angle in degrees.

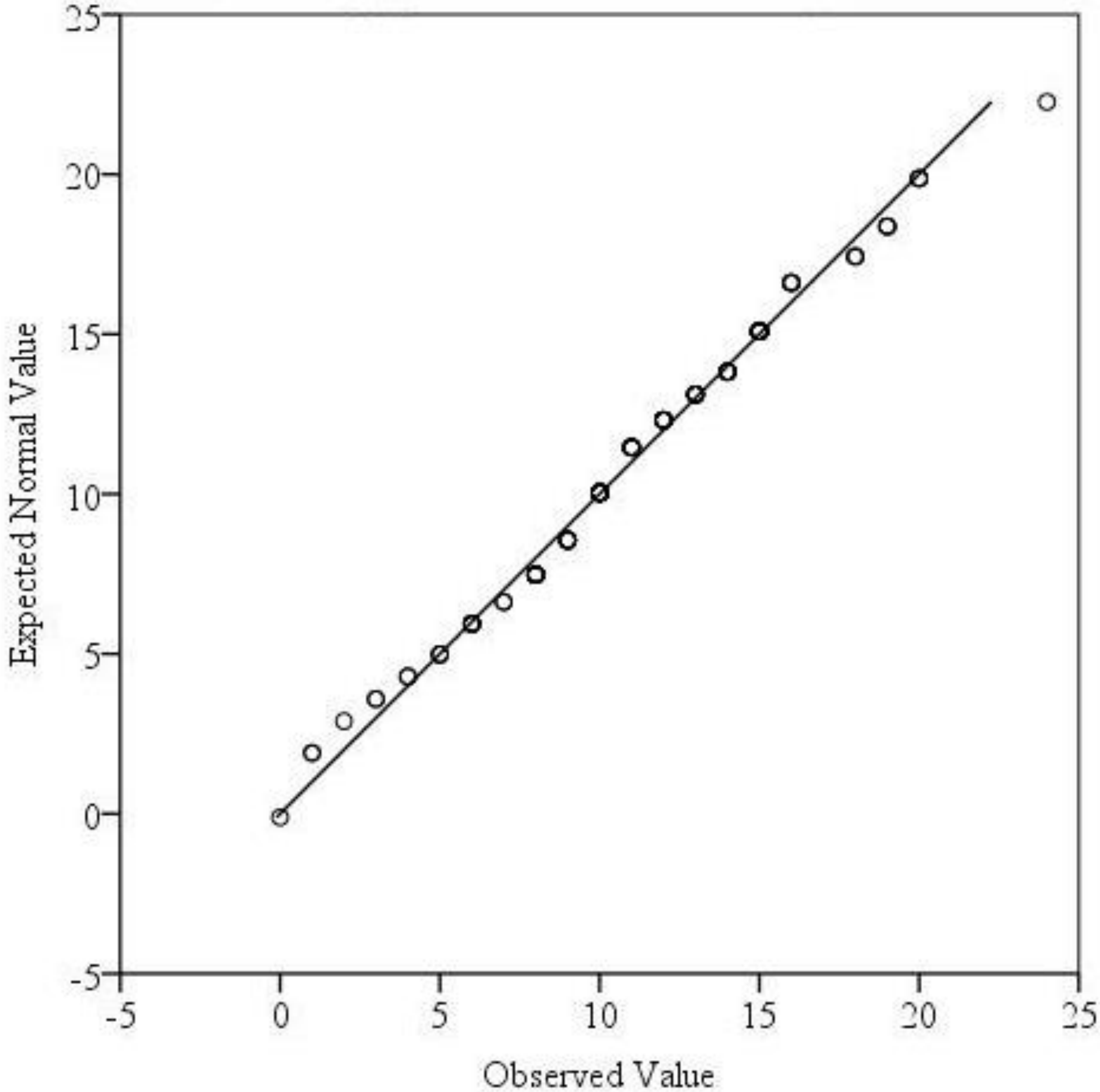


Figure 104. Normal Q-Q plot of the final seat base angle in degrees.

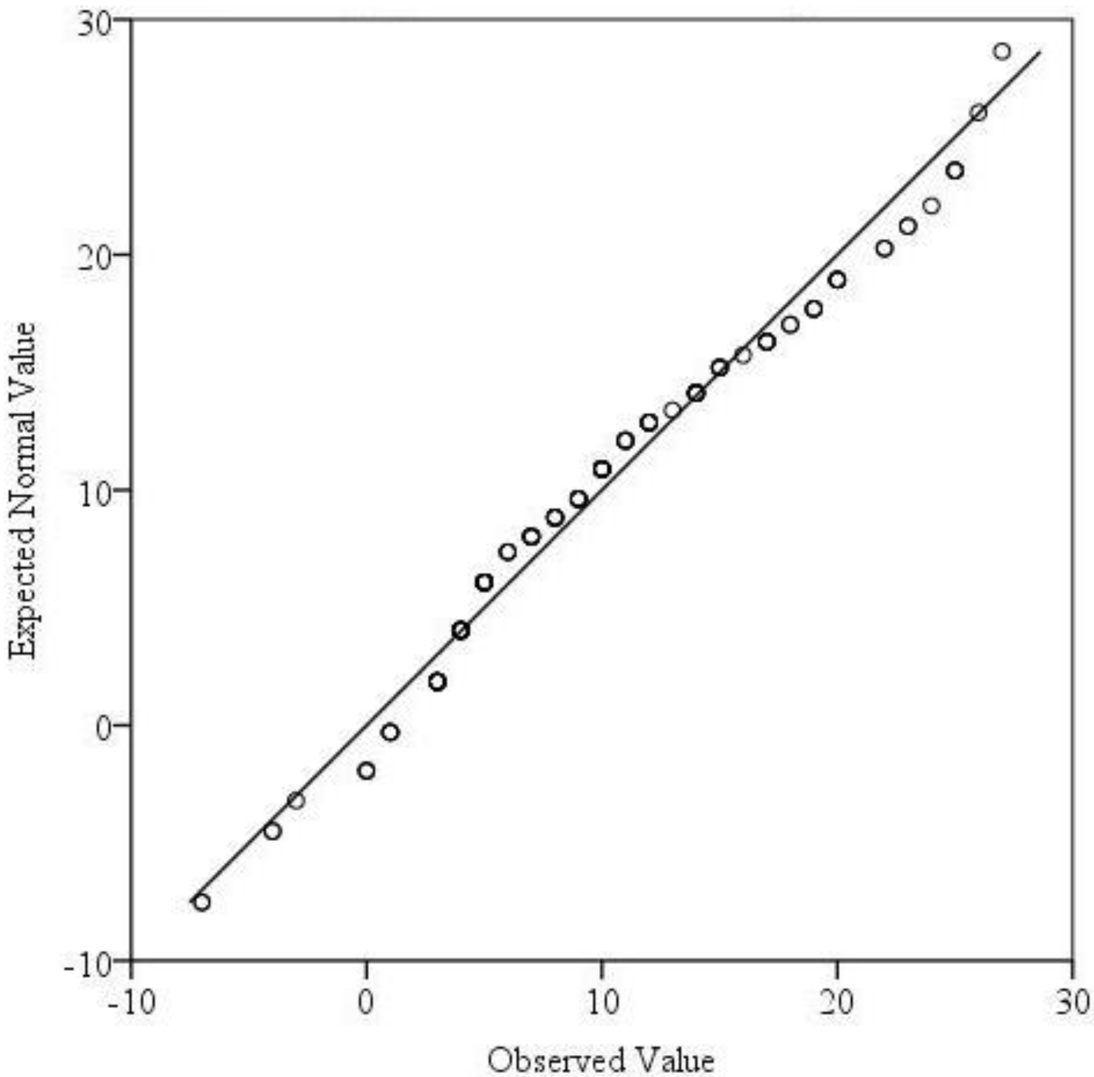


Figure 105. Normal Q-Q plot of the initial seat back angle in degrees.

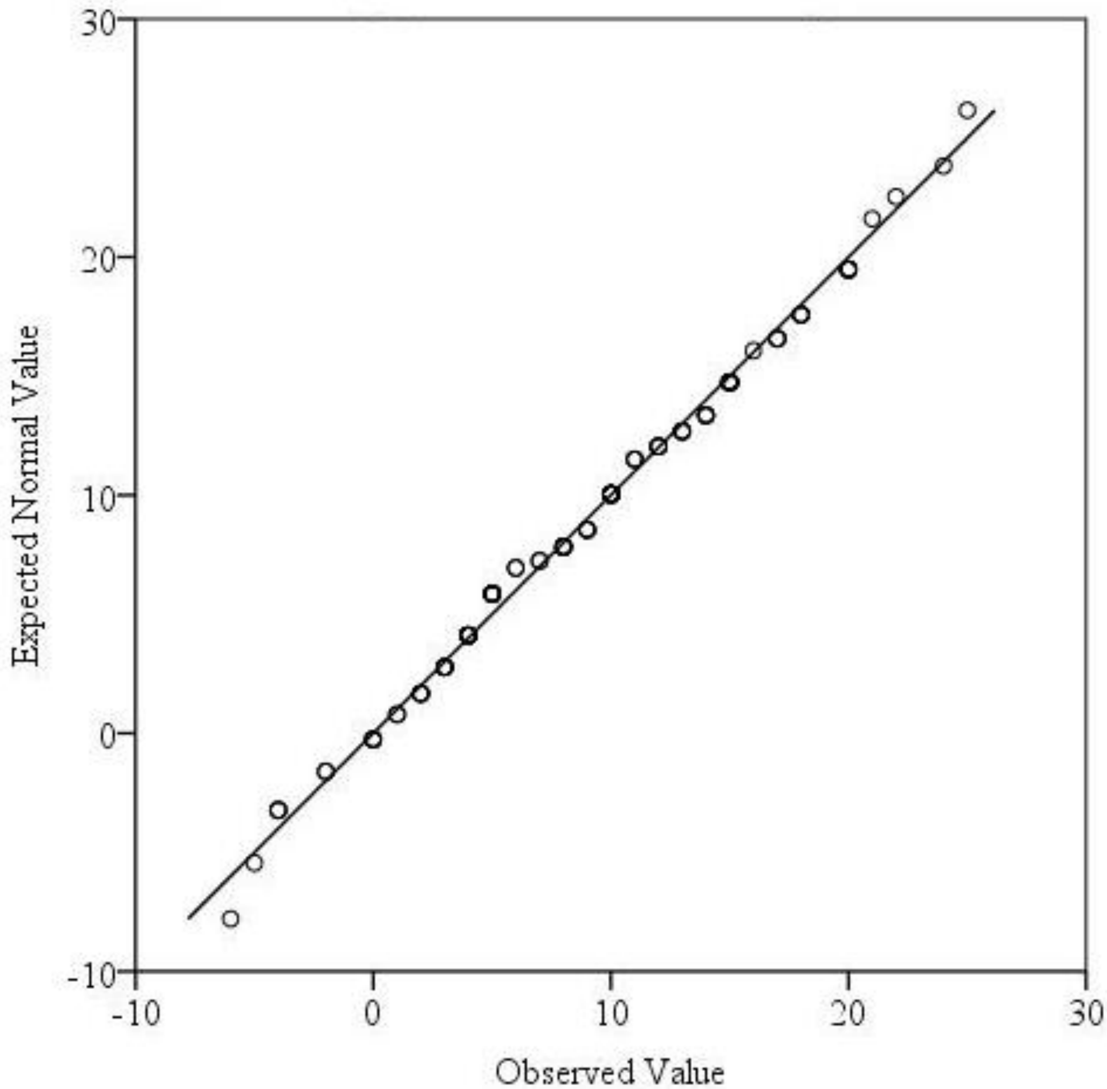


Figure 106. Normal Q-Q plot of the final seat back angle in degrees.

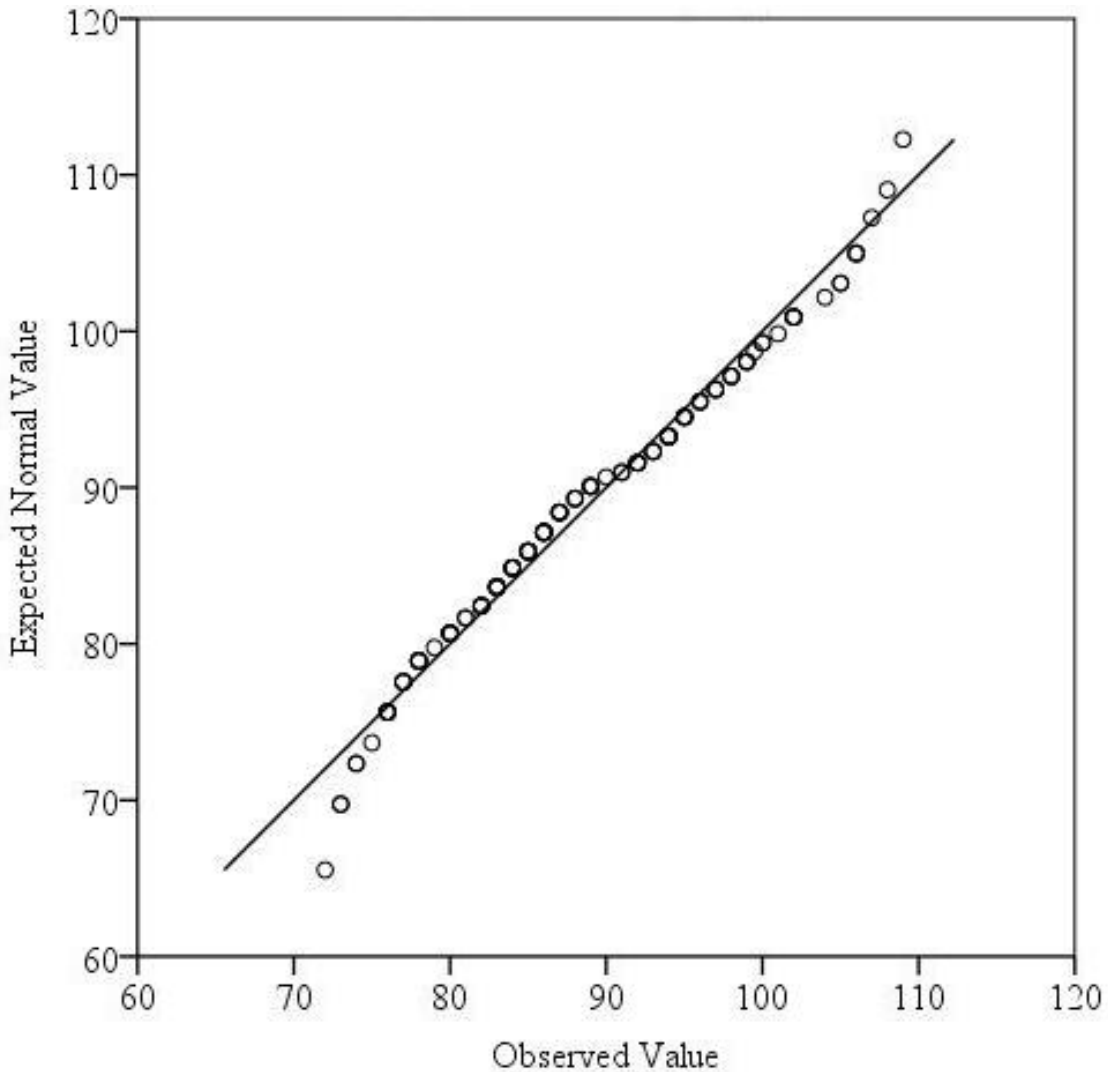


Figure 107. Normal Q-Q plot of the initial hip angle in degrees.

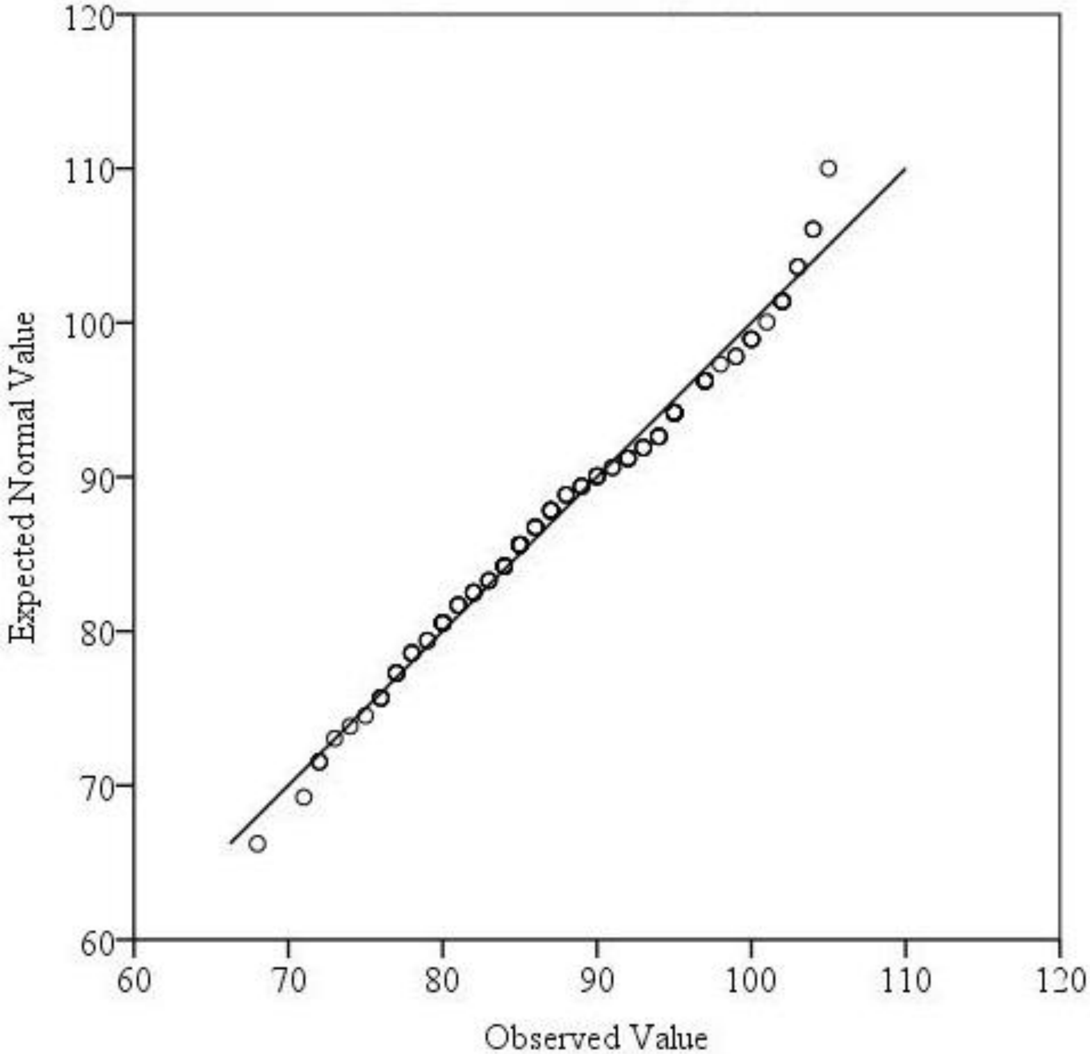


Figure 108. Normal Q-Q plot of the final hip angle in degrees.

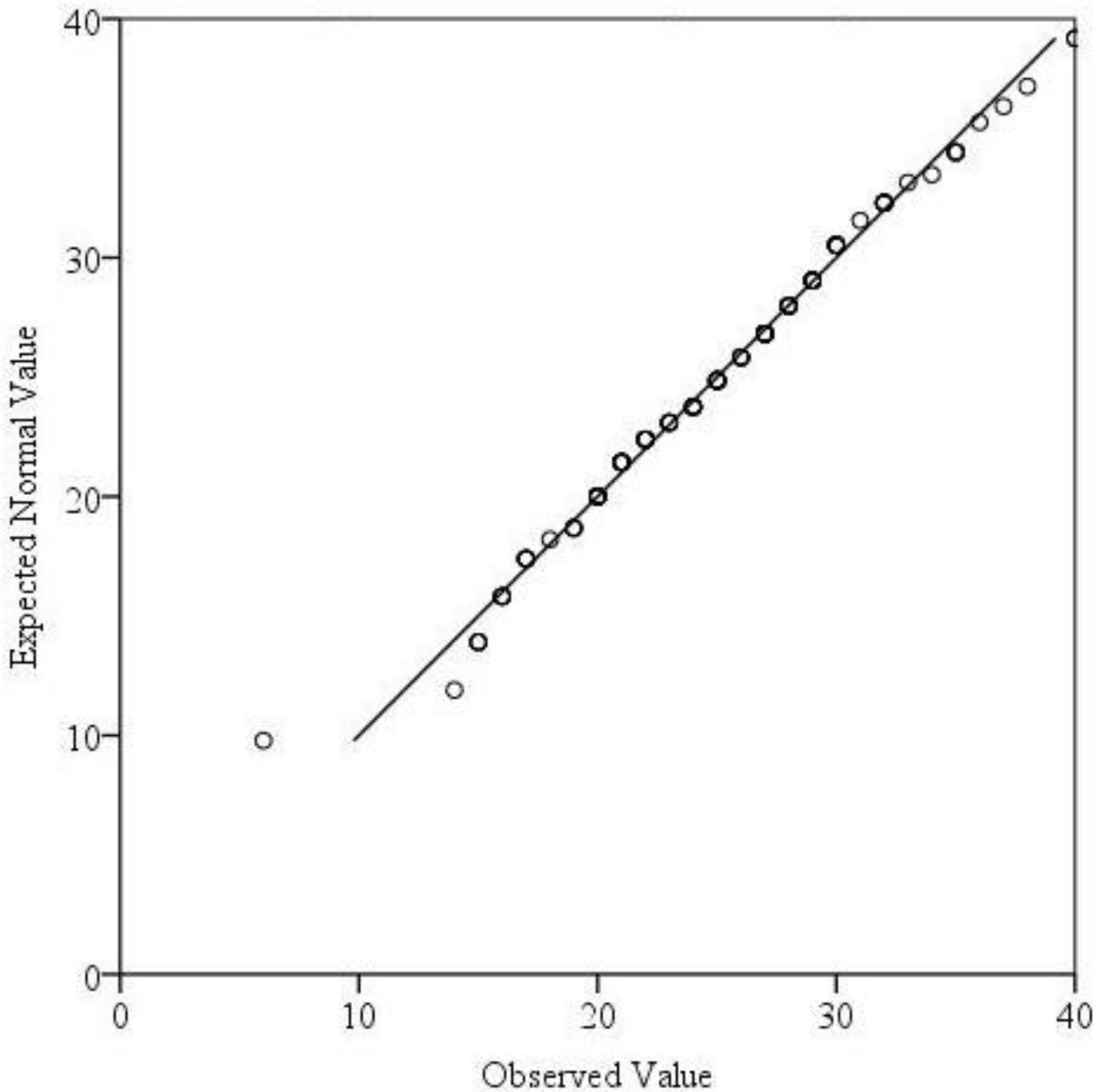


Figure 109. Normal Q-Q plot of the initial steering wheel angle in degrees.

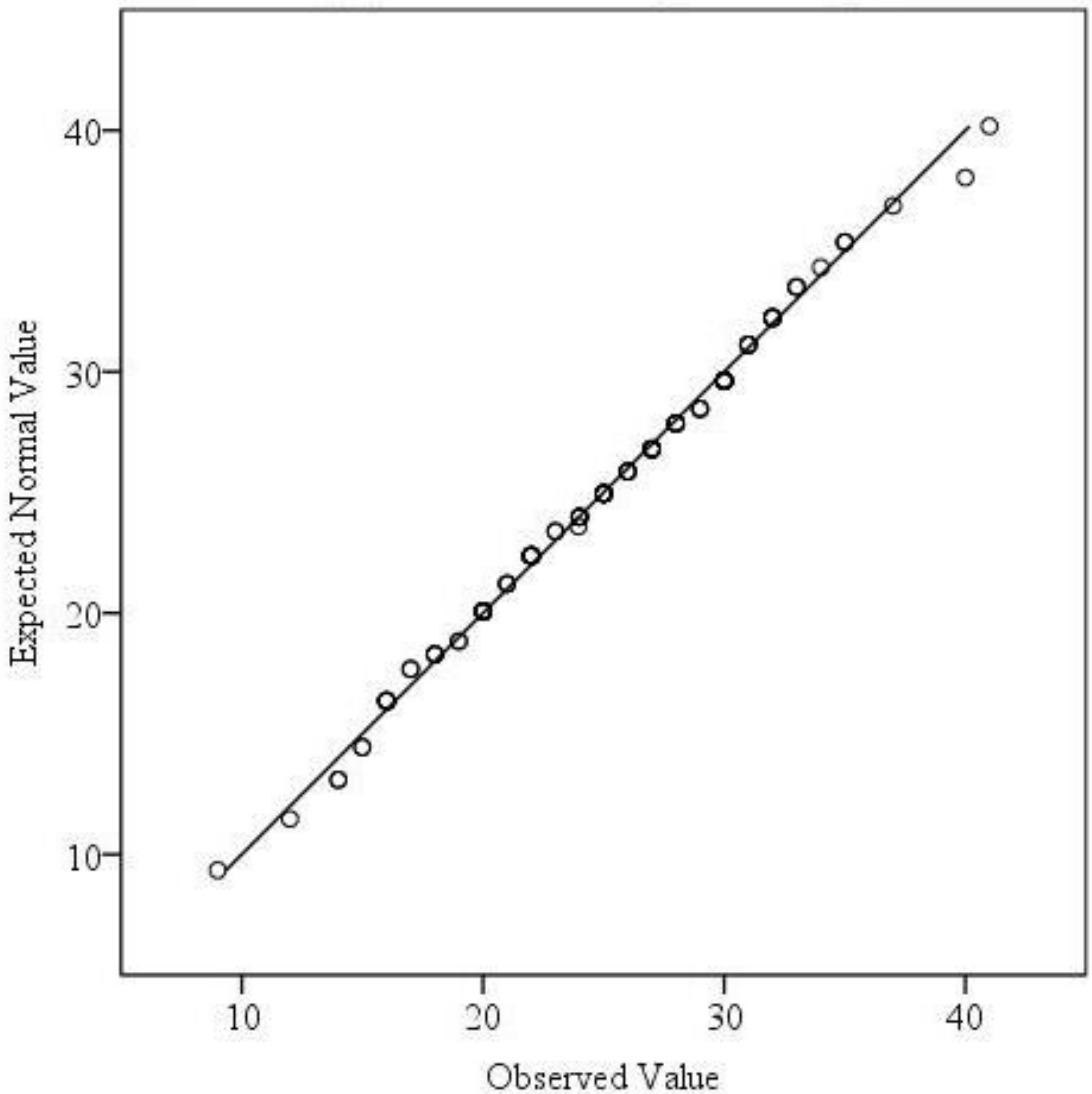


Figure 110. Normal Q-Q plot of the final steering wheel angle I degrees.

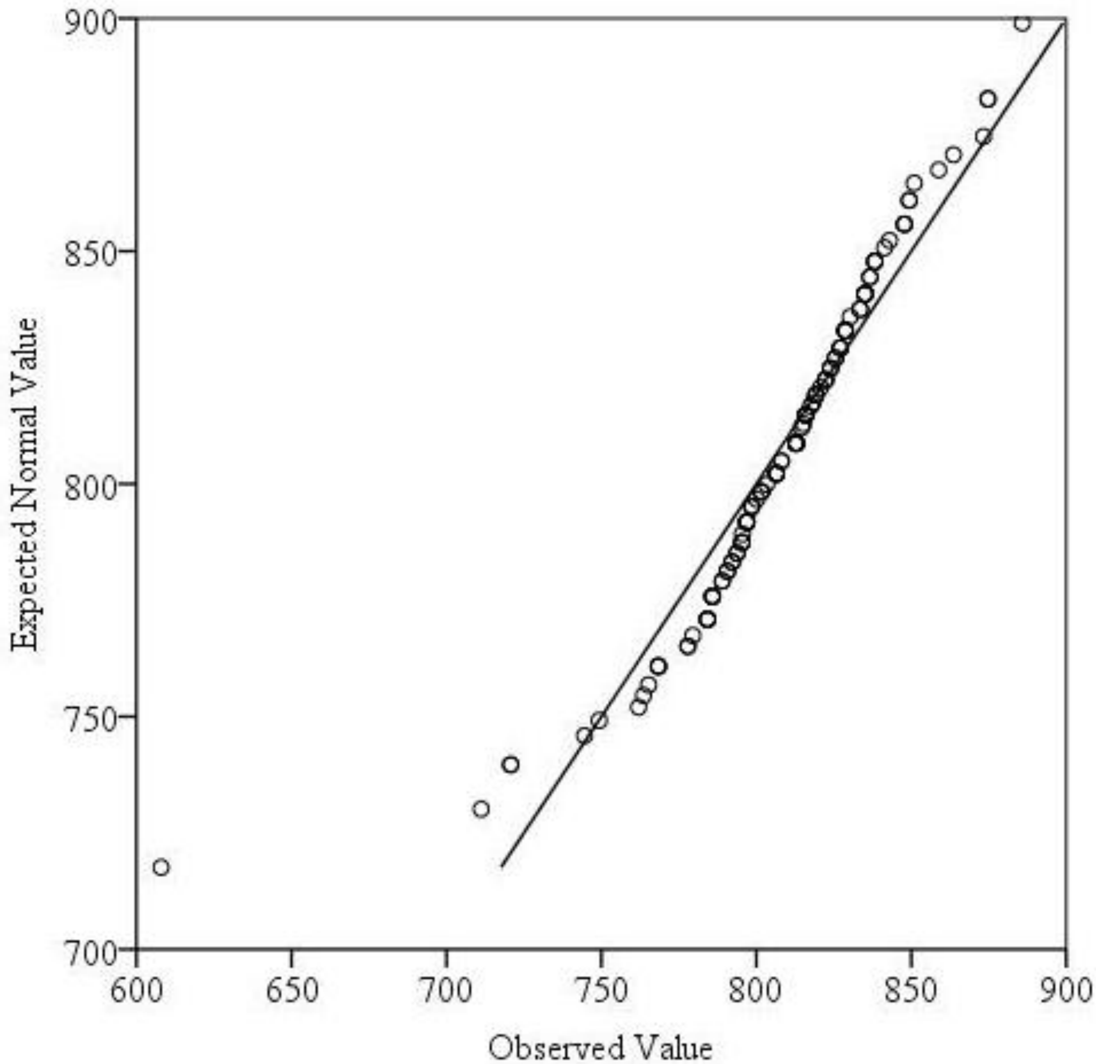


Figure 111. Normal Q-Q plot of the initial vehicle floor to top of steering wheel.

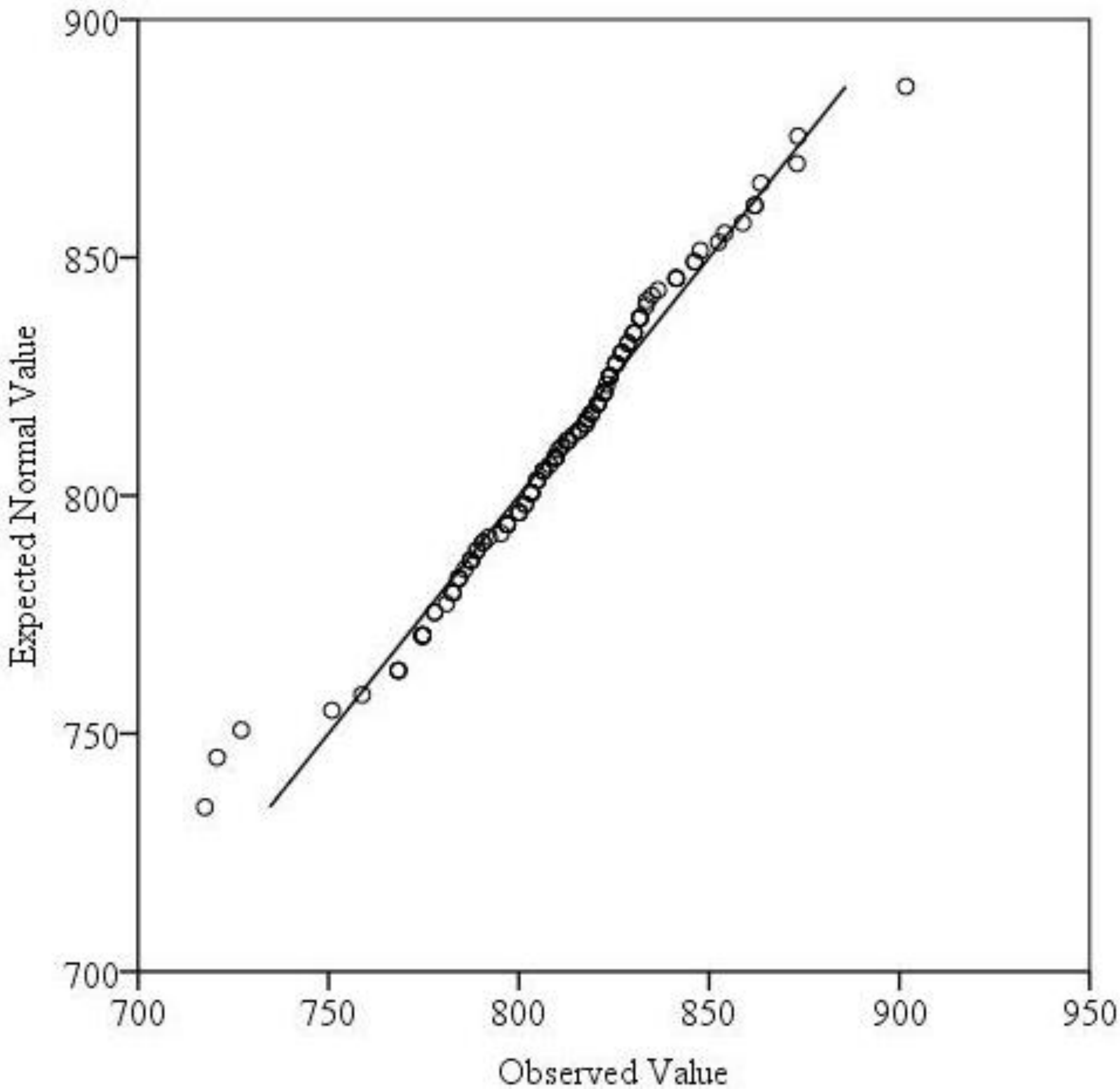


Figure 112. Normal Q-Q plot of final vehicle floor to top of steering wheel in millimeters.

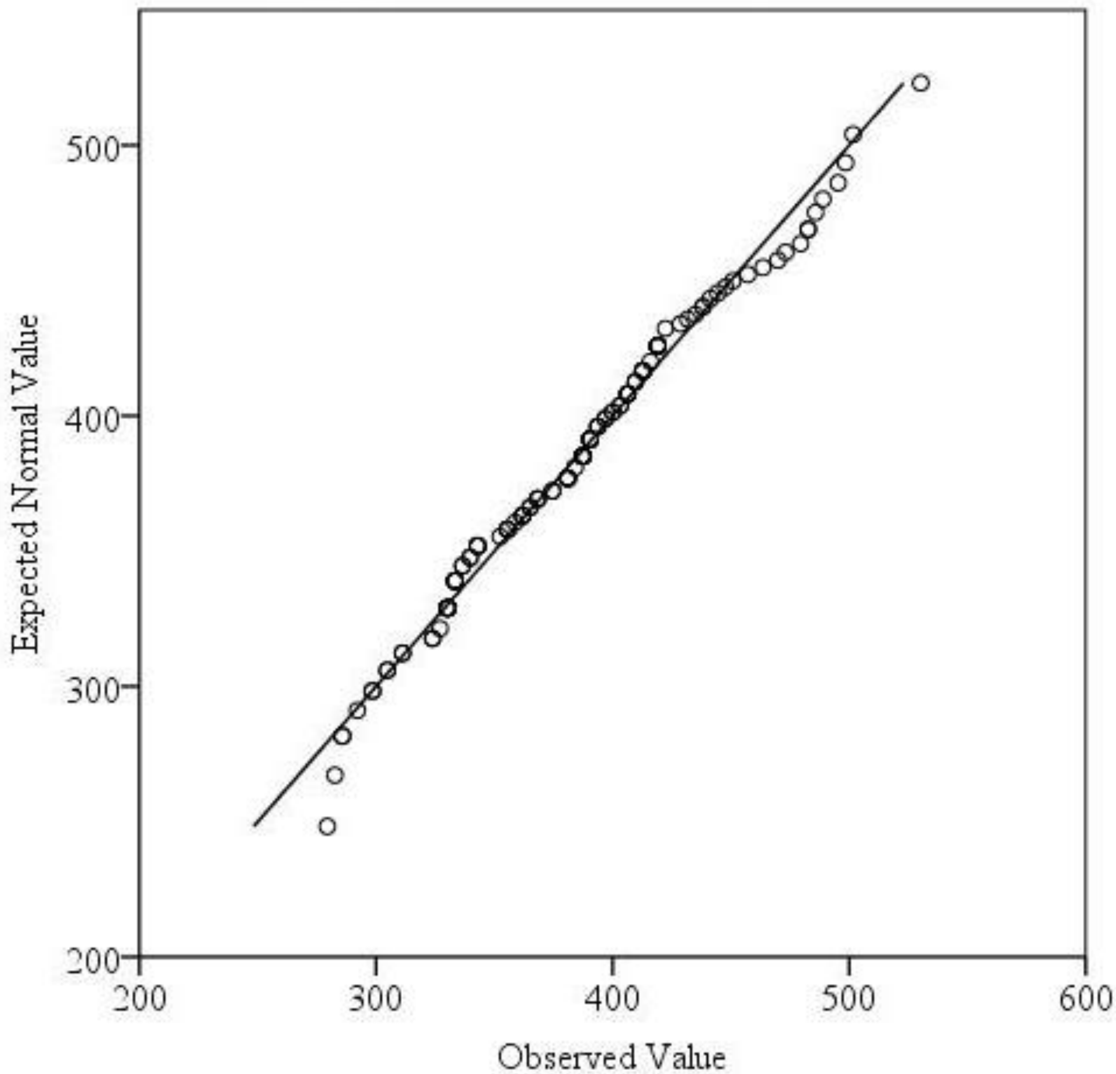


Figure 113. Normal Q-Q plot of the initial center of steering wheel to sternum in millimeters.

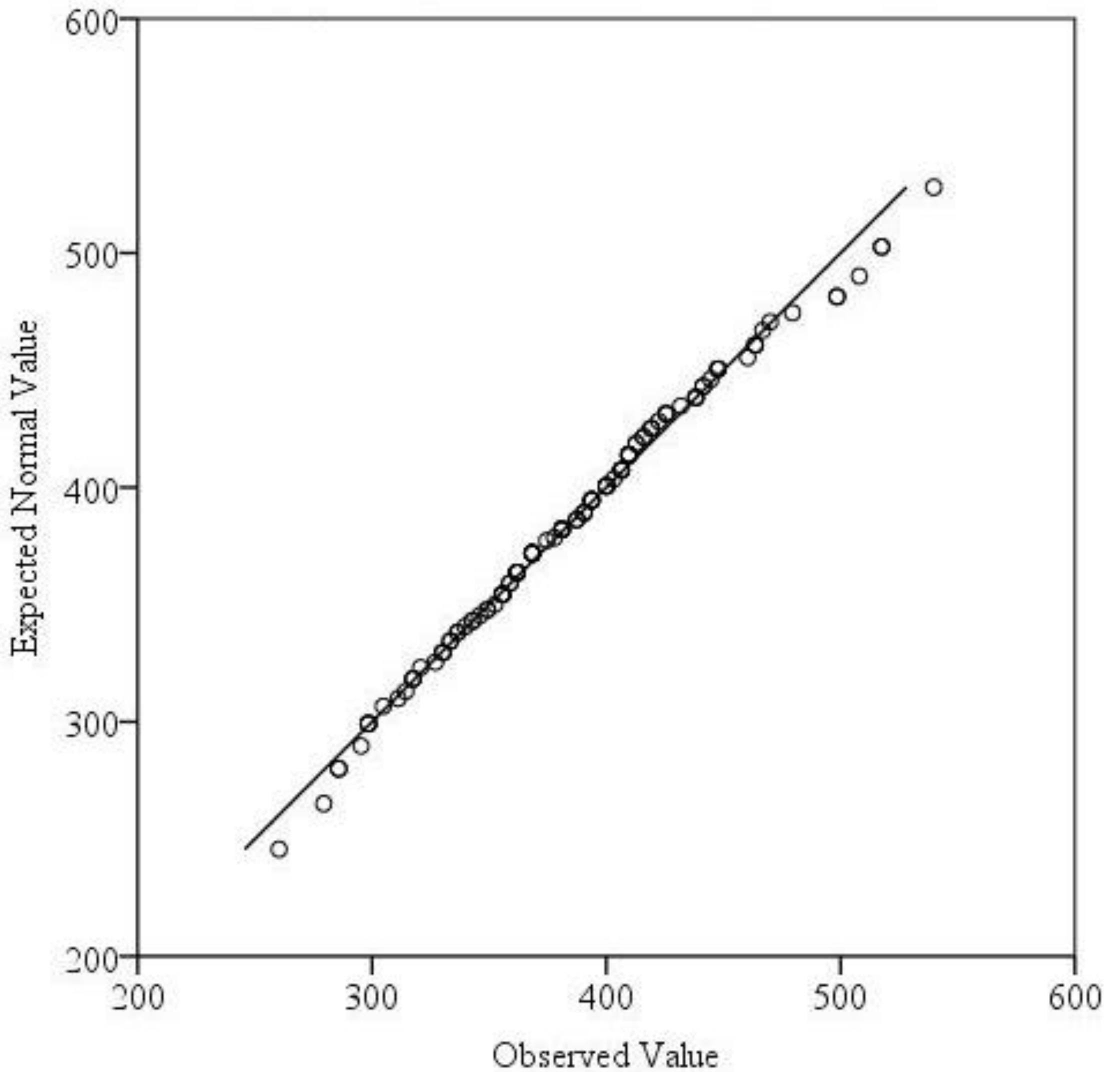


Figure 114. Normal Q-Q plot of the final center of steering wheel to sternum in millimeters.

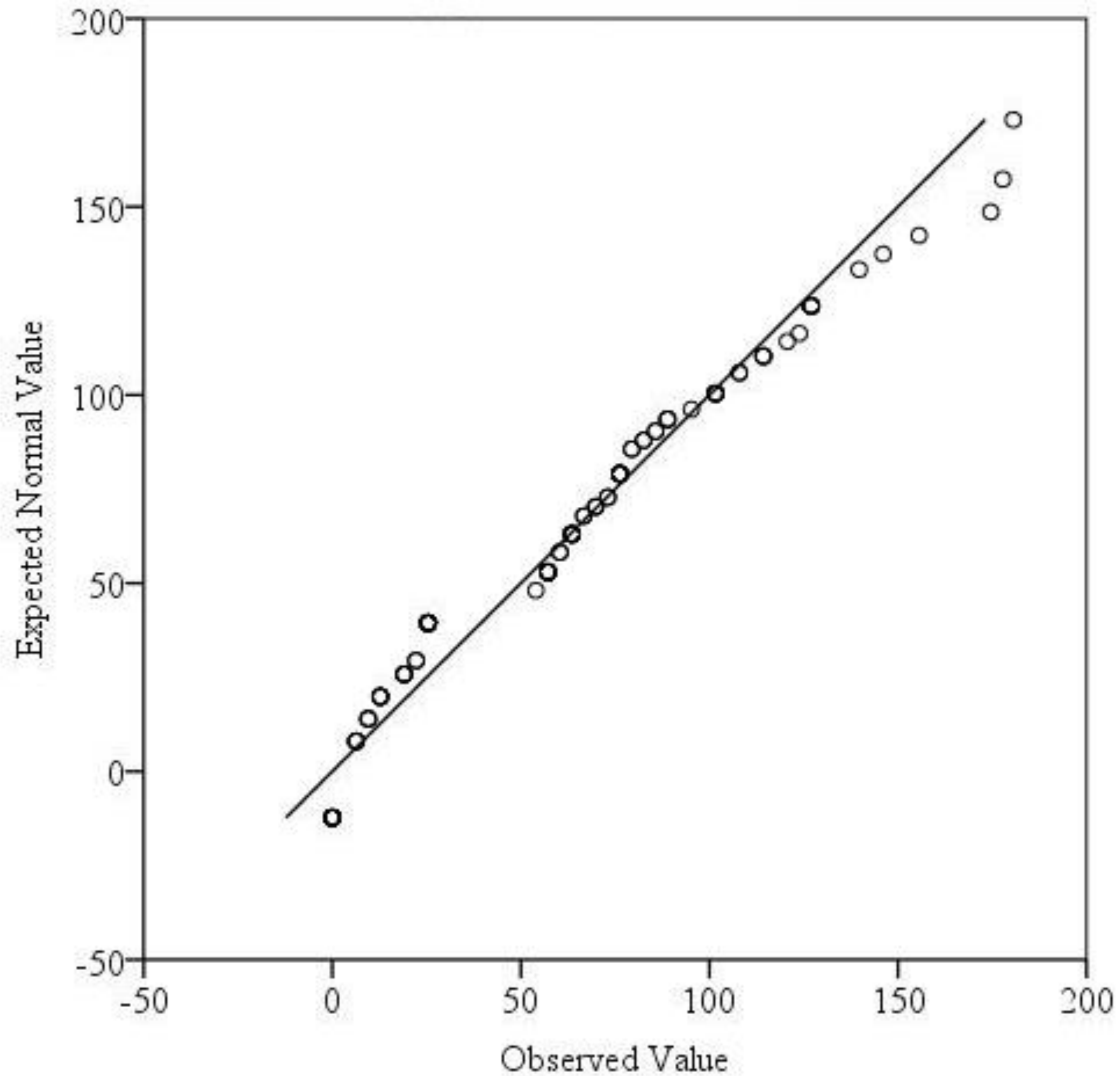


Figure 115. Normal Q-Q plot of the initial backset in millimeters.

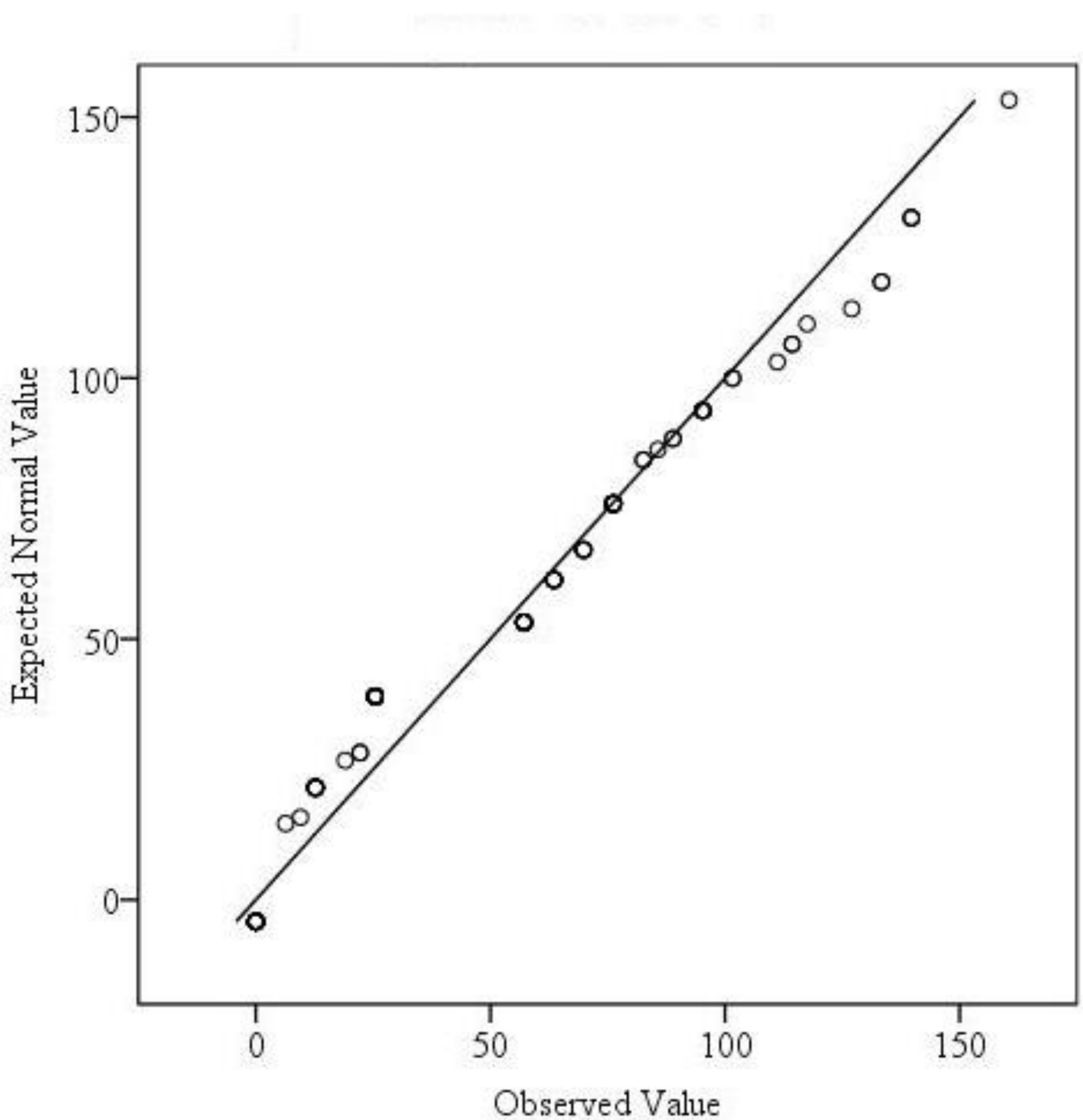


Figure 116. Normal Q-Q plot of the final backset in millimeters.

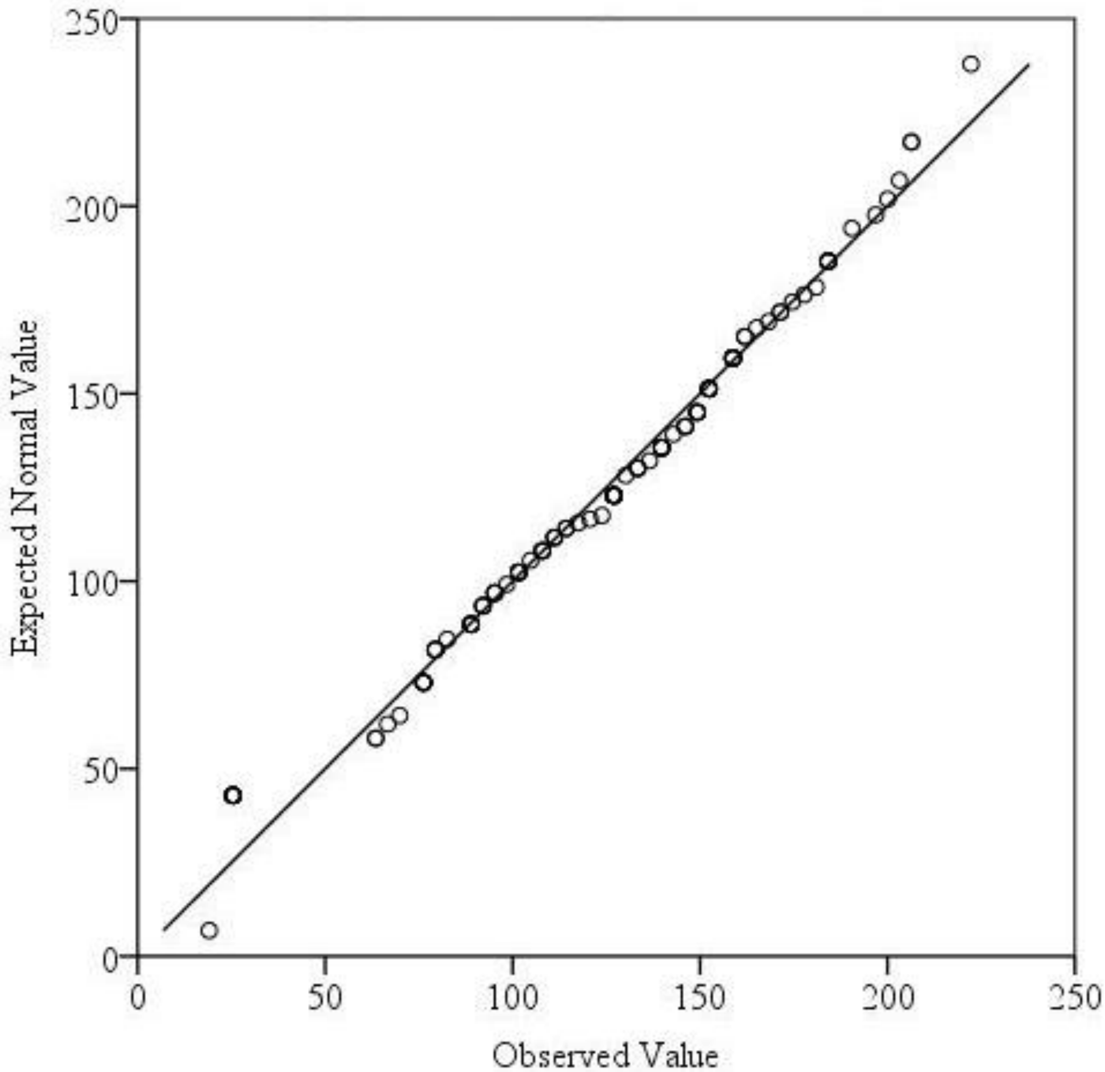


Figure 117. Normal Q-Q plot of the initial top of head to ceiling in millimeters.

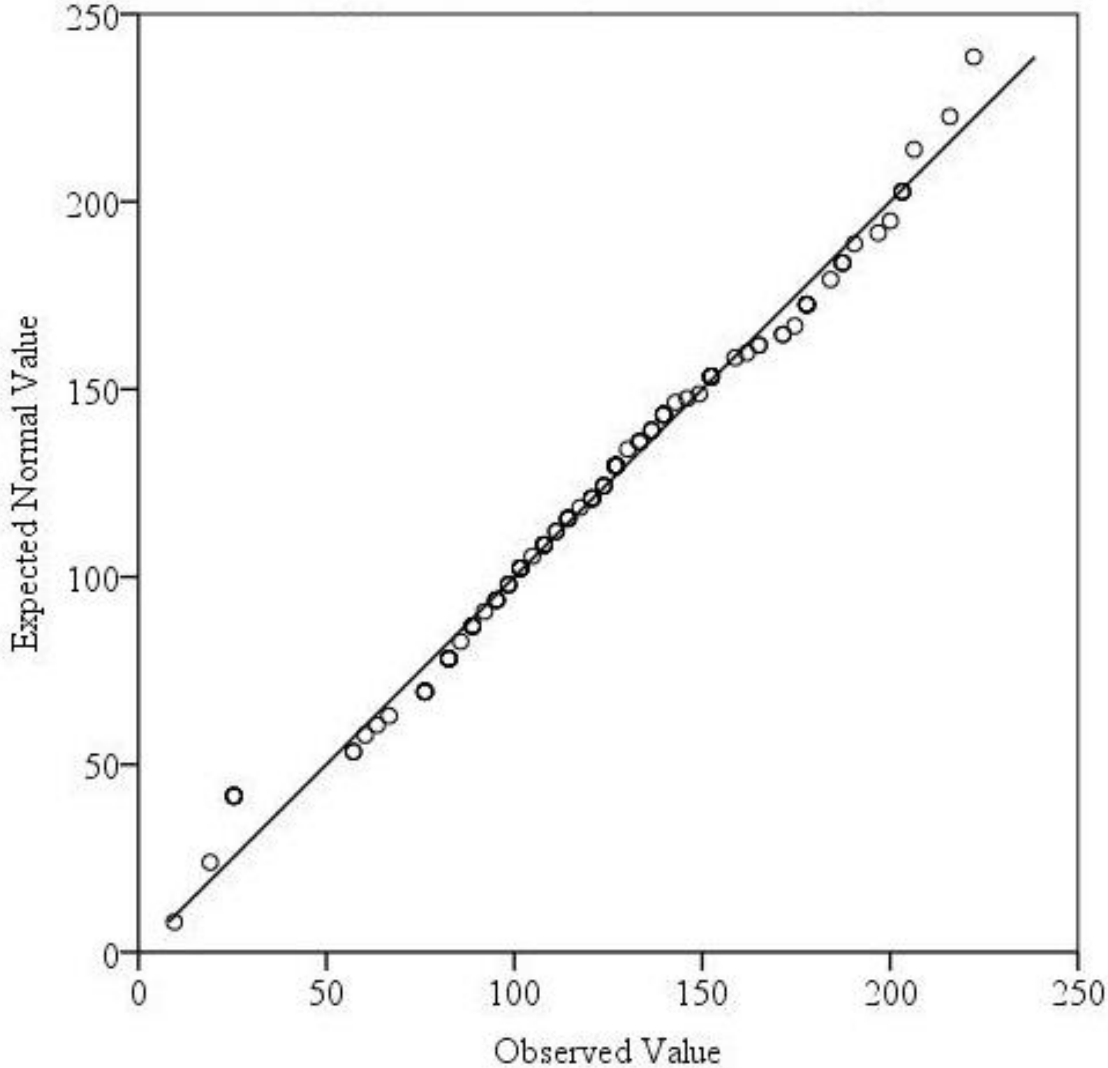


Figure 118. Normal Q-Q plot of the final top of head to ceiling in millimeters.

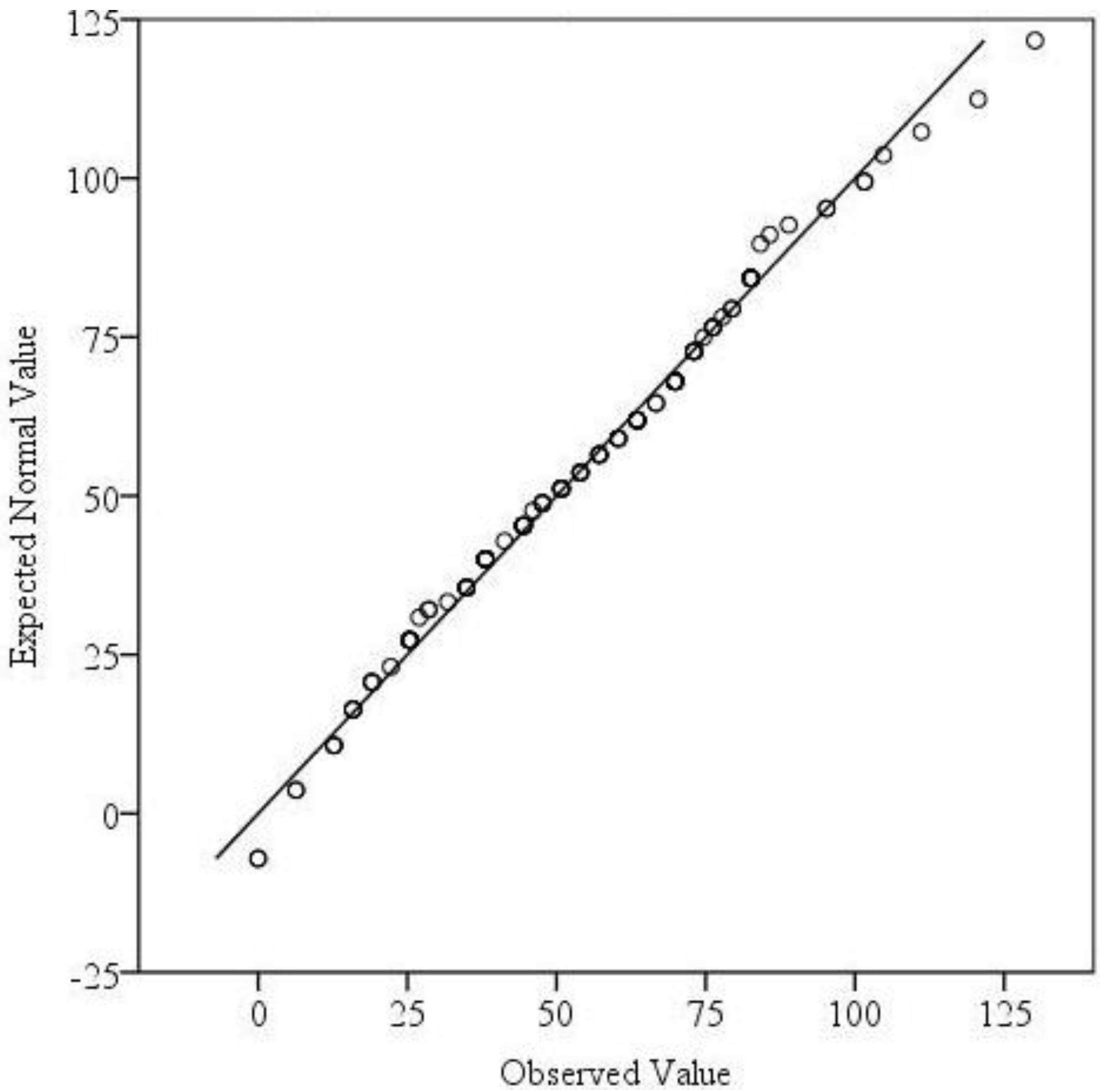


Figure 119. Normal Q-Q plot of the initial top of leg to bottom of steering wheel in millimeters.

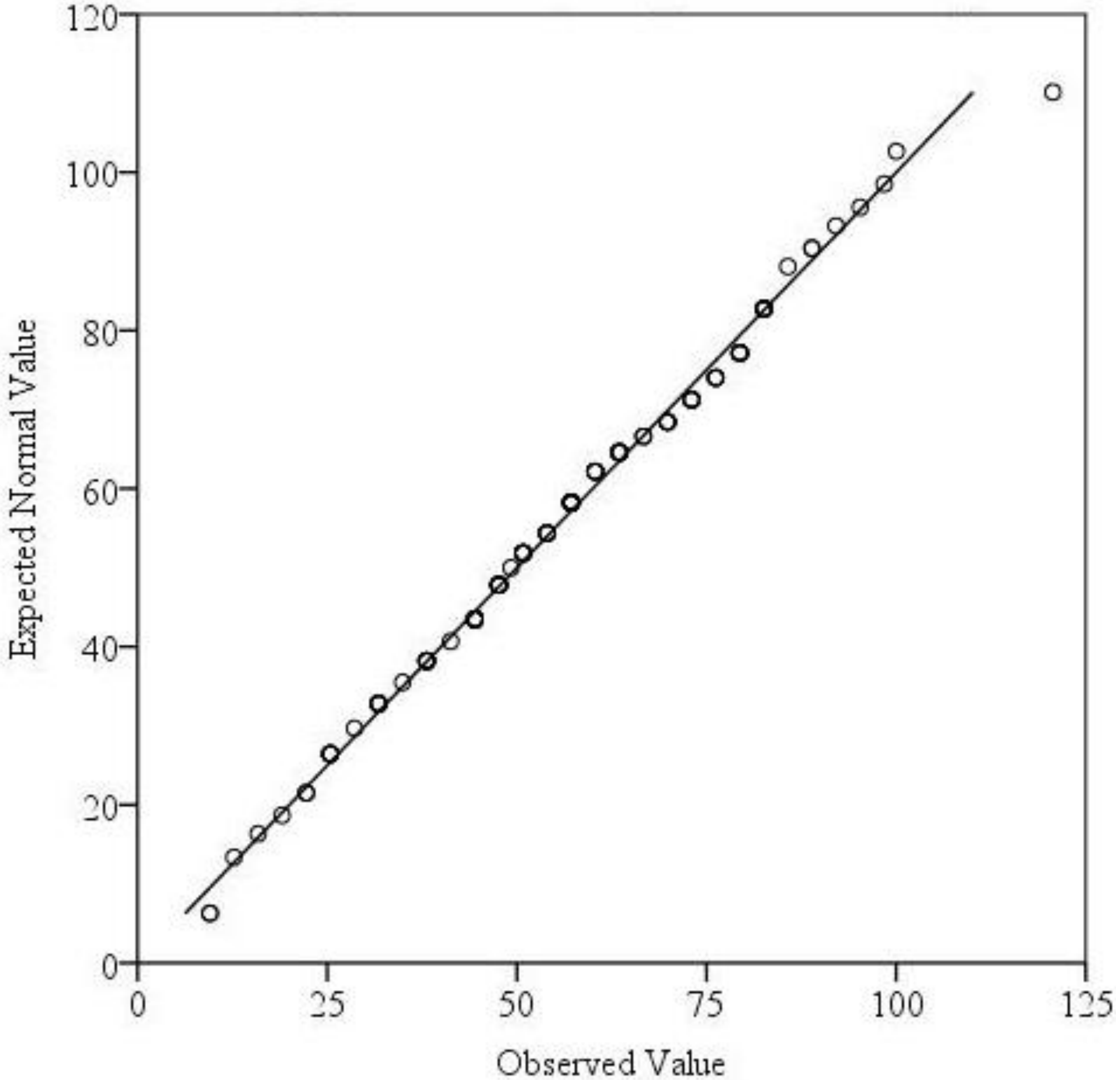


Figure 120. Normal Q-Q plot of the final top of leg to bottom of steering wheel in millimeters.

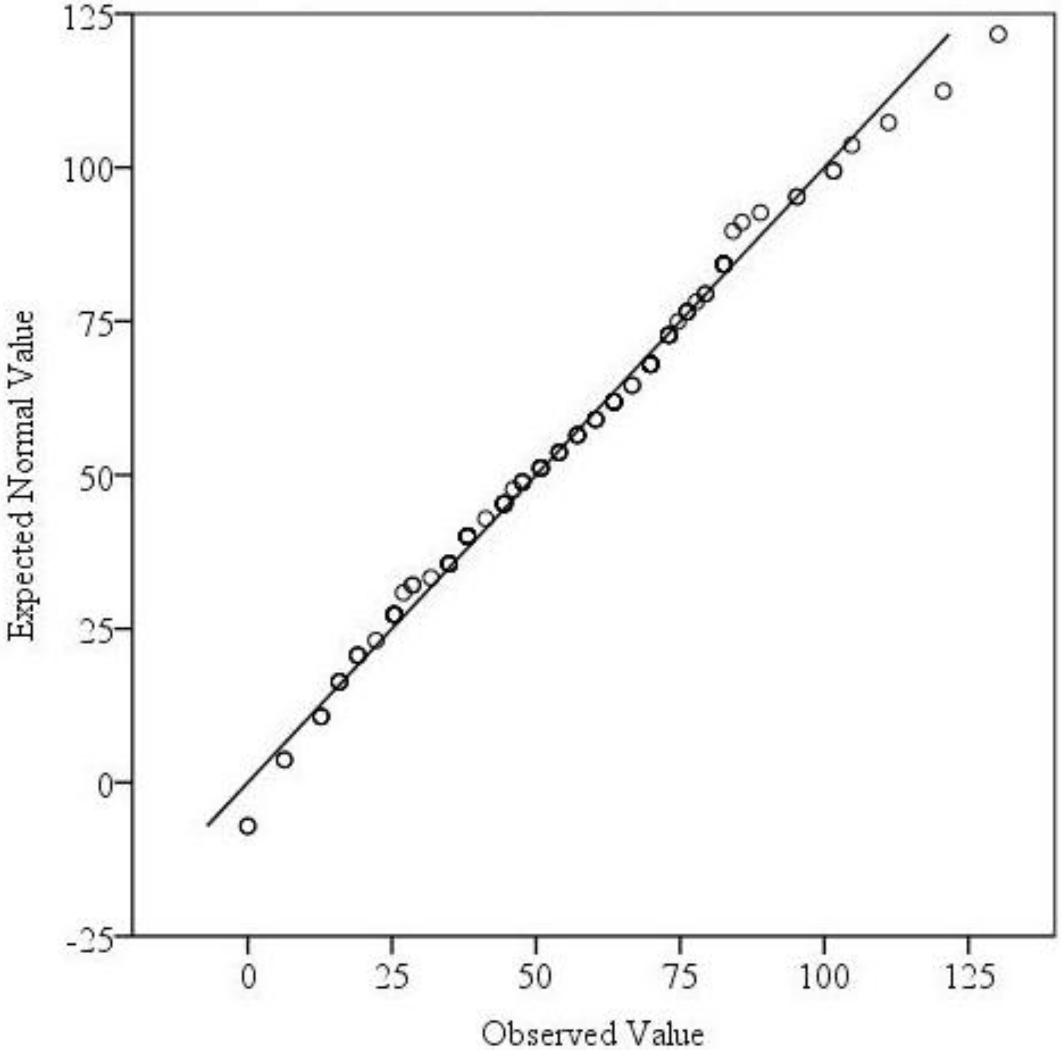


Figure 121. Normal Q-Q plot of the initial line of sight above the steering wheel in millimeters.

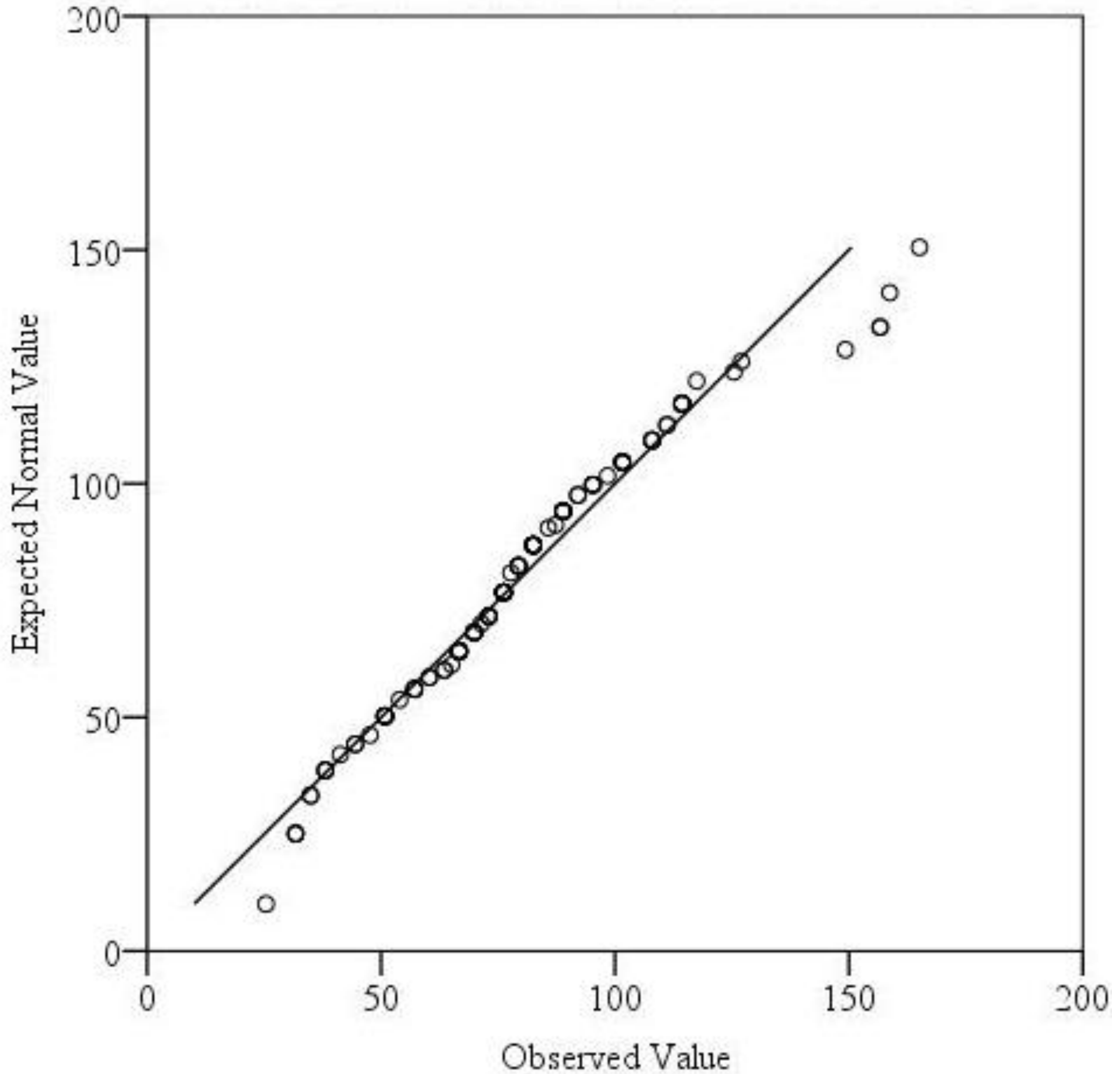


Figure 122. Normal Q-Q plot of the final line of sight above the steering wheel in millimeters.

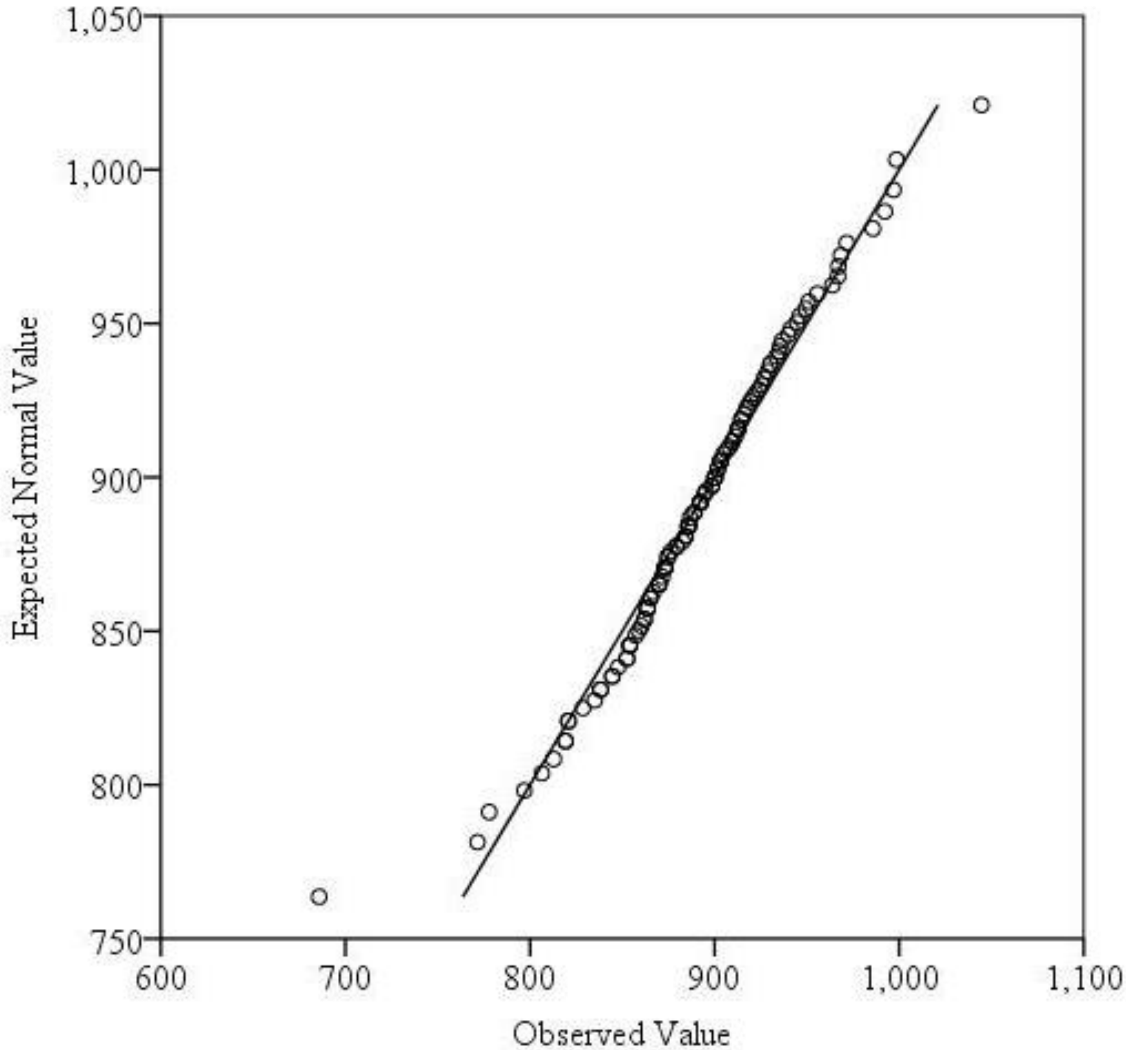


Figure 123. Normal Q-Q plot of the initial vehicle floor to eye level in millimeters.

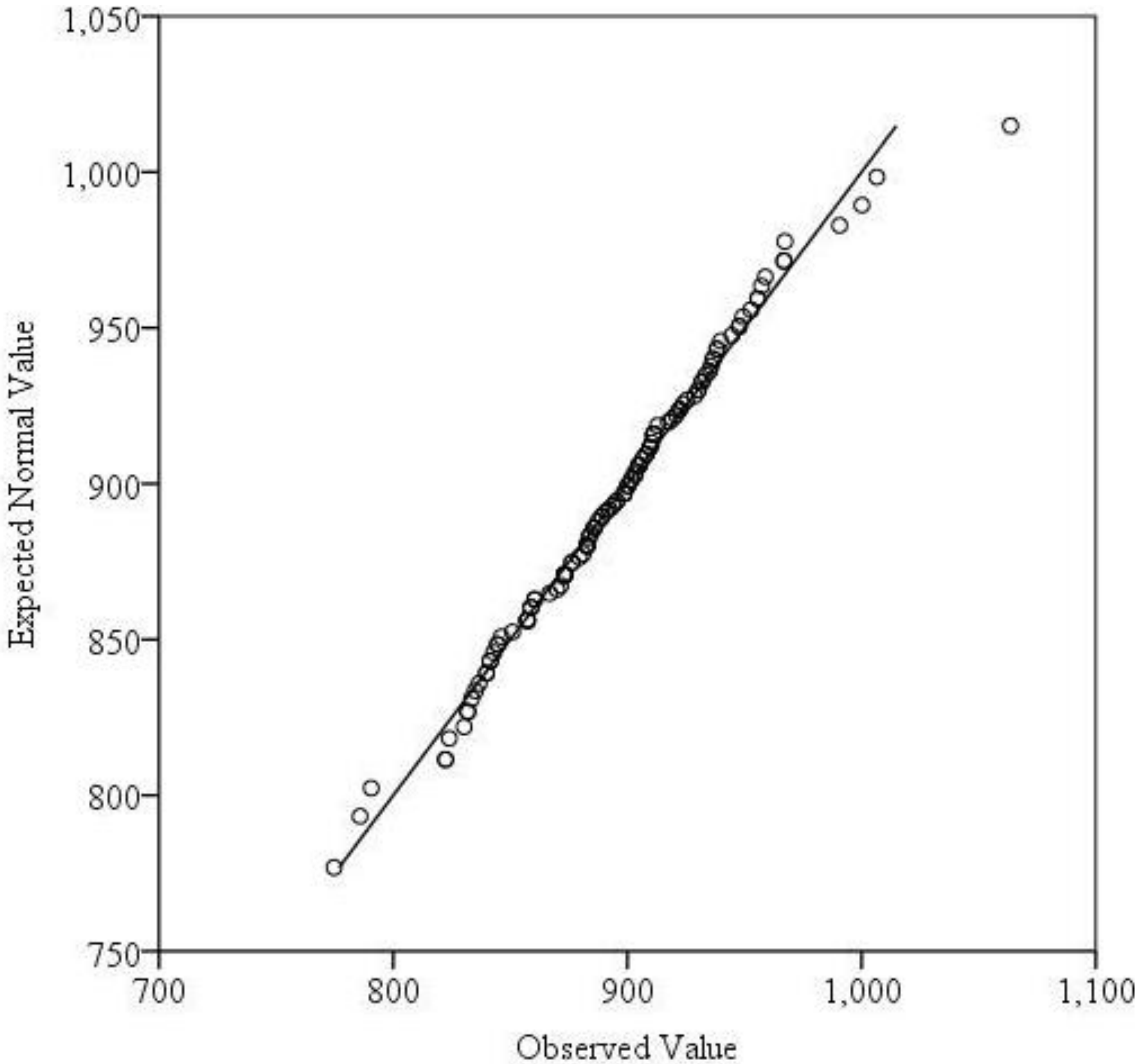


Figure 124. Normal Q-Q plot of the final vehicle floor to eye level in millimeters.

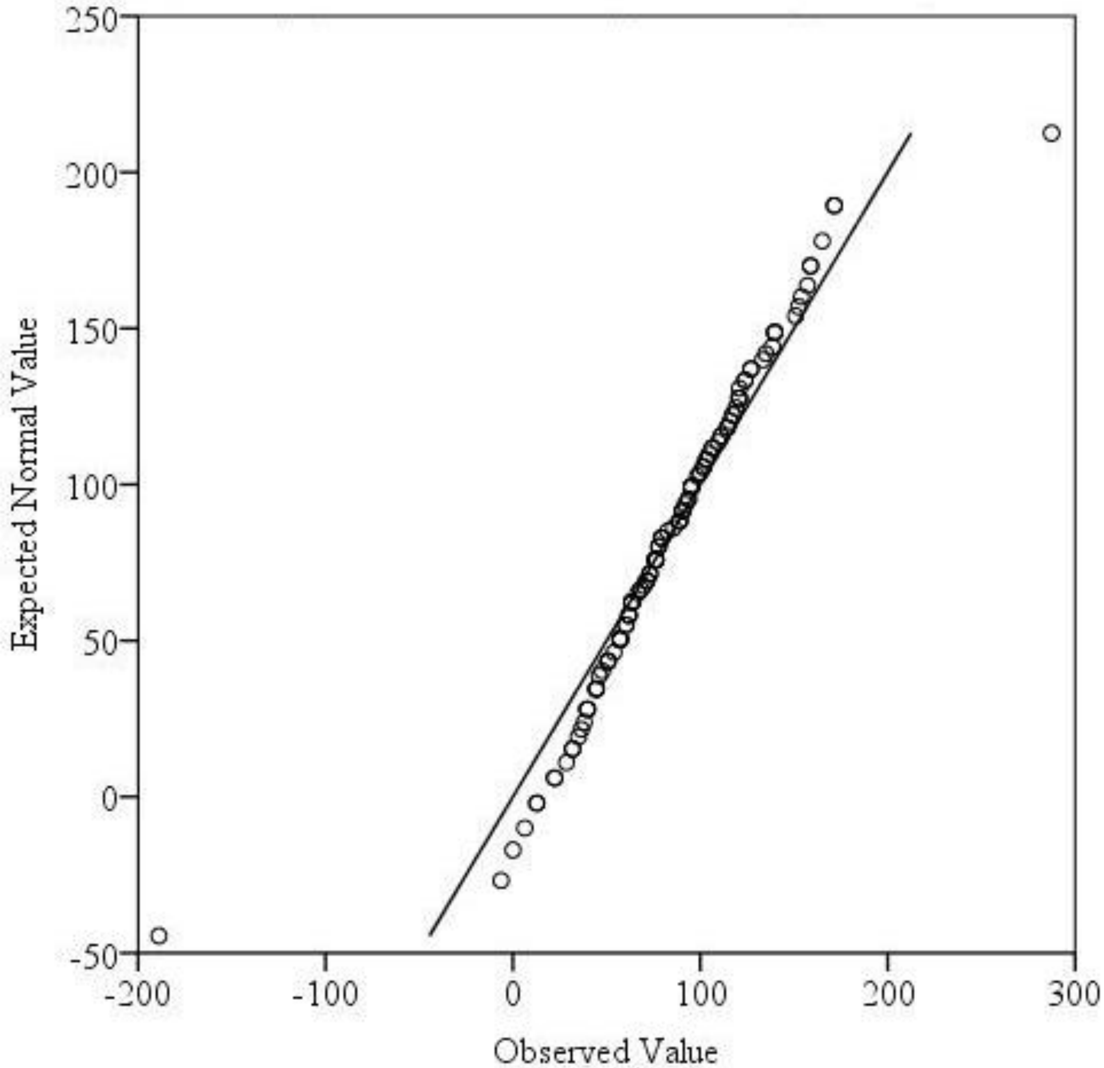


Figure 125. Normal Q-Q plot of the initial top of steering wheel to eye level in millimeters.

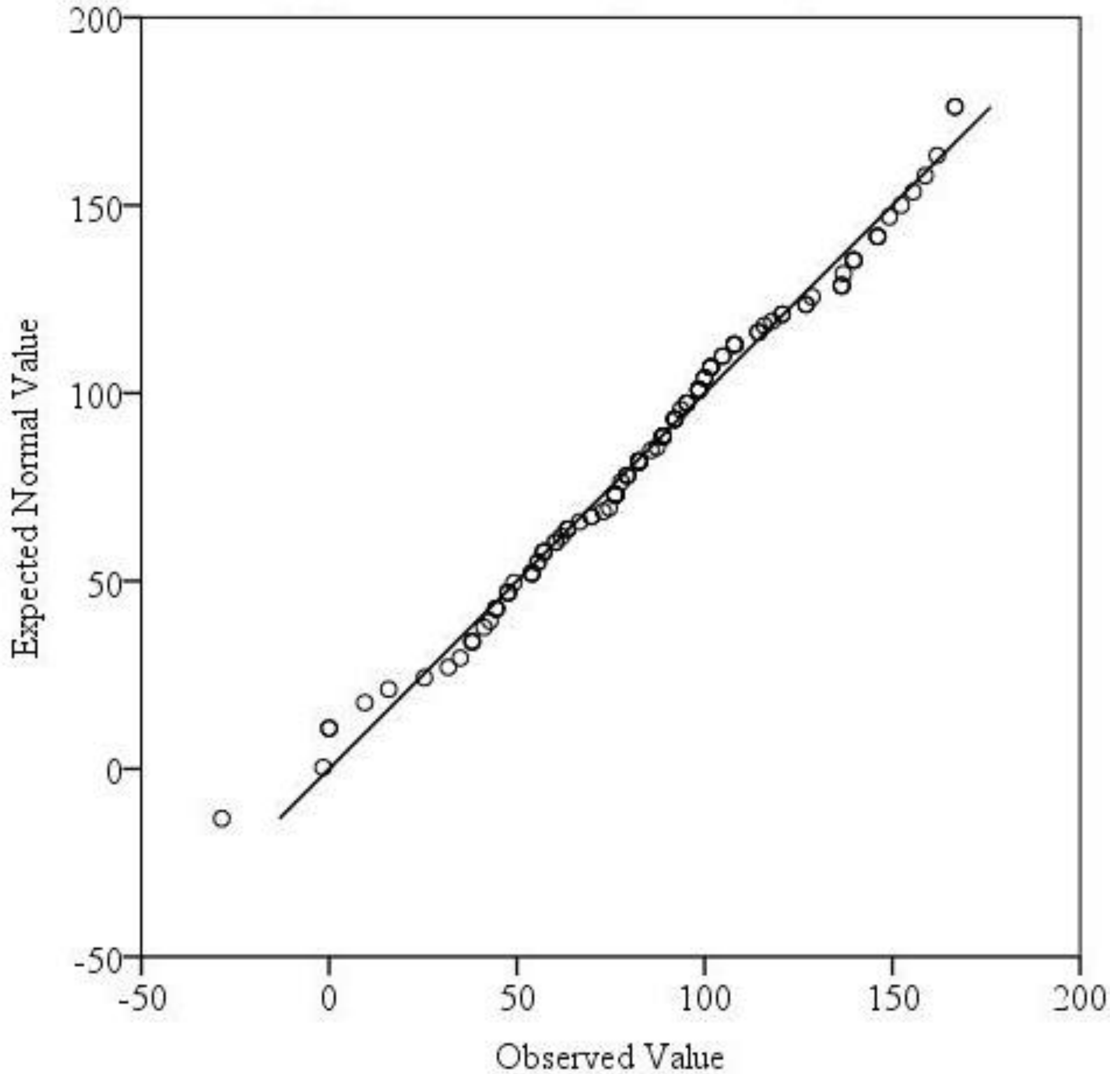


Figure 126. Normal Q-Q plot of the final top of steering wheel to eye level in millimeters.

E.2 Partial Regression Plots

The following plots for this section are the residuals of the measured BoFRP to H-point measurement compared to residuals of each of the continuous predictor variables used in the linear regression model performed in Chapter Seven. These plots were inspected for heteroscedasticity, non-linearity, and outlier bias in the measurements collected.

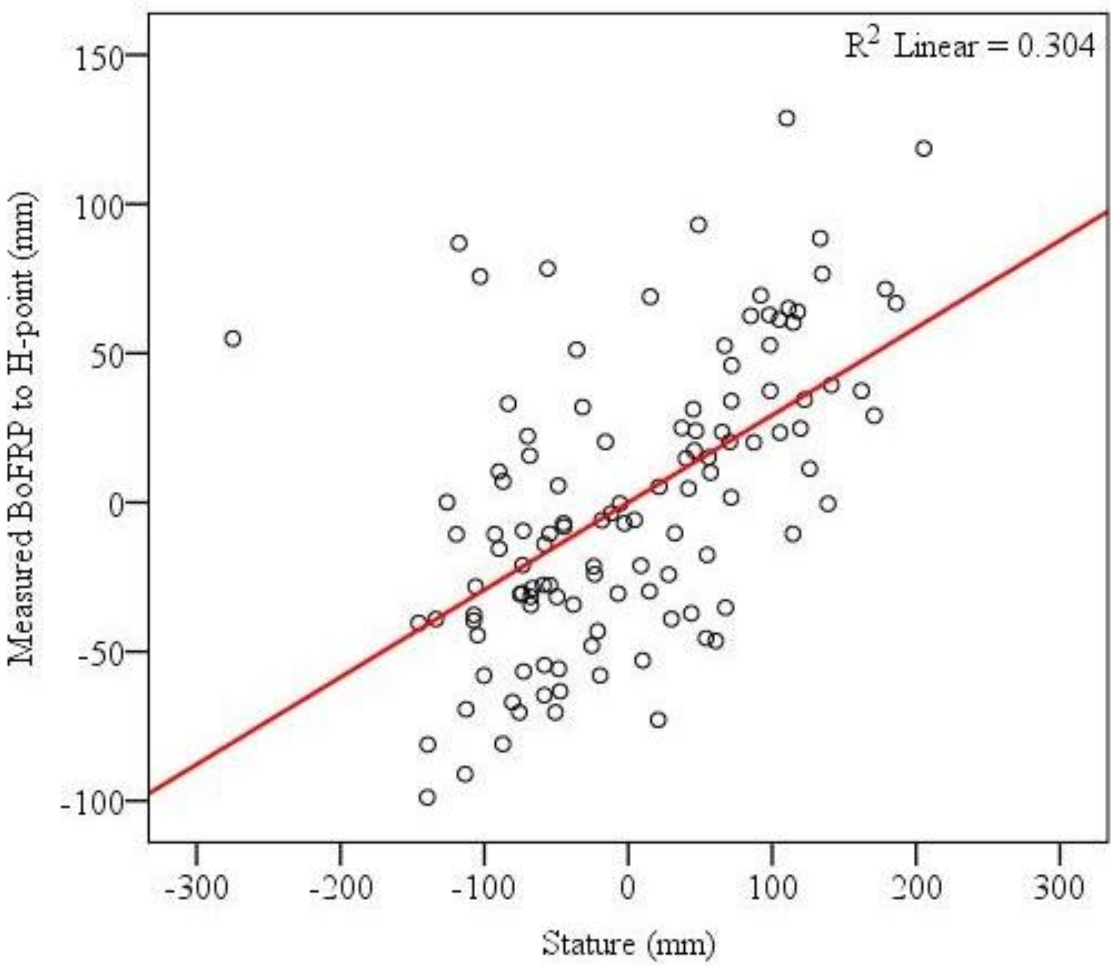


Figure 127. Measured BoFRP to H-point by stature partial regression plot.

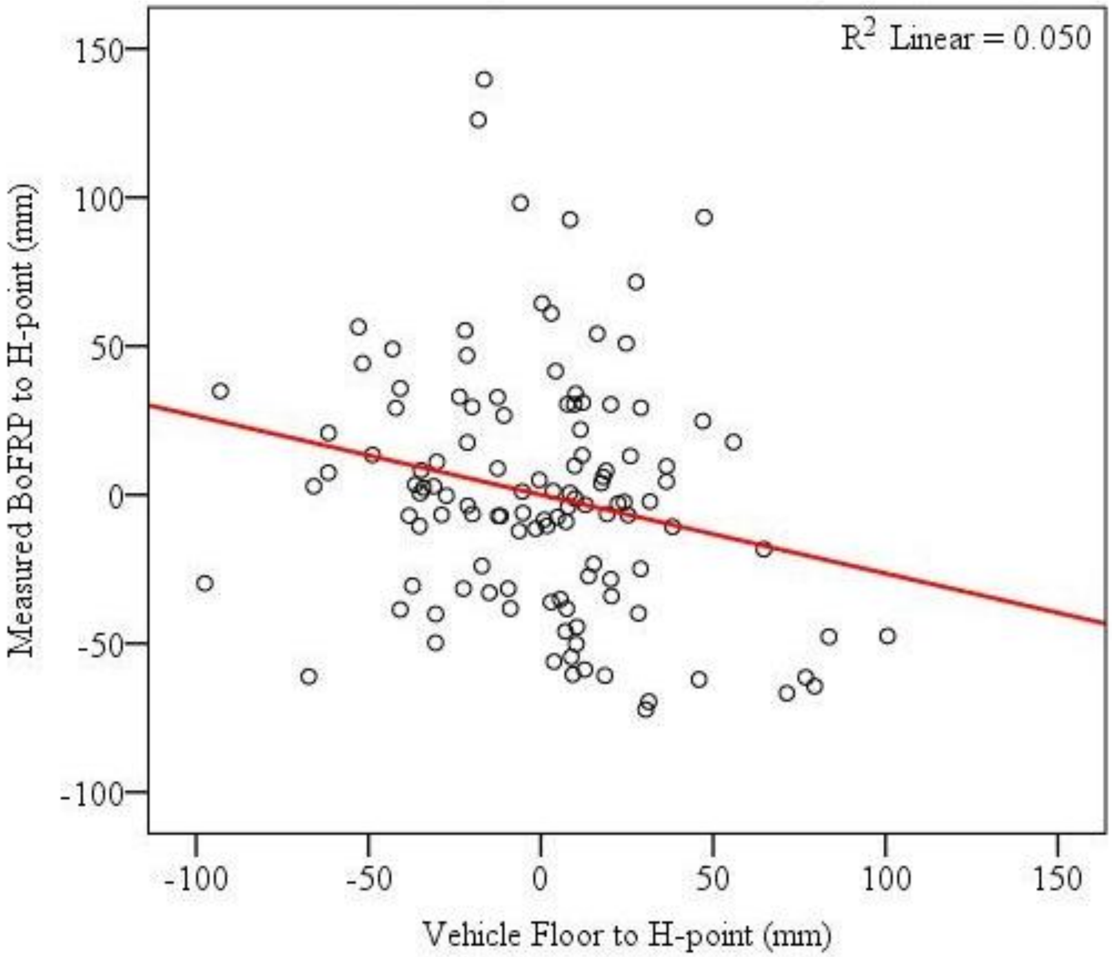


Figure 128. Measured BoFRP to H-point by vehicle floor to H-point partial regression plot.

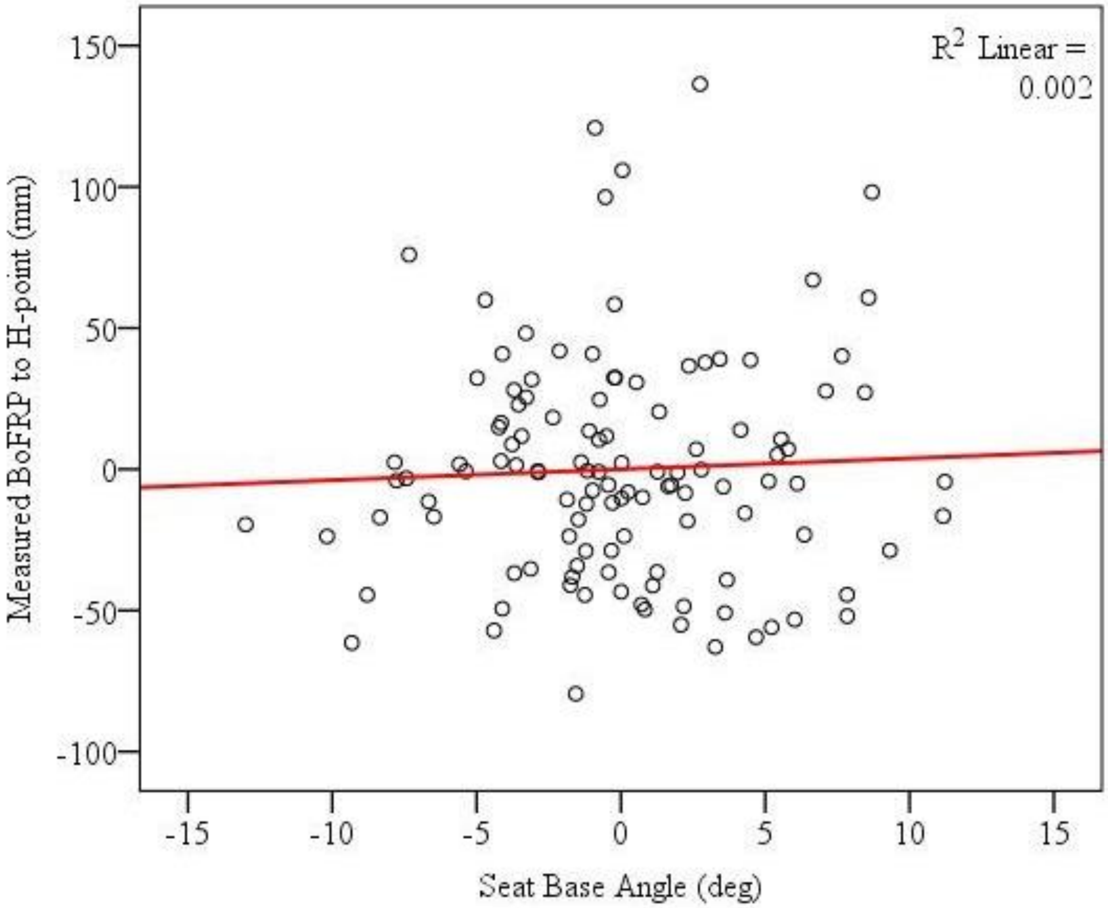


Figure 129. Measured BoFRP to H-point by seat base angle partial regression plot.

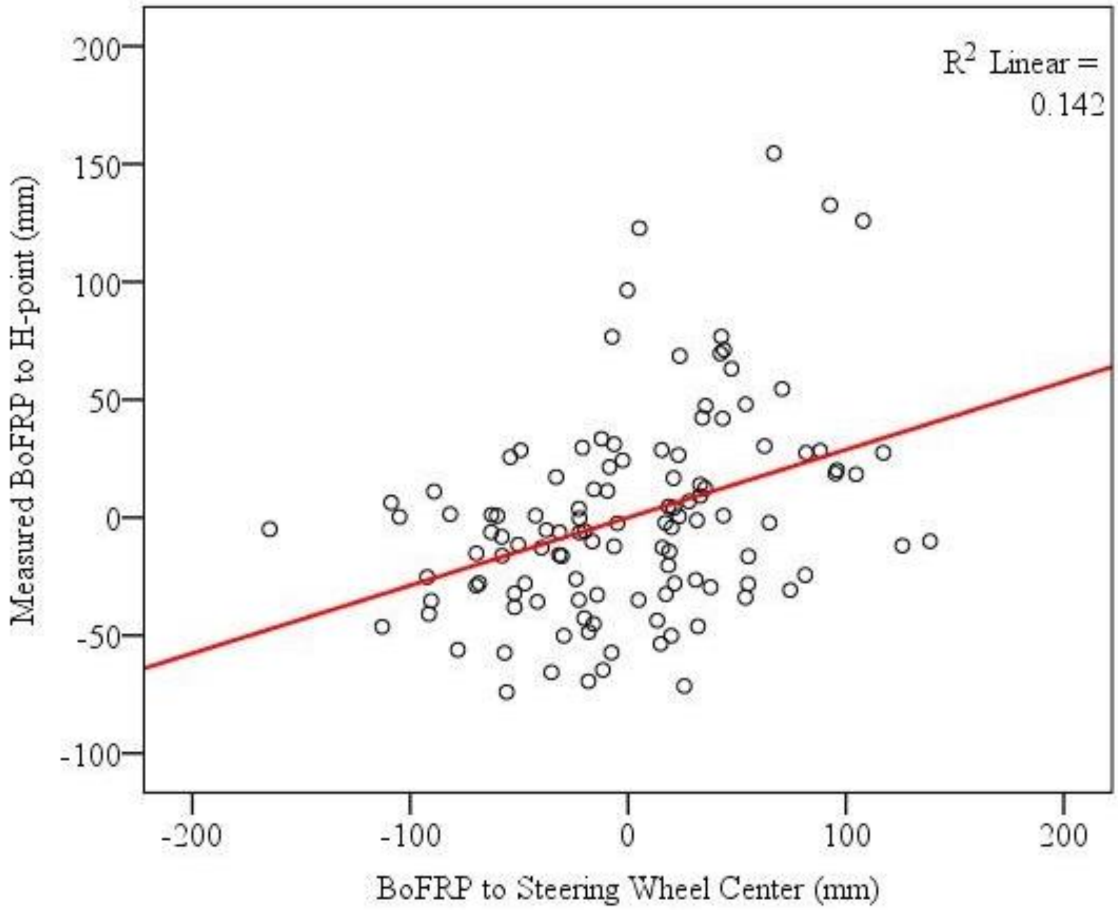


Figure 130. Measured BoFRP to H-point by BoFRP to steering wheel center partial regression plot.

APPENDIX F

CHANGES TO CarFit© DATA SHEET

This research used the CarFit© data sheet form number D18576, published November of 2010. Since the start of this research, CarFit© has made changes to the data sheet and published a new version of the data sheet in May of 2014. This appendix itemizes the changes made between the two data sheets for the portions used for this research. First, Table 94 compares the change in procedures for November 2010 and May 2014 data sheet. Second, Table 95 identifies the sub-questions that were added for the May 2014 data sheet, whereas Table 96 identifies the sub-questions that were eliminated from the November 2010 data sheet.

Table 94

Comparison of the Change in Procedures for the November 2010 and May 2014 CarFit© Data Sheet

	November 2010	May 2014
1	Are you the only driver?	Are you the only driver?
2	Is the driver using the vehicle's seat belt?	Safety belt (seat belt) use: Describe to participant how seat belt is worn-crossing midline, snug and low across the hips.
3	Steering wheel tilt/head restraint? Can the the driver view the speedometer?	Steering wheel tilt and position to airbag
4	Distance between chest and steering wheel (minimum 10")	Head restraint
5	Line of sight above steering wheel (should be ≥3")	Distance between chest and steering wheel
6	Positioning to gas pedal	Line of sight above steering wheel
7	Positioning to brake pedal	Positioning to gas pedal and brake pedal

Table 95

Items Added to the May 2014 CarFit© Data Sheet

2.	**Safety belt (seat belt) use: Describe to participant how seat belt is worn-crossing midline, snug and low across the hips.**
	Is the shoulder belt in the correct position (NOT behind the driver's back or under the arm)?
	Is the lab belt in the correct position (NOT hitting in the mid-section of the stomach)?

At this point, take initial measurements of the driver-vehicle fit to steering wheel position.
Distance between chest and steering wheel: Approx ______ inches
Line of sight above the steering wheel: Approx ______ inches

4.	**Head restraint**
	Does the vehicle have an adjustable head restraint?
5.	**Distance between chest and steering wheel**
	Was education provided regarding the minimum distance required?
	If an adjustment was made, has the driver achieved a safe distance?
7.	**Positioning to gas pedal and brake pedal**
	Are the brake lights in working order on this vehicle?

Table 96

Items Eliminated from the November 2010 CarFit© Data Sheet

2.	**Is the driver using the vehicle's seat belt?**	
	Is the driver able to unbuckle/buckle and reach for the belt without problems?	Yes No
	Is the driver able to use the belt without discomfort?	Yes No
3.	**Steering Wheel Tilt/Head restraint? Can the Driver view the speedometer?**	
	Does the driver know how to adjust the steering wheel?	Yes No
	Were verbal instructions given on the steering wheel tilt?	Yes No
	Does the driver know how to adjust the head restraint?	Yes No
	Were verbal instructions given on the head restraint?	Yes No
4.	**Distance between chest and steering wheel (minimum 10")**	Approx____inches
	Can the concern be resolved via a seat adjustment?	Yes No

APPENDIX G

UTILIZATION OF LESSONS LEARNED IN PILOT STUDY

The following appendix shows how the lessons learned, described above in Chapter Three, section 3.7, were utilized.

Table 97

Utilization of Lessons Learned During the Pilot Study

	Adjustment to the Data Sheet	Utilization of Lessons Learned
1	Have participants demonstrate each seat and steering wheel adjustment available.	Data used to answer Hypothesis 7 regarding the participant's knowledge of seat adjustments.
2	Include the length of the lower and the upper leg.	Data is to be used as part of the larger NHTSA study.
3	Add the question, "Have you ever participated in this research before?"	Verified that none of the participants from the pilot study were repeat participants in the third part of data collection.
4	Add the question, "Why did you select this seat position?"	Frequency of word use was analyzed and comfort was the overwhelming, dominate reason for seat position selection. Since comfort was outside the scope of this research, the data were omitted.
5	Include the distance from the right edge of the accelerator pedal to the center console wall, and the distance from the left edge of the brake pedal to the left footwell wall.	Data is to be used as part of the larger NHTSA study.
6	Add check boxes to indicate that the CarFit© guidelines were read to the participant.	This procedural addition to the data sheet provided confirmation that all participants were given the required CarFit© content for this research.
7	Change the tool used to measure the straight-line viewing distance above the steering wheel.	Kreg® Multi Mark™ was used to capture straight-line viewing distance above the steering wheel during all remaining data collection sessions.

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