U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 431

July 2017

Older-Driver Foot Movements

DISCLAIMER

Suggested APA Format Citation:

Lococo, K. H. Staplin, L., Mastromatto, T., Brooks, J. O., Srinivasan, R., & Sifrit, K. J. (2017, July). *Older-Driver Foot Movements* (Report No. DOT HS 812 431). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 812 431		

1. Title and Subtitle	5. Report Date
Older-Driver Foot Movements	July 2017
	6. Performing Organization Code
7. Authors Kathy H. Lococo,* Loren Staplin,* Tia Mastromatto,*Johnell O. Brooks,† Raghaven Srinivasan,± and Kathy J. Sifrit‡	8. Performing Organization Report No.
9. Performing Organization Name and Address *TransAnalytics, LLC 336 West Broad Street Quakertown, PA 18951 † Clemson University ICAR 4 Research Drive Greenville, SC 29607 ± Highway Safety Research Center, University of North Carolina 730 Martin Luther King, Jr. Blvd. Chapel Hill, NC 27599-3430	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTNH22-11-D-00223, Task Order No. 02
12. Sponsoring Agency Name and Address ‡Office of Behavioral Safety Research National Highway Traffic Safety Administration 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Dr. Kathy Sifrit was the NHTSA Task Order Manager on this project.

16. Abstract

This study explored how drivers 60 and older control the accelerator and brake while driving and parking. It built upon the findings of a study documenting the prevalence and characteristics associated with pedal misapplication crashes (Lococo, Staplin, Martell, & Sifrit, 2012). Researchers measured functional ability, and used an instrumented vehicle on a test route in actual traffic to obtain measures of foot movement and positioning that could be expected to affect the likelihood of a pedal error. Participants included two medical status groups: (1) a medical conditions group comprised of six drivers with peripheral neuropathy of the feet and two drivers with a recent right hip replacement, and (2) a group of 18 normally aging drivers. Researchers also documented participants' height, and femur and tibia length to determine whether these factors were related to pedal control. An additional objective was to learn how older drivers positioned their seat in relation to the brake, and whether poor vehicle fit was associated with stature, tibia or femur length, leg functional reach, and/or driver sex.

Anthropometry, rather than medical status group, accounted for the majority of significant differences in foot movements; differences by sex were also observed. Short stature and shorter tibia and/or femur length were related to lifting the foot during the transfer from accelerator to brake (rather than pivoting), more efficient foot movements, longer foot hover time, and foot placement on the brake closer to the center of the pedal. Females were more likely to lift the foot, while males pivoted. Females had faster transfer time and foot placement closer to the center of the brake. Normally aging participants pressed the brake slightly harder than those in a medical conditions group. There were no differences between groups in *on-road* performance. However, drivers with medical conditions scored significantly poorer than the normally aging drivers while *parking*. A logistic regression found that leg functional reach (but not sex, height, or any other individual lower limb measure), was significantly related to goodness of fit; as leg functional reach decreased, the probability of good fit decreased. Pedal extenders may be a solution for drivers who must fully extend their legs to reach their pedals to maintain a safe distance from the airbag. Power adjustable pedals as standard equipment would permit better fit for all drivers, without the inconvenience of acquiring and installing pedal extenders, especially for multiple-operator vehicles. Education to reinforce safe seat positioning for every trip is also recommended.

17. Key Words	18. Distribution Statement
Pedal application errors, pedal misapplication, unintended acceleration, safety, older drivers, driver performance, functional abilities, human factors, medical conditions, peripheral neuropathy, mild cognitive impairment, orthopedic surgery	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161. www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	183	

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

Acknowledgements

TransAnalytics sincerely thanks our collaborators, Greenville Health System (GHS) and Clemson University International Center for Automotive Research for their support and dedication to this research. Without the permission and support of the GHS Administrators, the referring physicians at GHS, the study clinicians who evaluated the participants in the OT clinic and on the road, and the participant schedulers and screeners we would not have been able to accomplish this work. In addition, we gratefully acknowledge the efforts of the professors and graduate students at Clemson University for their assistance in the instrumentation of the vehicle and in data reduction, along with the day-to-day tasks associated with the conduct of this research. Finally, we are grateful to Dr. Shayne McConomy and Dr. Yubin Xi, whose dissertation research provided source data for a number of the analyses included in this report.

Here are the team members from GHS and Clemson University in alphabetical order.

Leah Belle, CDRS	Roger C. Peace Rehabilitation Hospital, Greenville Health System
John DesJardins, Ph.D.	Associate Professor of Bioengineering, Clemson University
Nathalie Drouin, CDRS	Roger C. Peace Rehabilitation Hospital, Greenville Health System
Stan Healey, DHA, MBA, NHA, FACHE	Administrator, Roger C. Peace Rehabilitation Hospital, Greenville Health System
Sarah Hennessy	Research Assistant, Roger C. Peace Rehabilitation Hospital, Greenville Health System
Kevin Kopera, M.D.	Medical Director, Roger C. Peace Rehabilitation Hospital, Greenville Health System
Shayne McConomy, Ph.D.	Graduate Research Assistant, Automotive Engineering, Clemson University ICAR
Jeremy McKee	Research Assistant, Roger C. Peace Rehabilitation Hospital, Greenville Health System
Kylie Sprogis	Research Assistant, Roger C. Peace Rehabilitation Hospital, Greenville Health System
Stephanie Tanner	Research Coordinator, Greenville Health System
Paul Venhovens, Ph.D.	BMW Endowed Chair of Systems Integration, Automotive Engineering, Clemson University ICAR
Yubin Xi, Ph.D.	Graduate Research Assistant, Automotive Engineering, Clemson University ICAR
Melissa Youssef	Research Assistant, Roger C. Peace Rehabilitation Hospital, Greenville Health System

Referring Physicians and Medical Support Staff (in alphabetical order):

Brian Burnikel, M.D. – Steakman Hawkins Clinic of the Carolinas, Greenville Health System
Kyle Jeray, M.D. - Steakman Hawkins Clinic of the Carolinas, Greenville Health System
Meenu Jindal, M.D. – Medical Clinics, Greenville Health System
Shirley Parker, R.N. – Clinical Trials Research Coordinator, Greenville Health System
Carlisle Shealy –Clinical Research Coordinator, Hawkins Foundation
Sandra Weber, M.D. – Endocrinology Specialists, Greenville Health System

Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

AAA	American Automobile Association
AARP	American Association for Retired Persons
AMA	American Medical Association
BTW	behind the wheel
CDRS	Certified Driver Rehabilitation Specialist
CU-ICAR	Clemson University International Center for Automotive Research
DMV	Department of Motor Vehicles
DOT	Department of Transportation
DRS	Driver Rehabilitation Specialist
GHS	Greenville Health System
GPS	global positioning system
IRB	Institutional Review Board
MC	medical conditions
NA	normal aging
OP	orthopedic
OT	occupational therapist
PN	peripheral neuropathy
RA	research assistant
RCP	Roger C. Peace Rehabilitation Hospital
SAE	Society of Automotive Engineers
SBT	short blessed test
TUG	timed up and go

Executive Summary

This study explored relationships between drivers' foot movements and driver medical status, sex, height and leg length, and the way drivers positioned their seats with respect to the brake pedal. Researchers obtained in-clinic measures of physical, visual, and cognitive ability, and used an instrumented vehicle on a planned test route under normal traffic conditions to obtain measures of foot positioning behaviors that could be expected to increase the likelihood of a pedal error. Study participants included drivers with peripheral neuropathy of the feet (PN group) and those with recent orthopedic surgeries on their right leg (OP group) who were combined for analyses into a Medical Conditions group, and a fit, Normally Aging group. The goal was to identify the degree of functional loss associated with each medical condition that, in turn, could increase the risk of unintended accelerations or late/abrupt braking actions. Researchers also documented participants' height, upper and lower leg length (femur and tibia), and foot and shoe size to determine whether these factors were related to the way drivers used their pedals in the instrumented vehicle. An additional objective was to gain a greater understanding of how older drivers fit in their vehicles, and whether poor vehicle fit was associated with short stature and/or driver sex as mediating factors in pedal application errors, as suggested in an earlier research study.

Significant findings are provided below for the foot movement component of the study, followed by the on-road driving performance component, and then the driver-vehicle fit component. Unless otherwise noted, differences were determined to be statistically significant based on an alpha level of 0.05.

Foot Movement Study

Anthropometry

- Across the full sample of 26 participants, males were, on average, taller than females (69.3 inches versus 63.5 inches).
- Females had shorter tibia (lower leg) and femur (upper leg) lengths and significantly shorter overall leg lengths than males.
- Females' feet were smaller, on average, than males', and females' shoes on the day of their driving evaluation averaged 1.5 inches shorter than males'.

In-Clinic Physical Measures

- Normal Aging (NA) participants detected a lower force stimulus applied to the bottom of their right foot (performed better) than the Medical Conditions (MC) group.
- The NA group completed the timed up and go (TUG) test faster (better) than the MC group.

In-Clinic Cognitive Measures

- Participants in the NA group completed the Trail-Making Part B test significantly faster (performed better) than the MC group.

On-Road Foot Movements

The table on the following page summarizes significant differences in foot movements by study group and sex observed in at least one of the 10 locations on the driving route, as well as significant regression analysis outcomes where anthropometric, cognitive, and physical performance measures were significantly associated with foot movements.

Driving Performance: Behaviorally-Anchored Rating Scale (BARS)

On-Road Performance

- There were no differences in on-road performance for the 10 combined on-road driving tasks, as a function of study group. The NA, MC, and the PN groups each scored an average of 95% or higher on the combined on-road tasks.

Parking Performance

- Collapsing across parking tasks, the 8 MC drivers obtained scores significantly poorer than those of the 18 NA group drivers. Additionally, performance of the 6 drivers with PN was poorer than that of the 18 NA group drivers.
- The differences between groups in parking performance resulted from errors in determining turning radius when turning left into a parking space, multiple attempts to align/center the vehicle within the parking space, and failing to shift into park.

Driver-Vehicle Fit Study

- Average functional leg reach for drivers with "poor fit" (i.e., those who had to stretch their leg to depress the brake pedal) was 2.8 inches shorter than those with "acceptable fit" (32.9 in versus 35.7 in).
- A logistic regression to investigate the relationship of sex, height, tibia length, femur length, knee to ball-of-foot length, and functional leg reach with goodness of fit found that only functional leg reach was significantly related to fit; as functional leg reach decreased, the probability of "acceptable" fit decreased.
- Functional leg reach and driver-selected distance from the H-point to brake were moderately correlated across the sample of 33 participants (r=0.56); the correlation was stronger for females (r=0.62), than for males (r=0.27).

Summary: Foot Movement Type	
Pivot	**Lift**
Male[a] Taller drivers Longer tibia (lower leg) Poorer (longer) Trails A time Better (shorter) letter cancellation time	Female[a] Shorter drivers Shorter tibia Better (shorter) Trails A time Poorer (longer) letter cancellation time
Foot Transfer Time	
Longer Transfer Time	**Shorter Transfer Time**
Males Taller drivers Shorter femur Longer tibia Poorer (longer) TUG time Better (shorter) brake RT	Females Shorter drivers Longer femur Shorter tibia Better (shorter) TUG time Poorer (longer) brake RT
Foot Placement on Brake	
Closer to Right Edge	**Closer to Center**
Males Taller drivers Longer femur Longer shoe length Better (more pairs) symbol digit Poorer (longer) letter cancellation time Better (shorter) TUG time Better (shorter) brake RT	Females Shorter drivers Shorter femur Shorter shoe length Poorer (less pairs) symbol digit Better (shorter) letter cancellation time Poorer (longer) TUG time Poorer (longer) brake RT
Foot Contact Area on Brake	
Less Coverage	**More Coverage**
Taller drivers Longer femur Poorer (less pairs) symbol digit Better (shorter) Trails B time - (straight parking in garage) Poorer (longer) Trails B - (gate access to garage/not reach & swipe) Better (shorter) brake RT	Shorter drivers Shorter femur Better (more pairs) symbol digit Poorer (longer) Trails B - (straight parking in garage) Better (shorter) Trails B - (gate access to garage/not reach & swipe) Poorer (longer) brake RT
Conformance of Foot Movement with Direct Path	
Less Conformance	**More Conformance**
Longer femur Longer tibia Pivoters	Shorter femur Shorter tibia Lifters
Foot Internal/External Angle During Reach and Swipe	
Toe Points More Toward Right (Accelerator)	**Toe Points More Forward**
Longer shoe length Poorer (longer) brake RT Better plantar sensation	Shorter shoe length Better (shorter) Brake RT Poorer plantar sensation
Foot Internal/External Angle NOT During Reach and Swipe	
Toe Points More Toward Right (Accelerator)	**Toe Points More Forward**
Longer femur	Shorter femur
Average Brake Force	
More Brake Force	**Less Brake Force**
Better (shorter) brake RT	Poorer (longer) brake RT
Maximum Brake Force	
More Brake Force	**Less Brake Force**
Better (shorter) Trails A time Longer shoe length Better (shorter) brake RT Normal Aging Group Drivers	Poorer (longer) Trails A time Shorter shoe length Poorer (longer) brake RT Medical Conditions Group Drivers
Total Hover Duration	
Less Hover Time	**More Hover Time**
Taller drivers Longer femur Poorer (longer) Trails B time Poorer (longer) letter cancellation time (neighborhood reverse) Better (shorter) letter cancellation time (garage reverse)	Shorter drivers Shorter femur Better (shorter) Trails B time Better (shorter) letter cancellation time (neighborhood reverse) Poorer (longer) letter cancellation time (garage reverse)
Looking Right Duration	
Shorter Duration	**Longer Duration**
Normal Aging Group	Medical Conditions Group

[a.] Sex differences in foot movement type only approached statistical significance (p=0.053), and only at one of two locations studied.

Introduction and Background

Background and Understanding of the Problem

This study built upon the findings of recent problem identification research conducted for NHTSA that documented the prevalence of pedal application errors—specifically, the driver error of mistaking the accelerator pedal for the brake pedal—and the driver, vehicle, roadway, and environmental characteristics associated with these crashes (Lococo, Staplin, Martell, & Sifrit, 2012). The prior study included a literature review; an analysis of 3,341 pedal misapplication crashes with 899 from media reports, 2,411 from the North Carolina Department of Motor Vehicles, and 31 from the National Motor Vehicle Crash Causation Survey; and a meeting with certified driver rehabilitation specialists (CDRSs).

The analysis of news media reports over the past 10 years provided an estimate of 15 pedal misapplication crashes per month in the United States, and analyses of the NCDMV and NMVCCS crash databases suggested these driver errors were a factor in less than 1% of all crashes. However, the researchers identified limits to the reporting and archiving of these events that could result in underestimation. The literature review found only sparse evidence of the frequency of pedal application errors. Two predictors for pedal error events were identified: greater driver age and impairment in driver's "executive function."[1] These studies also demonstrated that pedal misapplications could be triggered by sudden changes in the environment that startled drivers. However, the studies included in this review were all conducted with driving simulators therefore may not reflect real-world driving behavior.

One simulator study found that older drivers' right foot movements were more variable than those of younger drivers when moving from the accelerator to the brake (Cantin, Blouin, Simoneau, & Teasdale, 2004). Older drivers had significantly greater foot movement amplitudes, and they made several sub-movements of the right foot following the release of the accelerator. Younger drivers rarely made such sub-movements. The authors noted that more research was needed to determine if there is a direct relationship between variability in lower limb movement and pedal misapplications.

Lococo, Staplin, Martell, and Sifrit (2012) found that crash involvement plotted against driver age produced a U-shaped function showing significant over-involvement by the youngest (age 16 to 20) and oldest (76+) drivers. In the media analysis as well as in the NCDMV crash database analyses, older drivers were more likely than other drivers to be performing a parking maneuver prior to making a pedal application error. In all three analyses, females accounted for nearly two-thirds of crashes resulting from pedal misapplication. Driver inattention and distraction were common contributing factors across all age groups. Pedal misapplication crashes described in the news media reports and in police narratives from the crash databases often mentioned situations that startled drivers or included a panic braking response.

---

[1] Executive function describes a variety of loosely related higher-order cognitive processes like initiation, planning, hypothesis generation, cognitive flexibility, decision-making, regulation, judgment, feedback utilization, and self-perception that are necessary for effective and appropriate behavior (Daigneault, Joly, & Frigon, 2002).

A panel of driver rehabilitation specialists (DRSs) convened during the earlier NHTSA study provided another perspective. Panelists drew on their clinical experience to discuss the medical conditions and functional deficits, the maneuvers, the locations, and the driving task demands associated with pedal application errors. The panel indicated most pedal application errors they observed in their clients occurred in parking lots. DRSs noted that their clients manifested one or more impairments that could undermine their driving abilities, so it is to be expected that they would have the greatest difficulty—and experience the greatest number of incidents—in parking lots where there is less room to recover/correct a pedal misapplication given the proximity of cars and other objects. The DRSs hypothesized that many more pedal misapplications may occur on-road than showed up in the media and crash analyses because drivers had the time and space to correct the error and avoid crashing.

The DRS panel identified three general populations of drivers they considered likely to make pedal application errors: (1) those with sensory defects in their feet; (2) those with cognitive limitations; and (3) those with no specific medical conditions or functional impairments but whose driving performance was undermined by other factors (e.g., inexperience, misfit in the vehicle, unfamiliar vehicle, distraction). DRSs expressed particular concern about peripheral neuropathy as a potential cause of pedal application errors. Panelists indicated that over the past 10 years increasing percentages of their referred clients reported difficulty feeling their pedals. Approximately 8 to 9% of Medicare recipients carry neuropathy as either a primary or secondary diagnosis—about *20 million* people—yet neuropathy is one of the least recognized conditions in the United States (Neuropathy Association, 2012). The panelists noted that many of their clients were unaware that they had a loss of sensation in their feet. Although hip and knee replacements, as well as many medical conditions and some medications can cause peripheral neuropathy, it may nevertheless be the case that physicians and occupational therapists do not test patients for sensation in their feet. Panelists recommended physician education about medical conditions that can cause peripheral neuropathy, testing of patients for loss of foot sensation, and discussions between physicians and patients about the implications of peripheral neuropathy for driving. They recommended that physicians refer patients with loss of sensation in their feet to driver rehabilitation specialists for evaluation.

DRSs observed pedal application errors among their clients who performed poorly in clinical tests of executive function. They were familiar with the concept of sub-movements described in the earlier literature review. Many indicated that they had observed such foot "wandering" in cognitively impaired, older clients. DRSs commented that clients who began driving with both feet late in their driving careers were more likely to make pedal application errors, compared to those who had been driving with both feet their entire driving career. They noted an evolution from one- to two-footed driving among the cognitively impaired older driver population during their on-road evaluations, particularly in parking lots.

In addressing the overrepresentation of women in pedal misapplication crashes, the panelists commented that women tend to be smaller and their "fit" in the driver's seat is often poor. Many sit with their hips stretched forward, which can cause leg cramps as well as temporary loss of sensation in their foot and leg. These observations point to issues with the vehicle as a cause of pedal misapplications as opposed to a medical condition. At CarFit[2] events, DRSs have often observed women sitting too far away from the steering wheel, sitting too low, reaching for controls, and stretching with their toes to reach the pedals.

Pedal application errors can result in crashes. This issue is of particular concern for the aging population, whose members have been shown to be over-represented in pedal error crashes (Lococo, Staplin, Martell, & Sifrit, 2012), because they remain overwhelmingly dependent on the private automobile for the activities of daily living. This study refines the understanding of the relative contributions of cognitive and functional impairments on driver foot movements and describes when sensory loss significantly increases sub-optimal foot movements. This information will assist clinicians who perform driving evaluations and also help physicians and nurses determine when a referral to a CDRS for a driving evaluation is appropriate.

Project Objective

This study was conducted to explore how older drivers use their feet to accelerate and brake during on-road driving and when parking a vehicle. Researchers obtained in-clinic measures of functional ability, and used an instrumented vehicle on a planned test route under normal traffic conditions to obtain measures of foot positioning behaviors for groups of drivers with and without selected medical conditions. The goal was to identify driver characteristics, including the degree of functional loss associated with medical conditions that could pose an increase in the risk of unintended accelerations or late/abrupt braking. Researchers documented participants' height, upper and lower leg length (femur and tibia), and foot and shoe size to determine whether these factors were related to the way drivers used their pedals. For example, foot and/or shoe size could affect whether drivers pivot their foot or lift the entire foot when moving between pedals, which could affect speed and accuracy of foot movement and placement.

An additional objective was to gain a greater understanding of how older drivers fit in their vehicles, and whether poor vehicle fit was associated with short stature and/or driver sex as mediating factors in driver foot movements, as suggested in the earlier study. Researchers documented each driver's selected seat position in his or her own vehicle using a subset of the CarFit protocol as each arrived to participate in the study, as well as measures of the distance from the brake pedal to the driver's hip point at the selected seating position. Safety considerations precluded researchers from collecting foot movements in the instrumented vehicle using self-selected seating positions matching the own-vehicle positioning if it was not optimal for safety. Therefore, the study did not address whether poor vehicle seating position was related to problematic foot positioning behaviors in the on-road driving portion of the study.

[2] CarFit was developed in collaboration between the American Society on Aging, AARP, the American Occupational Therapy Association, and AAA to provide a quick yet comprehensive check to determine how well older adults "fit" in their car. The organizers of CarFit provide guidelines to allow the driver to gain the optimal position in their vehicle and allow them to utilize their strength, range of motion, and visual scanning abilities to their fullest potential.

Analyses addressed the following research questions:

- Did foot position and/or variability in foot movement differ by medical status?
- Did foot position and/or variability in foot movement differ by sex?
- Was position and/or variability in foot movement related to driver height and/or shoe size?
- Was poor driver-vehicle fit related to driver height or sex?
- Was late/abrupt braking associated with a measured degree of functional loss associated with peripheral neuropathy?

Methods

The foot movement study was conducted in three sessions over a period of approximately six weeks for each study participant. Participants who provided their consent underwent an in-clinic screening procedure; an in-clinic assessment of their cognitive, physical, and visual abilities; and an on-road driving evaluation in an instrumented vehicle to measure pedal-to-pedal and floor-to-pedal foot movements. Participants provided separate consent for the research team to collect data describing their usual seating position in their own vehicle plus additional measurements describing pedal and seating geometry. Seating position data and vehicle measurements were obtained during the in-clinic appointment. The following sections describe the research activities and instrumented study vehicle used during the on-road evaluations.

Participant Recruitment and Screening

Recruitment. All study participants were recruited through physician referrals to the Driving Rehabilitation Program at the Roger C. Peace (RCP) Rehabilitation Hospital, which is part of the Greenville Health System (GHS) in Greenville, South Carolina. The RCP Medical Director and other members of the research team met with physicians and staff of several practices within the GHS system to provide information about the study and the need for appropriate patient referrals into the Driving Rehabilitation Program. The practices consisted of family medicine, internal medicine, neurology, endocrinology, orthopedics, and vascular surgery. In addition, staff contacted representatives of two newsletters that target all GHS physicians (*Medical Staff Times* and *What's Happening at GHS*) and provided a short study description and flyer/referral form to each for publication. The same material was provided to the Physician Relations Department at GHS, and an e-mail with the attachments was sent to all GHS physicians for the first time in May, 2012. Posters describing the study and how to contact the study team were placed in the hospital cafeteria, as well as the waiting rooms in several GHS practices, and other practices in the community. Recruitment flyers were also distributed at CarFit events conducted throughout the study period.

Although the participants were physician-referred, project staff posted recruitment flyers in physicians' offices in the departments of family medicine, internal medicine, geriatrics, orthopedic surgery, as well as other locations within the hospital with a large volume of older adult foot traffic including the hospital's community wellness center and the volunteer office. The RCP/Clemson study registry, a compilation of names of participants from past research studies who have agreed to be contacted for future studies, was used to recruit normally aging participants beginning in December 2013.

Study groups. The researchers sampled three groups of older licensed drivers, two with medical or functional impairments: peripheral neuropathy and orthopedic surgery, and a third comprised of normally aging drivers without physical impairments. Selection criteria for each of the three study groups are provided below. Specific tests mentioned below are described in more detail in the screening section of this report.

Peripheral neuropathy (PN). The Peripheral Neuropathy group was comprised of cognitively intact drivers 60 and older with a measured degree of peripheral neuropathy in their feet. Peripheral neuropathy was defined as loss of sensation using the 8-g monofilament from the

Semmes-Weinstein Enhanced Sensory Test. For this study, individuals with loss of sensation using the 8-g monofilament were included in the PN sample and excluded from the other study samples. Loss of sensation was defined as the inability to correctly detect two or more of the three applications on at least one of the four sites tested on the bottom of the right foot. Participants selected for the PN group scored 0-4 on the Short Blessed Test (normal cognition), and had not undergone orthopedic surgery for a right hip replacement or right hip fracture within the previous 18 months, nor experienced other injuries or problems with their right leg affecting their ability to walk within the past year.

Orthopedic (OP). The Orthopedic group was comprised of cognitively intact drivers age 60 and older who had orthopedic surgery on their right hip for a fracture or a right hip replacement within the past 12 to 18 months. Candidates with peripheral neuropathy (defined as loss of sensation at 8-g) were excluded from the OP group. OP group members scored 0-4 on the Short Blessed Test, indicating normal cognition.

Normal aging (NA). The NA group was comprised of normally aging drivers, age 60 and older without cognitive or physical impairment. NA group members scored 0-4 on the Short Blessed Test (indicating normal cognition), had no loss of sensation using a 8-g monofilament on any of the four sites tested on their right foot, had intact proprioception, and had not had an orthopedic surgical procedure within the 18 months prior to study screening, nor experienced other injuries or problems with their right leg affecting their ability to walk within the past year. They also must have completed the Timed Up and Go test in 10 seconds or less.

Inclusion criteria:

- 60 or older
- Possess a valid driver’s license
- Meet the South Carolina vision requirement for licensure
- Have a minimum of three years of driving experience
- Drive a minimum of three trips per week
- Read, write and speak in English
- Agree to complete the study within 6 weeks
- Be between 60 and 74 inches tall. (It was a goal to include driver heights ranging from the 15th–85th percentile.)
- Agree to wear comfortable snug-fitting shoes such as tennis shoes or walking shoes when driving. (Flip flops, sandals, high-heeled shoes, clogs, work boots, etc., were not permitted.)
- Meet criteria to fall within one of the three participant groups
- Provide informed consent

Exclusion criteria:

- Answering “yes” to the screening question: *Has your doctor told you not to drive for any reason?*
- Having had a driving evaluation administered by a DRS within the last year.
- Receiving (at time of data collection) treatment from an occupational or physical therapist.
- Reporting diagnosis of Parkinson’s disease

- Using (at time of data collection) orthopedic support braces for right lower extremity (e.g., casts, splints, and boots)
- Having driven for less than 3 years after having a stroke
- Having driven legally for less than 1 year after having a seizure
- Having had any injury or condition of 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)
- Failing a proprioception screening test
- Driving pickup truck, large SUV (e.g., Expedition, Tahoe, Escalade) or full-size van as the primary, everyday vehicle

Initial screening. When the RCP Driving Rehabilitation Program received a physician referral, the standard hospital procedure was for an RCP scheduling staff member to contact the person by phone to schedule the standard driving evaluation. For physician-referred people with conditions that fit study inclusion criteria, the scheduling staff member informed the potential participants about the study, assessed their willingness to participate, and determined whether they met the general inclusion and exclusion criteria, as listed in the physician referral material. The RCP scheduler then scheduled the first study appointment, provided that the participant met study requirements. If the individual was contacted from the RCP/Clemson study registry and passed the pre-phone screening, the scheduler mailed a copy of the consent form, doctor's referral form, and physician's flyer to the individual. The individual was responsible for taking the referral form to their physician to sign and fax back to RCP. Once RCP received the referral, the scheduler contacted the individual for the phone screening and to schedule the in-clinic screening.

In-clinic screening. At the beginning of the in-clinic screening visit, the research assistant (RA) explained the study in detail, provided a consent form, and encouraged participants to ask questions before signing the form. Following consent, the RA measured the participant's height, weight, foot length and width, and shoe size (Brannock device). The RA then administered a short cognitive screen, a test of protective foot sensation, and a mobility test. The RA was trained in these tests and scoring procedures by an RCP occupational therapist. These screening measures and their study inclusion/exclusion cut points are described below.

The Short Blessed Test (SBT) was used to exclude candidates with mild cognitive impairment and dementia from study participation. Appendix A provides the SBT content, scoring, and interpretation.

The RA used monofilament testing to assess the loss of protective sensation as recommended by several practice guidelines to detect peripheral neuropathy in otherwise normal feet (e.g., those without visible ulcers). The 5.07/10-g monofilament has been described in the diabetes literature as the best indicator to determine loss of protective sensation. The Semmes–Weinstein 5.07 monofilament exerts 10 grams of force when bowed into a C-shape against the skin for one second. Those who cannot reliably detect application of the 10-g monofilament to designated sites on the plantar surface of their feet are considered to have lost protective sensation. This loss of protective sensation is not equivalent to the total absence of sensation.

Appendix B contains the test procedure for assessing loss of protective sensation with the 10-g monofilament. The test procedure was changed for this study, using the 8-g monofilament as the screening threshold (see Plucknette, Brogan, Anain, & Terryberry, 2012; and Thomson, Potter, Finch, & Paisey, 2008). Candidates for the peripheral neuropathy group had at least diminished protective sensation using the 8-g monofilament (defined as the inability to correctly detect two or more of the three applications on at least one of four sites) and were excluded from other study samples.

The TUG test measures mobility in people who are able to walk. The test began with the participant sitting in an arm chair with his/her back resting against the back of the chair. The RA instructed participants to stand up, walk at their regular pace to a marker placed on the floor 3 meters (approximately 10 feet) from the chair, turn around, and walk back to the chair and sit down; the score was the time, in seconds, required to complete the task. Participants completed the TUG three times, and the RA recorded their average time. Candidates were excluded from study participation if their average time was 21 seconds or more. Only candidates who completed this measure in 10 seconds or less were included in the NA group.

The in-clinic screening session lasted approximately 90 minutes (including time to consent). Provided that participants completed the in-clinic screening with results classifying them into a certain study group, the RA scheduled the in-clinic evaluation.

Candidates who failed to meet the criteria for study participation were given a letter explaining that although they did not meet study eligibility requirements, their physician referred them to the driving program for a complete evaluation, which would require billing their health insurance (or self-payment) for the in-clinic evaluation and self-payment for the on-road evaluation. Those who elected to comply with their physician's recommendation scheduled the evaluations outside of the study parameters; others who did not elect to undergo the physician-requested driving evaluation were advised that that their physician would be notified of this decision.

In-Clinic Assessment

The in-clinic evaluation was a standardized assessment offered by the driving program at RCP that began with a medical history including medical conditions, medications, and the following evaluations:

- A physical evaluation—assessing physical capacity including functional strength, range of motion, sensation and coordination, and brake reaction time.
- A cognitive evaluation—assessing visual processing, memory, attention span, and judgment.
- A perceptual motor evaluation—assessing the ability to interpret and react to the environment.
- Vision screening—conducted using a Stereo Optec 5000P vision testing machine.

Specific tests conducted within each functional modality are presented below.

- Physical Assessments:
    - Upper extremity: shoulder flexion, extension, adduction-abduction, internal rotation, external rotation; elbow extension-flexion; forearm supination and pronation; and wrist flexion and extension. Range of motion was scored as within normal limits or within functional limits; actual measurement only if below functional limit. Manual muscle testing was scored as shown in Table 1.
    - Lower extremity: hip flexion and extension, knee extension-flexion, ankle dorsiflexion, and plantar flexion. Range of motion was scored as within normal limits or within functional limits; actual measurement only if below functional limit. Manual muscle testing was scored as shown in Table 1.
    - Neck range of motion (rotation, flexion, extension).
    - Hand strength and coordination: gross grasp, 9-hole peg test, gross upper and lower extremity coordination.
    - Brake reaction time.
    - Upper and lower extremity sensation: light touch and proprioception. Recorded as intact, impaired, or absent.
- Neuropsychological Battery
    - Symbol Digit Modalities Test.
    - Trail Making A and B.
    - Benton 3-D Constructional Praxis Test.
- Visual-Perceptual Battery
    - Peripheral vision.
    - Near and far visual acuity.
    - Color perception.
    - Far lateral and vertical phoria.
    - Near lateral phoria.
    - Far depth perception.
    - Far fusion.
    - Sign recognition.
    - Occulomotor positions.
    - Functional visual scanning with letter cancellation test.

A brake response time monitor (Delta Integration, Inc., part number 203-01, serial number 122) was used to measure reaction time to move the right foot from the “accelerator pedal” to the “brake pedal.” Participants began each trial by pressing on the accelerator when a green light illuminated on the monitor, and then moving their foot to the brake when a red light illuminated. Participants practiced 3 times, and then completed 10 trials. Their score was the average of the 10 trials.

To test dorsiflexion, the OT/CDRS instructed the participant to “bring your foot up like this (demonstrate), now hold it while I try to push it down. Don’t let me push it down.” To test plantiflexors, the OT/CDRS asked the participant, “Can you stand up on your tip toes without holding onto the table? You can hold my hand if you need some help.” The scoring metric used for this study is shown in Table 1.

Table 1. Manual Muscle Test Scoring Metric[3]

Medical Research Council (Frese et al., 1987)	Daniels and Worthingham (1986)	Kendall et al., (1993)	Explanation
5	**Normal(N)**	**100%**	**Holds test position against maximal resistance**
4+	Good + (G+)		Holds test position against moderate to strong pressure
4	**Good(G)**	**80%**	**Holds test position against moderate resistance**
4-	Good – (G-)		Holds test position against slight to moderate pressure
3+	Fair + (F+)		Holds test position against slight resistance
3	**Fair (F)**	**50%**	**Holds test position against gravity**
3-	Fair- (F-)		Gradual release from test position
2+	Poor + (P+)		Moves through partial ROM against gravity OR Moves through complete ROM gravity eliminated and holds against pressure
2	**Poor(P)**	**20%**	**Able to move through full ROM gravity eliminated**
2-	Poor – (P-)		Moves through partial ROM gravity eliminated
1	**Trace(T)**	**5%**	**No visible movement; palpable or observable tendon prominence/flicker contraction**
0	**0**	**0%**	**No palpable or observable muscle contraction**

To assess proprioception, the OT passively positioned a joint of the involved extremity and asked the participant to imitate the position with the other extremity. Scoring was as follows:

- Absent: Participant was unable to identify body part being moved or in what position it was placed.
- Impaired: Participant was able to identify body part being moved or its position but was unable to identify both; responded inconsistently or noticeably slower than expected.
- Intact: Participant consistently identified body part moved and in what position it was placed.

To assess light touch, the OT/CDRS lightly touched various locations below the knee over clothing or shoes and asked participants to respond “now” when they felt something. Locations included front and back of calf, sides of ankle, and top of foot. Participants were scored as light touch “intact” if they felt all touches, “impaired” if they had a delayed response or only felt a few of the touches, and “absent” if they felt none of the touches.

Gross lower extremity coordination was assessed by having participants tap their toes on the floor, alternating quickly between feet. Performance was scored as intact, impaired (slow to complete), or absent (cannot perform task). Those with scores of “impaired” were permitted in the peripheral neuropathy and orthopedic surgery study groups. However, the NA group required intact proprioception.

[3] From: “Principles of Manual Muscle Testing”http://highered.mcgraw-hill.com/sites/0071474013/student_view0/chapter8/manuaul_muscle_testing.html

Four additional measures—beyond those included in the standardized assessment given by RCP—were included in the in-clinic evaluation for this study: ankle inversion and eversion (range of motion and strength), tibia and femur length, contrast sensitivity, and right foot sensation.

Normal range of motion for ankle inversion (turning the ankle to point the foot toward the center of the body) is 0-35 degrees, and for eversion (turning the ankle to point the foot away from the center of the body) is 0-15 degrees. Range of motion was scored as within functional limits (WFL); actual measurement was scored only if below functional limit.

Contrast sensitivity was measured with a Pelli-Robson chart with 16 triplets of Sloan letters arranged in 8 rows of two triplets each. The contrast within each triplet was equal, with contrast decreasing from one triplet to the next by 0.15 units, reading from left to right and continuing on successive lines. Log CS ranged from 0.00 to 2.25. Participants stood 1 meter from the chart and named each letter in succession. Sensitivity was measured as the faintest triplet for which 2 of 3 letters were named correctly.

Right foot sensation testing was conducted to better classify the degree of peripheral neuropathy, as the initial screening was conducted only using the 8-g monofilament for inclusion in the PN group, and exclusion from the OP and NA groups. During the in-clinic evaluation, the OT completed threshold testing using the 20 piece Touch-Test Sensory Evaluators kit (Semmes-Weinstein Monofilaments), testing the same sites as in the screening on the right foot and holding the monofilament at a 90 degree angle against the skin until it bowed. It was held for 1.5 seconds and then removed. Table 2 shows the evaluator size and associated target force and plantar thresholds.[4] For monofilament evaluators labeled 1.65 to 4.08, the stimulus was applied to the same location up to 3 times to elicit a response. A single response indicated a positive response. For monofilament evaluators labeled 4.17 through 6.65, the stimulus was applied only once. The evaluator labeled 2.83 was used first, and if the participant responded to the stimulus in all sites, the OT recorded normal cutaneous sensation and the examination was complete. If the participant did not respond to the stimulus, the OT chose the next largest monofilament and repeated the process. When the participant indicated a response, the OT noted the filament size.

The in-clinic evaluation required between 1.5 and 3 hours to complete, per study participant. Drivers who passed the in-clinic evaluation were scheduled for the on-road evaluation at no cost to the participant. If the participant passed the in-clinic assessment, but did not meet study inclusion criteria (e.g., their medical record showed evidence of cognitive impairment indicating dementia, even though they scored below 10 on the SBT), he or she was offered the on-road evaluation at cost to the individual. Only drivers who passed the in-clinic evaluation[5] were permitted to have an on-road evaluation with the CDRS.

---

[4] The Semmes Weinstein monofilaments are labeled to give a linear scale of perceived intensity (a logarithmic scale of applied force). Handle markings = Log10 of (10 x force in milligrams).

[5] Pass or fail was determined according to RCP criteria, and the OT did not find reason to believe the drivers were permanently at-risk for safety on the road.

Table 2. Touch-Test Sensory Evaluators and Associated Foot Plantar Thresholds

Evaluator Size (Monofilament Handle Label)	Target Force (grams)	Plantar Threshold
1.65	0.008	Normal
2.36	0.02	
2.44	0.04	
2.83	0.07	
3.22	0.16	
3.61	0.4	
3.84	0.6	Diminished Light Touch
4.08	1	
4.17	1.4	
4.31	2	
4.56	4	Diminished Protective Sensation
4.74	6	
4.93	8	
5.07	10	Loss of Protective Sensation
5.18	15	
5.46	26	
5.88	60	
6.10	100	
6.45	180	
6.65	300	Deep Pressure Sensation Only

If a participant failed the in-clinic assessment, the CDRS evaluated the individual for appropriate, adaptive driving equipment training, and the participant was excused from study participation. If the CDRS determined that the individual was no longer appropriate to drive under any circumstance, the CDRS reported the driver to the South Carolina Department of Motor Vehicles, following standard reporting procedures for the Driving Rehabilitation Program.

On-Road Evaluation

The on-road evaluation was a standardized assessment offered by the driving program at RCP. The road course used in this study was identical to that used by RCP patients, with the addition of a parking lot component, a parking garage component, and a component designed to emulate the startle response. The on-road and parking evaluations were completed in one session that lasted between 1.5 and 2.5 hours.

Before the drive, the CDRS assisted the research participant in adjusting the seat of the instrumented vehicle to ensure the best fit in the vehicle. Although poor fit in the vehicle was identified in the earlier study as a potential contributing factor to pedal application errors, the RCP driving program and the GHS IRB did not allow the CDRS to permit a driver to participate in a driving evaluation using poor seat adjustment that may have corresponded to the usual way he or she would select the seating position in his or her own vehicle. Following the necessary seating adjustments, the CDRS oriented the driver to the vehicle’s controls and displays.

The CDRS directed each participant to proceed along a 27-mile route through the community that included a mix of residential, arterial, and interstate traffic conditions which exposed the driver to a broad range of roadway types, speeds, intersection control, and maneuvers. The route included intersections with stop signs and traffic signals, and left- and right-turn maneuvers—situations that required frequent accelerator to brake movements.

A parking skills assessment was conducted on the GHS campus. This was scheduled at the conclusion of the on-road course for two reasons: (1) the CDRS would have a good understanding of the drivers' capabilities and limitations; and (2) earlier research suggested that older drivers make the largest percentage of their pedal application errors during parking maneuvers, and often at the end of a trip, when they relax their vigilance.

Participants were directed to access two gated parking lots; these included a garage that provided a low visual contrast environment, and an outdoor lot in daylight. The CDRS directed the participant to stop the vehicle at a gated access and lean out of the driver's side window to swipe a parking pass, and then to proceed into the parking garage. This maneuver replicated several actions described in the pedal application crash narratives/news media reports examined by Lococo, Staplin, Martell, and Sifrit (2012). Those actions included retrieving food from a drive-through window, stopping at a gate to a self-storage facility or other gated facility and entering a pin number to access the facility, and conducting transactions at drive-through automatic teller machines. In these situations, the drivers' heads were turned, and they were reaching (out of driving position, perhaps) and performing some non-driving activity before resuming driving.

When possible, participants performed four parking maneuvers between a GHS vehicle and an exterior wall. Two maneuvers required the participants to pull straight into this designated space; the other maneuvers required the participant to approach the designated space and perform a 90-degree parking maneuver.

Near the end of the drive, The CDRS instructed participants that at some unknown time, she would ask them to perform an emergency stop as quickly as possible. The CDRS directed participants to proceed through a gate into a parking lot, requiring them to swipe a parking pass. Then they drove around a short, sparsely traveled perimeter road. When there were no other cars in the area, the CDRS gave a loud, urgent command to "stop" (a simulated startle stimulus). Earlier research indicated that drivers often made pedal application errors when startled. When planning this component of the study, the CDRS determined that forewarning participants of the emergency stop was in the best interest of public safety, and maintained professional integrity and trust between the therapist and client, as opposed to providing a truly unaware startle stimulus.

Throughout the test drive, the CDRS scored performance using an assessment protocol consisting of the standard evaluation checklist (see Appendix C). A behaviorally anchored rating scale developed for this project was also used to evaluate driving performance (See Appendix D), but the CDRS completed this evaluation following the drive by watching video recorded by the in-vehicle cameras. This was to avoid heads-down paperwork task demands on the CDRS during the drive. The CDRS was blind to group assignment (as the OT conducted the in-clinic assessment), and study group assignment was not provided to the CDRS who conducted the on-road evaluation.

None of the study participants failed the on-road assessment. Had there been a failure, the CDRS would have evaluated the individual for appropriate adaptive driving equipment training. If the CDRS determined that the individual was no longer appropriate to drive under any circumstance, she would have reported the driver to the South Carolina Department of Motor Vehicles, following standard reporting procedures for the Driving Rehabilitation Program.

Sample Recruitment Outcome

The goal was to recruit two groups of 15 older licensed drivers, each with specific medical or functional impairments (orthopedic surgery and peripheral neuropathy), and to compare the performance of each of these groups to a group of 15 normally aging drivers without cognitive or physical impairments. This goal was not met for the reasons described below.

There were 677 patients referred to the driving program at RCP in 2013 and 2014, *apart* from the drivers referred for the purposes of this research study. Each month the study team reviewed the paperwork underlying these referrals to determine whether any were appropriate as research participants. None qualified for the study because the patients typically referred for driving evaluations had an injury or a medical condition at a level of severity that was outside the inclusion criteria.

A total of 80 drivers were referred *specifically* for the study by the physician practices within the GHS:

- 13 with a qualifying surgery for the OP group,
- 25 with PN and
- 42 with NA.

Of the 13 OP referrals, five failed pre-screening, six declined to participate, and two passed both the in-clinic and behind-the-wheel (BTW) evaluations. However, because of instrumented vehicle equipment malfunctions, there was missing video and throttle data for one OP participant. Although this participant completed a second BTW evaluation, only partial foot-movement data were captured for this participant. The missing data made it impossible to calculate conformance of actual foot movement path with the linear path when moving the foot from the accelerator to the brake pedal. This left only one participant in the orthopedics group with complete foot movement data.

Of the 25 PN referrals, 6 failed pre-screening, 2 declined to participate, 4 dropped out of the study on the date they were scheduled for the in-clinic screening, 5 did not respond to study recruitment phone calls, and 1 completed the in-clinic evaluation with normal results and was therefore moved to the NA group. Of the 7 PN participants who completed the study, 6 had good-quality instrumented vehicle data (throttle data and foot-movement video as well as foot contact location and pressure data). One participant's data were unusable because he used his left foot to brake. His foot was out of the camera view, and there were no reflective dot markers on his left shoe to capture foot trajectory.

Of the 42 referrals for the NA group, five failed the pre-screening seven declined to participate, two did not respond to study recruitment phone calls, and two were no-shows. The remaining 26 passed the pre-screening and were eligible to continue study participation. However, one participant experienced a hip injury just prior to the BTW evaluation and no longer qualified for the study due to a change in health status, and another withdrew from the study the day before the scheduled in-clinic evaluation. Of the 24 NA drivers who completed the study, 13 had complete instrumented vehicle and reflective dot marker data. An additional five NA participants produced partial instrumented vehicle data. The six remaining NA participants did not produce usable instrumented vehicle data, including one who used the left foot to brake and had a misaimed front-view camera.

Vehicle Instrumentation for Recording Foot Movements

The instrumented vehicle was a 2011 Chevrolet Malibu with a dual-braking system to allow the CDRS (who accompanied all study participants in the front passenger seat) to stop or slow the vehicle if such intervention was necessary to maintain safe vehicle control. The vehicle was equipped with sensors to permit precise recording of where and how hard a participant's foot contacted the pedals through force and location pressure-sensing covers on the accelerator and brake pedals. Optical video recording of foot movement in the car using two orthogonal cameras provided data about variability in foot position. Three additional video cameras continuously recorded the driver's face and road scene, which was used to assist in the selection of events for the analysis of foot movements (e.g., on approach to a stop sign or signal where a driver must stop or slow). Synchronization of the video data acquisition capabilities with the additional sensors via an onboard computer allowed an integrated analysis of foot movements.

The test vehicle was instrumented with two data collection systems to examine foot movements: (1) a TekScan Contact and Pressure Mapping System and (2) a Videometric Tracking System. Vehicle instrumentation proceeded under the direction of Clemson University's bioengineer and automotive engineer. These systems provided a means of quantifying the dependent foot movement variables in this study:

- brake actuation latency; and
- variability in foot position (just before and during transition from accelerator to brake).

TekScan contact and pressure mapping system. This system measured foot application kinetics and included a TekScan F-Socket2 Versa Tek System (pedals) and a MatScan System (floor). Output from this system documented the physical interaction of the feet on the brake and accelerator pedals and the floor pan. Specifically, it provided foot/pedal event and location contacts with the floor and pedals, pedal application pressures, and rates of loading and unloading. All of the force, location, and pressure mapping sensors were integrated before being linked with the vehicle's other instrumentation.

The TekScan floor mat replaced the standard floor mat in the Chevy Malibu and was placed so all occasions of foot resting could be recorded. Pedal instrumentation was accomplished by placing the sensor material under the brake and accelerator pedal cover to minimize changes to pedal surfaces. This system resulted in low driver invasiveness; the instrumented pedals looked and felt like the stock equipment in the vehicle.

Video equipment specification and layout. Five Weldex WDB 5407 SS 1/3" color bullet cameras were installed in the instrumented vehicle. The camera locations are shown in Figure 1 and described in Table 3.

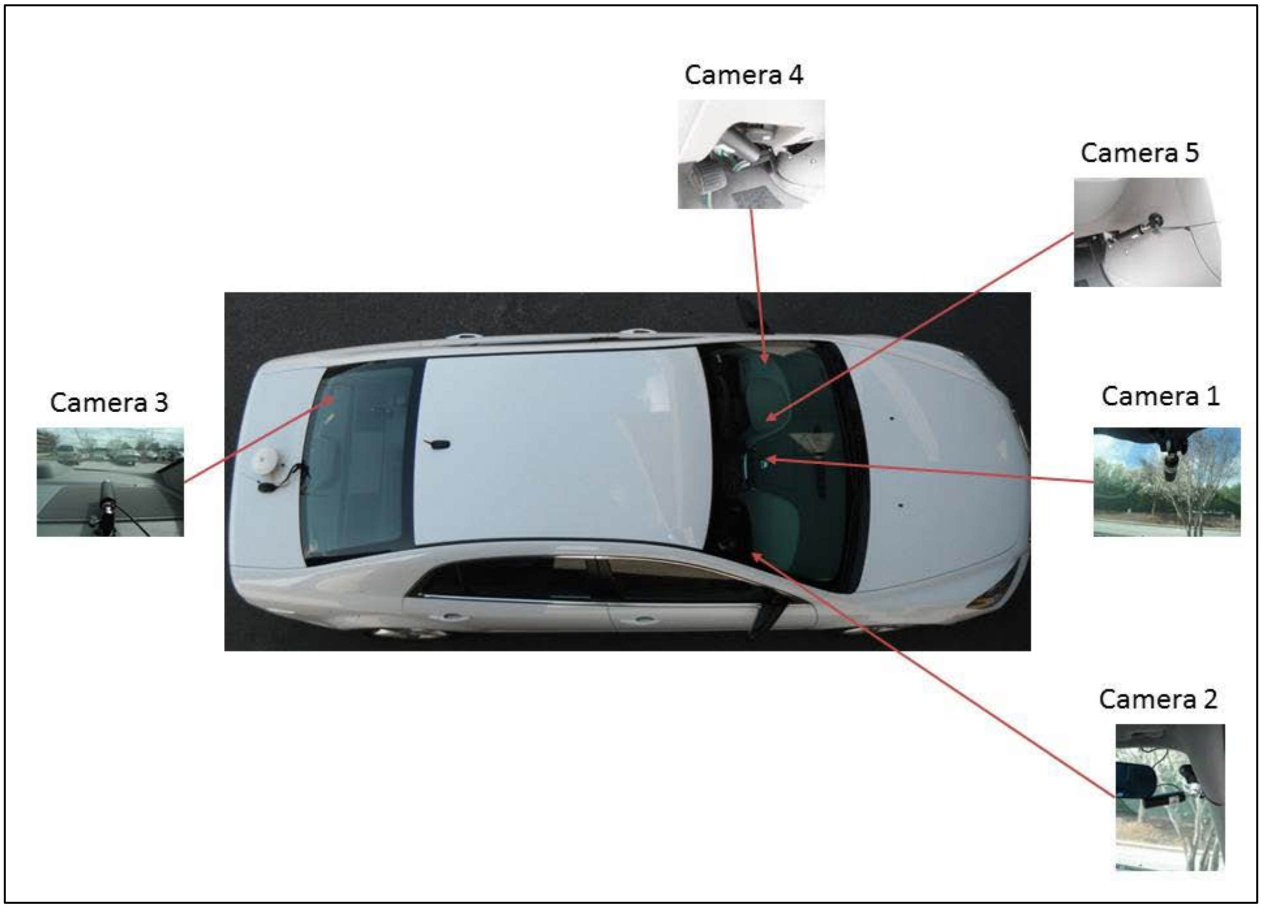


Figure 1. Camera locations.

Table 3. Location and Captured View for the 5 Video Cameras in the Instrumented Vehicle

Camera Number	Location	Camera Direction
1	On the inside of the front windshield behind rear view mirror	Forward traffic
2	On the inside of the front windshield suctioned to the upper passenger side	Driver's bust, hands and vehicle steering wheel
3	Mounted to the rear speaker tray	Rearward traffic
4	Mounted to the underside of the dash on the driver side.	Side view of driver's feet, brake and accelerator
5	Mounted to the center console in the driver foot well	Top down view of driver's feet, brake and accelerator

The Weldex WDB 5407 SS 1/3" CCD color bullet cameras (see Figure 2) had 400 lines of resolution, or 512 (H) x 492 (V) effective pixel resolution. The camera lens angle was 3.6 mm and a fixed focus length. The cameras had a diameter of 21mm and a length of 71 mm. The camera video signals were fed into two VM 401A quad processors, which compiled multiple camera feeds into one feed per quad processor. The total effective pixel resolution of the quad processors was a maximum of 720 (H) x 480 (V), or 180 (H) x 120 (V) for each camera feed. In this case, the resolution was camera limited. The two quad processor feeds were then captured on the Dewetron DEWE-211 data acquisition system. The DEWE-211 captured the quad processor video feeds with 320(H) x 240 (V) effective pixels, I420 video compression, 30 frames per second (fps), and xvid *.avi compression. The final resolution and speed of each camera feed was 80 (H) x 60 (V) effective pixel resolution at 30 fps.

Figure 2. Weldex WDB 5407 SS bullet camera.

Videometric tracking system. This system optically recorded and measured foot/leg positioning and displacements with respect to the car and pedals. The system included two foot-well video cameras (to record top and side views of the feet, see Figure 3) and post-testing video analysis software.

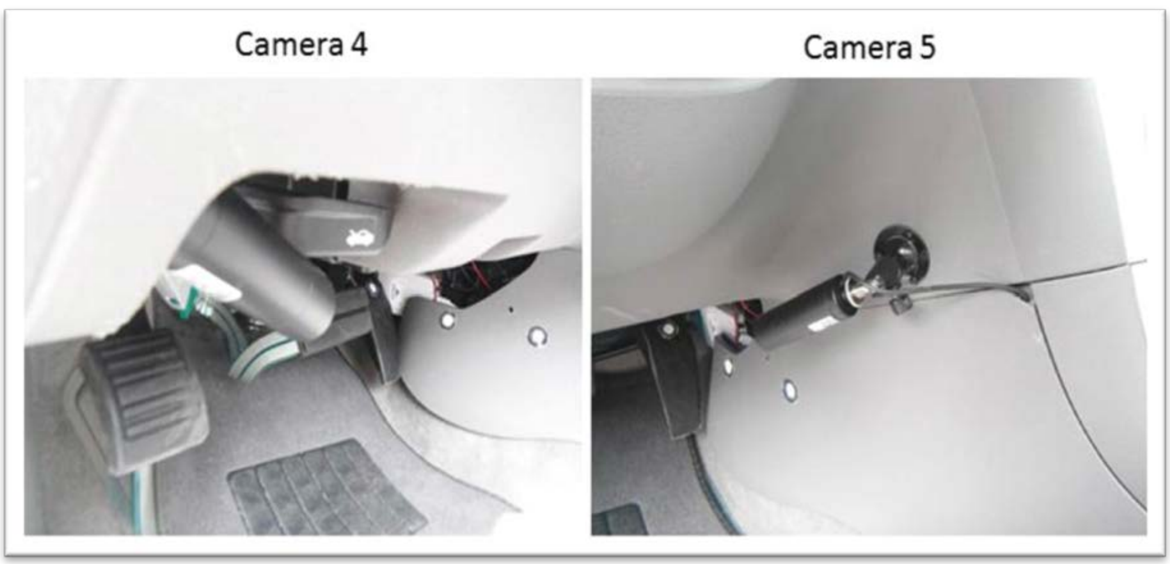


Figure 3. Driver foot well camera location.

To enable assessment of the video and extraction of usable biomechanical measures of foot and leg motions, adhesive-backed paper “dots” were attached to the driver’s feet and legs to allow for the digitization of specific anatomical landmarks. These dots were flat, one inch in diameter, and were easily detached without leaving a residue or damaging surfaces. The dots were placed as shown in Figures 4 and 5 on test participants’ shoes and lower legs or onto their clothing, which was clamped tightly around the leg to prevent the dot from moving out of position with respect to the body. These pictures show the approximate locations of the dot markers. However, all drivers wore shoes.

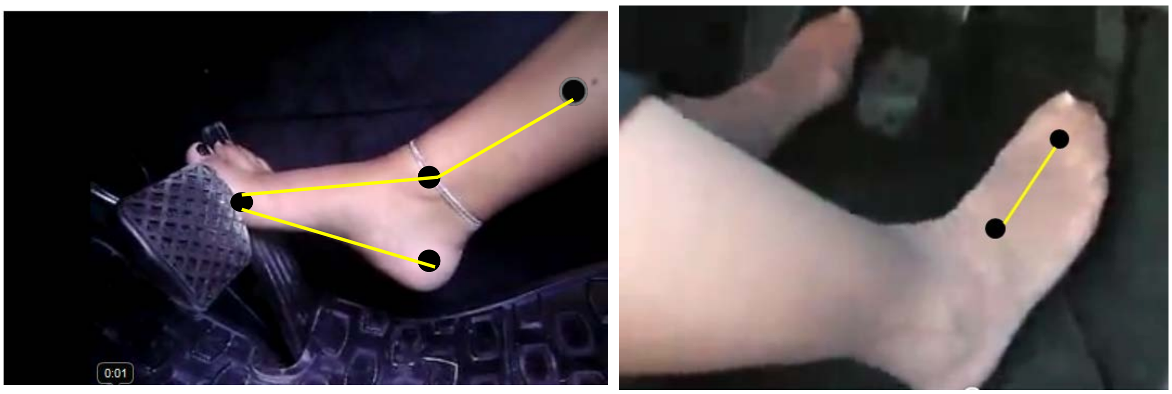


Figure 4: Videometric tracking system.

Figure 5: Driver foot well camera signal.

Dot-digitization software was used to assist post-video analysis; this included a MATLAB add-in tool (DLTdv5) for digitizing video files and calibrating cameras.[6] The system provided motion assessment accuracy, measuring motion in the frontal (left-right) and sagittal (front-back) planes to an accuracy of +/- 1 mm. Additional lighting under the dash provided fore-light for the cameras. The lighting was accomplished by adding three LEDs as shown in Figure 6. The LEDs,

6 www.unc.edu/~thedrick/software1.html

manufactured by Hewlett Packard, had 10,000 mcd of luminous intensity and a view angle of 15 degrees. The three LEDs were wired in parallel and operated from the vehicle's power.

Figure 6: Driver foot well lighting.

Video recording of forward and rearward roadway scene and driver's face. Three Weldex WDB 5407 SS cameras (described earlier) captured the driver's environment. Figure 7 shows images of the mounted cameras. As seen in Figure 8, the cameras were aimed to record the forward traffic, rearward traffic, and the driver.

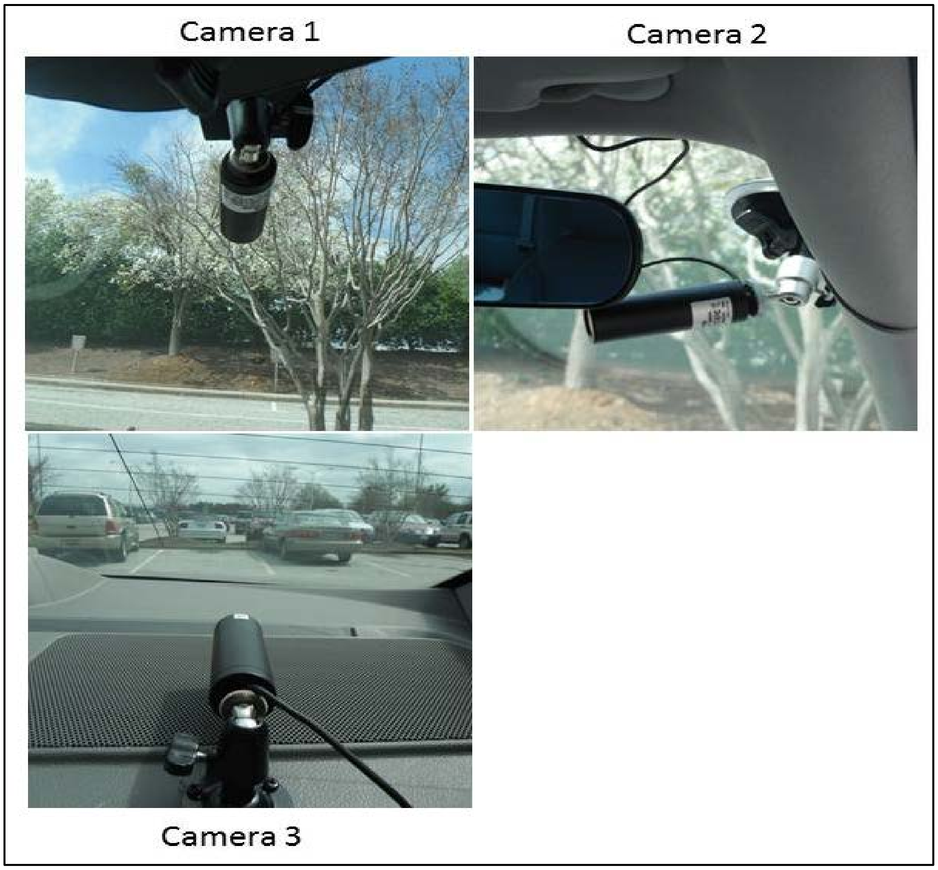


Figure 7. Driver environment cameras.

Figure 8. Driver environment camera feed.

Global positioning system (GPS). The GPS system used in this study was a Trimble Ag 432 unit with differential correction from an Intuicom RTK bridge. (See Figure 9). The two systems used in tandem provided for vehicle positioning that was accurate within ± 1 cm.

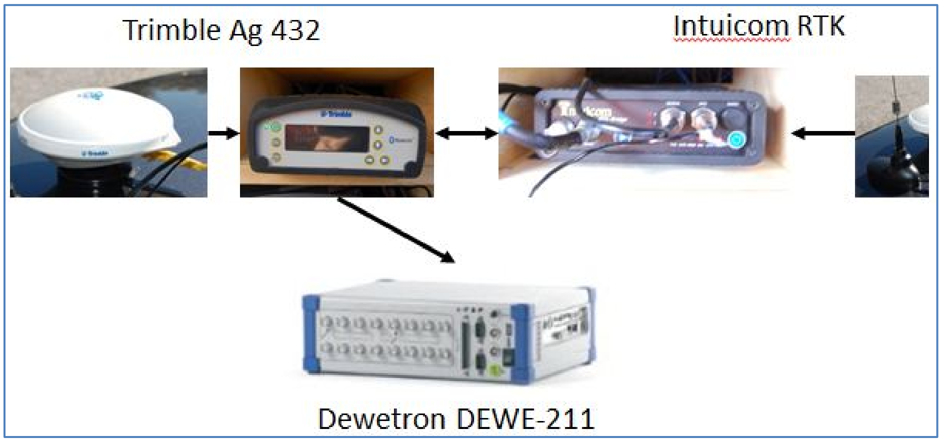


Figure 9. GPS and Dewetron data acquisition components.

The GPS reported three data streams to the Dewetron DEWE-211. These data streams are identified as "GGA," "RMC," and "VTG" in Table 4, which also includes the specific data elements that were saved during each drive. A sample data message received from the GPS system by the DEWE-211 follows.

Table 4. GPS Data Saved During Test Drives

	GGA	RMC	VTG
UTC of position	x	x	
Latitude	x	x	
Direction of latitude	x	x	
Longitude	x	x	
Direction of longitude	x	x	
GPS quality indicator	x		
Number of satellites in view	x		
HDOP	x		
Antenna height	x		
Geoidal separation	x		
Base station ID	x		
Status		x	
Speed over ground		x	x
Track made good		x	x
Date		x	
Magnetic variation		x	
Direction of magnetic variation		x	
Mode indication		x	

Sample GPS message:

$GPGGA,151924,3723.454444,N,122020269777,W,2,09,1.9,-17.49,M,-25.67,M,1,0000*57
$GPRMC,184804.00,A,3723.476543,N,12202.239745,W,000.0,0.0,051196,15.6,E*7C
$GPVTG,0,T,,,0.00,N,0.00,K*33

The Dewetron deciphered received messages similar to the one above 20 times per second to yield the following measures (see Figure 10):

- X absolute
- Y absolute
- Z
- Velocity
- Direction
- Used Satellites
- Current sec
- GPS X,Y, Direction

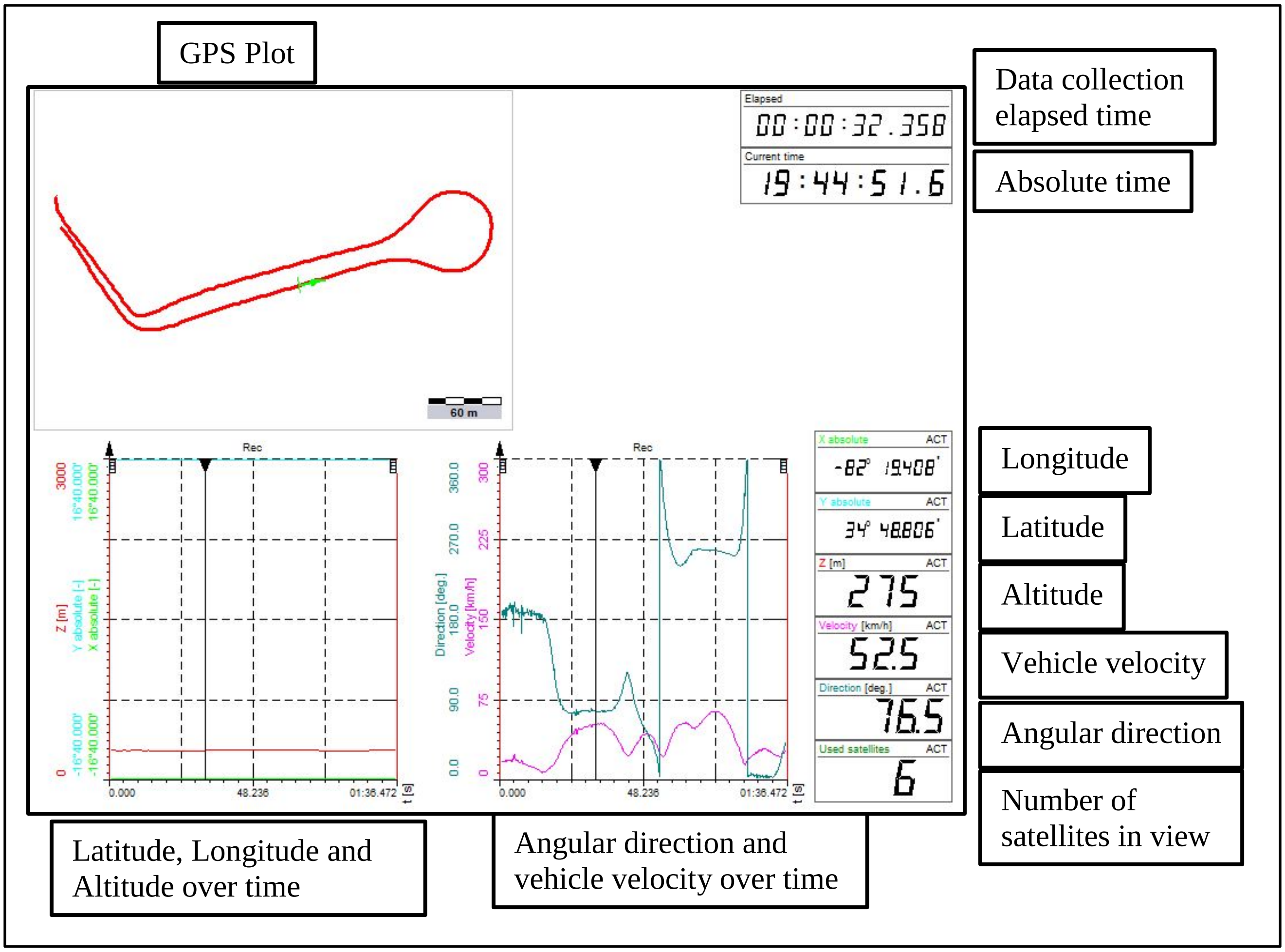


Figure 10. Measures derived by Dewetron from GPS data.

These GPS data allowed analyses of the driver's position in relation to unusual or inefficient foot movements. Using GPS data with Google Earth allowed for a graphical representation of the data. Data provided by the GPS was the only source of vehicle velocity acquired during data collection.

Personal Vehicle Measures

The GHS IRB required separate consent for the personal vehicle measures portion of the study because it was not related to any of the protocols used by the driving program and was considered as a separate study. Appendix E contains the data collection form used to record the driver seat position and interior vehicle measurements. Personal vehicle measures were collected in a parking lot at RCP during the in-clinic session.

The research team obtained the interior vehicle measuring equipment from NHTSA and completed training in its use from NHTSA engineers to ensure proper data collection techniques. Standard tools used to measure the data included:

- A 6-, 12-, and 24-inch Starrett stainless steel ruler with 4R graduation type and graduations of 8ths, 16ths, 32nds, and 64ths.
- 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.
- 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.
- A tailor's measuring tape. The tailor's tape has graduations of 1/8th inch.
- 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.
- 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.

Tools created to obtain the measurements for the data capture were the following:

- A wooden jig was constructed to measure the location of the H-point (hip point). It was made to lessen investigators' physical contact with the participant. The H-point jig simulates the location of the hip joint for the 95th percentile person. The jig dimensions reflect those of the mannequin hip dimensions specified in Society of Automotive Engineering (SAE) standard J826, "Devices for Use in Defining and Measuring Vehicle Seating Accommodation." The H-point jig is shown in Figure 11.

Figure 11. 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. 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. Figure 12 depicts the Vertical Post Rule.

Figure 12. Vertical post rule to capture vertical position of eye-level, steering wheel height, and H-point height.

Data were collected with the vehicle in a parking space, the vehicle gear in the “park” position, the vehicle ignition in the “off” position, the participant sitting in the driver seat of their vehicle, the participant’s hands on the steering wheel, and the participant’s right foot resting on the brake pedal. After the RA took several measures to indicate how the participant was seated in the vehicle, the participant proceeded inside GHS to continue with the in-clinic assessment. Meanwhile, the data collector recorded further detail regarding the vehicle and the driver’s seat selection. After the details were collected, the participant returned and proceeded through the seating portion of the CarFit procedures. Once the participant considered the CarFit guidelines and repositioned his or her seat into a comfortable position, the RA repeated the initial measures.

The OT at RCP, who routinely conducted CarFit sessions, trained the research team members to collect the relevant CarFit data (see Appendix E). The measurements used to “fit” drivers in their seat were used in this study to ensure that participants, whose seats may have been moved for the engineering vehicle measurements, drove away from the study with proper placement.

Results: Foot-Movement Behavior Study

Sample Demographics and Anthropometry

Age and sex. As previously discussed in the Methods-Sample Recruitment Outcome section, there were usable instrumented vehicle data for 26 participants. In Table 5, this set of participants is the analysis group for the foot-movement behavior study. The 18 NA participants include the 13 with complete instrumented vehicle and reflective dot marker data and the five with partial instrumented vehicle data. The PN group includes six participants with good-quality instrumented vehicle data but excludes the participants who used his left foot to brake. The OP group included the one participant with complete foot movement data and the one with partial data. Due to the small PN and OP samples, data for these two groups were combined into one Medical Conditions (MC) group for analysis. A t-test confirmed no significant difference in age between the NA and MC samples.

Table 5. Age by Study Group

Group	n	Age Range (Years)	Average Age (Years)	Standard Deviation (Years)
Normal Aging	**18**	**63-85**	**71.67**	**6.14**
Medical Condition	**8**	**61-83**	**73.50**	**7.89**
Neuropathy	6	61-83	73.33	8.78
Orthopedic Surgery	2	69-79	74.00	7.07
Total	**26**	**61-85**	**72.23**	**6.62**

As shown in Table 6, the male-to-female ratio in the NA group was similar to that of the MC group. A chi-square test confirmed no significant difference in the male-to-female ratio in the NA versus the MC sample.

Table 6. Sex by Study Group

Group	Total Both Sexes (n)	Female (n)	% Female	Male (n)	% Male
Normal Aging	**18**	**7**	**39%**	**11**	**61%**
Medical Condition	**8**	**3**	**38%**	**5**	**63%**
Neuropathy	6	2	33%	4	67%
Orthopedic Surgery	2	1	50%	1	50%
Total	**26**	**10**	**38%**	**16**	**62%**

Height. Table 7 shows little difference in the height distribution as a function of study group. A t-test confirmed no significant difference in height for the NA versus the MC group.

Table 7. Height by Study Group

Group	N	Average Height (in.)	Standard Deviation (in.)
Normal Aging	**18**	**66.81**	**3.42**
Medical Condition	**8**	**67.69**	**4.12**
Neuropathy	6	68.22	4.71
Orthopedic Surgery	2	66.08	1.14
Total	**26**	**67.08**	**3.59**

Table 8 displays height by sex within study group. In both study groups, males were taller on average than females. Across the full sample of 26 participants, males averaged 69.3 inches and females 63.5 inches. *A t-test confirmed that the sample of males was significantly taller than the sample of females ($t=6.56$, $df=24$, $p<.005$).* Both sexes were similar in height across medical status groups.

Table 8. Height by Study Group and Sex

Group	Sex	N	Average Height (in.)	Standard Deviation (in.)
Normal Aging	Female	7	63.52	2.03
	Male	11	68.90	2.25
Medical Condition	Female	3	63.49	2.44
	Male	5	70.20	2.37

Leg length. The ranges and averages for femur, tibia and total leg lengths by sex are shown in Table 9. The femur is the large bone between the hip socket and knee cap, and the tibia is the bone in the lower leg from the knee cap to the ankle bone. As expected, female participants had shorter tibia and femur lengths and shorter overall leg lengths compared to the male study participants. *A t-test confirmed significant differences in total leg length as a function of sex ($t=3.06$, $df=24$, $p<.005$).*

Table 9. Femur, Tibia, and Total Leg Length, by Sex

Sex	N	Femur Length (in.)			Tibia Length (in)			Total Leg Length (in.)		
		Range	Average	SD	Range	Average	SD	Range	Average	SD
Female	10	15.0 – 19.7	17.8	1.4	11.5 – 15.3	13.1	1.2	26.5 – 33.5	30.9	2.3
Male	16	16.1 – 21.2	18.9	1.2	11.0 – 16.6	14.6	1.4	29.5 – 36.5	33.5	2.0

Foot and shoe size. Descriptive statistics presenting women's and men's measured right foot length (inches) without a shoe are shown in Table 10, while Table 11 presents statistics describing the length and width of participants' right shoes (in inches), by sex, on the day of their behind-the-wheel evaluation. Not surprisingly, female participants' feet, and their shoes on the day of testing, were significantly smaller than male participants'. *A t-test confirmed a significant positive difference between males' and females' right foot length ($t=6.24$, $df = 24$, $p<.005$, right shoe length ($t=5.9$, $df=23$, $p<.005$), and right shoe width ($t=3.62$, $df=23$, $p=.001$).* There were no significant differences between overall shoe length and width as a function of study group.

Table 10. Measured Length of Right Foot by Sex

Sex	Right Foot Length (in.)			
	N	Range	Average	SD
Female	10	8.5 – 10.5	9.39	0.63
Male	16	10.12 - 11.26	10.63	0.38

Table 11. Right Shoe Length and Width by Sex

Sex	N	Right Shoe Length (in.)			Right Shoe Width (in.)		
		Range	Average	SD	Range	Average	SD
Female	10	10.16 – 11.97	10.84	0.49	3.46 – 4.53	4.12	0.29
Male	15[a]	11.65 – 14.17	12.39	0.72	3.93 – 4.88	4.5	0.26

[a] Right shoe length and width were not obtained for one male participant in the Control Group

In-Clinic Physical Measures

Light touch, proprioception, and range of motion. Analyses were focused on the lower right extremities (foot and leg), as these are related to vehicle pedal control for most drivers and for the analysis sample. Table 12 displays participants' lower right extremity light touch and proprioception, by study group.

All 18 NA participants, and both OP participants, had intact lower right extremity light touch and ankle proprioception. Of the 6 PN participants, 1 male had impaired light touch sensation, and 1 female had impaired proprioception.

Table 12. Light Touch and Proprioception by Study Group

Group	N	Light Touch: Right Lower Extremity		Proprioception: Right Lower Extremity	
		Intact	Impaired	Intact	Impaired
Normal Aging	**18**	**18**	**0**	**18**	**0**
Medical Condition	**8**	**7**	**1**	**7**	**1**
Neuropathy	6	5	1	5	1
Orthopedic Surgery	2	2	0	2	0
Total	**26**	**25**	**1**	**25**	**1**

There was little difference in range of motion scores across participants as all 26 scored within functional limits on the right hip, right knee, and right ankle elements of the active range of motion (AROM) test. On the manual muscle test, nearly all received a maximum score of five (holds test position against maximal resistance). Exceptions included one participant who scored a four (holds test position against moderate resistance) on right hip flexion, one who scored a four on right knee extension/flexion, and one who received a score of just less than four (holds test position against slight to moderate pressure) on right ankle dorsiflexion.

Gross lower extremity coordination. Table 13 displays gross lower extremity coordination by study group. Two of the 18 NA participants and 4 of the 8 PN participants had impaired gross coordination of the right lower extremity. Both OP participants scored as intact on this measure.

Table 13. Gross Lower Extremity Coordination

Group	N	Intact (N)	Impaired (N)
Normal Aging	**18**	**16**	**2**
Medical Condition	**8**	**4**	**4**
Neuropathy	6	2	4
Orthopedic Surgery	2	2	0
Total	**26**	**20**	**6**

Foot plantar threshold. The occupational therapist conducted a comprehensive test of right foot sensation to better characterize plantar threshold and the severity of peripheral neuropathy in the PN group since the initial screening was conducted only using the 8g monofilament (4.93 evaluator size) for group assignment. Figure 13 displays the number of participants at each foot plantar threshold by study group.

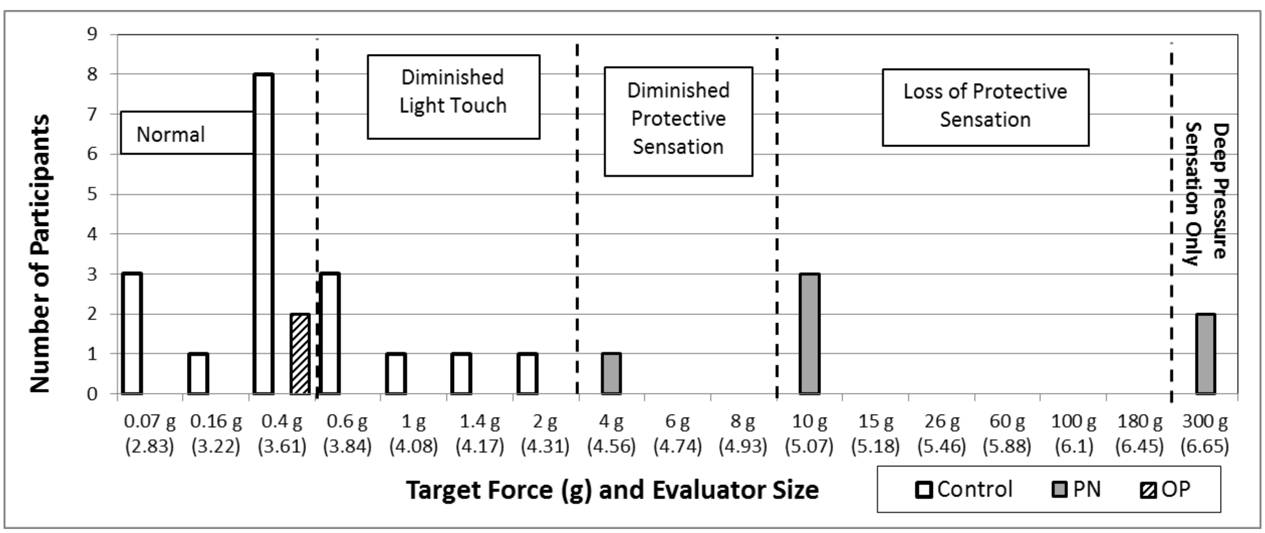


Figure 13. Plantar threshold, target force (grams) and evaluator size (handle marking), by study group.

Table 14 presents the average and standard deviation target force (g) by group. The wide range in measured target force (g) and small number of participants resulted in a large group variance for the MC group. Therefore, statistical analyses of differences in foot plantar thresholds were performed using the evaluator size (a logarithmic scale of applied force that provided a linear scale of perceived intensity). As expected given the study design, *t-tests indicated significant differences in plantar threshold between the NA and MC groups (t=3.49, df=8, p=.008).*

Table 14. Average Target Force (grams) and Evaluator Size, by Study Group

Group	N	Target Force (g)	
		Average	SD
Normal Aging	**18**	**0.54**	**0.49**
Medical Condition	**8**	**79.35**	**136.25**
Neuropathy	6	105.67	150.55
Orthopedic Surgery	2	0.4	0
Total	**26**	**24.79**	**81.08**

TUG test. Table 15 presents the descriptive statistics for the TUG measure by study group. Performance of the NA and OP groups was similar, but participants in the PN group took longer to perform the TUG. *A t-test confirmed significant differences in the time to complete the TUG for NA versus MC participants (t=-3.10, df=24, p<.005).*

Table 15. Average TUG Scores, by Study Group

Group	N	Average (sec.)	Standard Deviation (sec.)	N with Impairment (>9 seconds)
Normal Aging	**18**	**7.72**	**1.05**	**2**
Medical Condition	**8**	**9.26**	**1.43**	**6**
Neuropathy	6	9.70	1.11	5
Orthopedic Surgery	2	7.95	1.89	1
Total	**26**	**8.20**	**1.36**	**8**

Brake reaction time. Table 16 compares brake reaction time by study group, and shows that the groups performed similarly. All but one of the participants used their right foot for the brake reaction time test. One male with PN used his left foot on this device, but he used the right foot for braking and acceleration movements in the BTW portion of the study. A t-test found no significant difference in brake reaction time as a function of study group.

Table 16. Brake Reaction Time, by Study Group

Group	N	Average (sec.)	Standard Deviation (sec.)
Normal Aging	**18**	**0.48**	**0.09**
Medical Condition	**8**	**0.53**	**0.10**
Neuropathy	6	0.53	0.11
Orthopedic Surgery	2	0.52	0.06
Total	**26**	**0.49**	**0.09**

Neck range of motion. Normal AROM of the neck is 60 degrees rotation, 40 degrees flexion, and 45 degrees extension. Five of the 26 participants had abnormal neck AROM. These included both OP group participants (one with half the normal range of motion and the other with a very slight limitation in AROM), one PN group participant (half ROM), and two NA group participants (one with ¼ lost ROM and the other with ½ lateral ROM).

Trunk control/sitting balance. All 26 participants' static and dynamic trunk control/sitting balance was assessed as intact. Intact static trunk control was the ability to sit at the edge of a chair unsupported. Intact dynamic trunk control was the ability to maintain sitting balance when the OT slightly pushed the participant forward and back, and side to side.

Pain. Self-reported pain on a 0-10 scale was 0 for 23 of the 26 participants. One NA group participant reported a pain level of 6 for the left knee, and two PN group participants reported pain at levels of 4 and 2 without any specific site.

In-Clinic Cognitive and Visuospatial Measures

This section summarizes performance on a selected subset of the cognitive and visuospatial measures collected during the in-clinic evaluation.

Short blessed test. Descriptive statistics for this measure by study group are shown in Table 17. All three groups scored in the normal range, which required making no more than two errors. A t-test found no significant difference in SBT score as a function of study group.

Table 17. Short-Blessed Test Performance, by Study Group.

Group	N	Average Score	Standard Deviation
Normal Aging	**18**	**0.67**	**1.37**
Medical Condition	**8**	**2.00**	**1.85**
Neuropathy	6	2.00	1.79
Orthopedic Surgery	2	2.00	2.83
Total	**26**	**1.08**	**1.62**

Trail-Making Test. The trail-making tests are a measure of executive functioning. Parts A and B both test visual scanning, numeric sequencing, and visuomotor speed; Part B also includes mental flexibility or divided attention. As shown in Table 18, performance on the Trail Making Part A test was similar across study groups. A t-test confirmed that there were no significant differences in Trails A performance as a function of study group.

Table 18. Trail-Making Test Part A Performance, by Study Group

Group	N	Average (sec.)	Standard Deviation (sec.)
Normal Aging	**18**	**31.00**	**10.79**
Medical Condition	**8**	**32.00**	**7.96**
Neuropathy	6	32.17	8.47
Orthopedic Surgery	2	31.50	9.19
Total	**26**	**31.31**	**9.86**

Table 19 shows that participants in the NA group completed the Trail-Making Part B test faster than the PN and OP groups. *A t-test indicated a significant difference in completion time between the NA and MC groups (t=-2.17, df = 24, p=.04)).* None of the study participants evidenced a significant impairment (180 seconds or more) on this measure of search and sequencing with divided attention.

Table 19. Trail-Making Test Part B Performance, by Study Group

Group	N	Average (sec.)	Standard Deviation (sec.)
Normal Aging	**18**	**82.00**	**23.13**
Medical Condition	**8**	**101.38**	**14.51**
Neuropathy	6	103.00	13.16
Orthopedic Surgery	2	96.50	23.33
Total	**26**	**87.96**	**22.50**

Benton Three-Dimensional Constructional Praxis Test. This test identifies disturbance in the spatial aspects of assembling, building, and drawing exhibited by people who have had a severe head injury or stroke, although age-related changes may also produce signs of constructional apraxia in healthy older adults (Fall, 1987). Time to assemble each of the three designs in this test of constructional apraxia by study group is shown in Table 20; number of errors is shown in Table 21. Participants constructed each design by copying a completed design. Model 1 was the easiest, and Model 3 was the most complex. T-tests confirmed that there were no statistically significant differences in completion time or number of errors in model construction as a function of study group.

Table 20. Completion Time by Study Group for the Benton Three-Dimensional Constructional Praxis Test

Completion Time (Seconds)		Normal Aging (n = 18)	Medical Condition (n = 8)	Neuropathy (n = 6)	Orthopedic Surgery (n = 2)
Model I	Minimum (sec.)	**5**	**6**	6	7
	Maximum (sec.)	**15**	**12**	12	10
	Average (sec.)	**8.89**	**9.00**	9.17	8.50
	Standard Deviation (sec.)	**2.59**	**1.93**	2.04	2.12
Model II	Minimum (sec.)	**12**	**17**	18	17
	Maximum (sec.)	**36**	**39**	39	39
	Average (sec.)	**20.94**	**25.88**	25.17	28.00
	Standard Deviation (sec.)	**7.01**	**9.14**	8.13	15.56
Model III	Minimum (sec.)	**35**	**29**	29	44
	Maximum (sec.)	**128**	**100**	100	59
	Average (sec.)	**56.94**	**62.00**	65.50	51.50
	Standard Deviation (sec.)	**22.94**	**21.23**	23.45	10.61

Table 21. Number of Errors by Study Group for the Benton Three-Dimensional Constructional Praxis Test

Number of Errors		Normal Aging (n = 18)	Medical Condition (n = 8)	Neuropathy (n = 6)	Orthopedic Surgery (n = 2)
Model I	Minimum	0	0	0	0
	Maximum	0	0	0	0
	Average	0	0	0	0
	Standard Deviation	0	0	0	0
Model II	Minimum	0	0	0	0
	Maximum	2	0	0	0
	Average	0.22	0	0	0
	Standard Deviation	0.65	0	0	0
Model III	Minimum	0	0	0	0
	Maximum	4	4	4	0
	Average	0.33	0.50	0.67	0
	Standard Deviation	1.03	1.41	1.63	0

Symbol Digit Modality Test. The Symbol Digit Modality Test (SDMT) measures the time to pair abstract symbols with specific numbers. The test requires elements of attention, visuoperceptual processing, working memory, and psychomotor speed. It has been used to detect the presence of brain damage, as well as changes in cognitive functioning over time and in response to treatment. The score is the number of correctly coded items, from 0-110, in 90 seconds. Table 22 shows the number of correctly coded items on the written SDMT by study group. A t-test indicated no significant differences as a function of study group.

Table 22. Number of Correctly Coded Digits on the Written Symbol Digit Modality Test by Study Group

Group	N	Average Correct	Standard Deviation Correct
Normal Aging	**18**	**45.5**	**6.94**
Medical Condition	**8**	**42.13**	**4.73**
Neuropathy	6	42	5.51
Orthopedic Surgery	2	42.5	2.12
Total			

Letter Cancellation Test. The Letter Cancellation Test is used to evaluate the presence and severity of visual scanning deficits and to evaluate hemi-spatial neglect. Table 23 shows time to complete this test by study group, and Table 24 shows the number of errors. T-tests indicated an absence of significant differences between groups for letter cancellation time or errors.

Table 23. Letter Cancellation Completion Time, by Study Group

Group	N	Average (sec.)	Standard Deviation (sec.)
Normal Aging	**18**	**71.39**	**9.36**
Medical Condition	**8**	**72.25**	**21.42**
Neuropathy	6	78.50	21.21
Orthopedic Surgery	2	53.50	4.95
Total	**26**	**71.65**	**13.72**

Table 24. Letter Cancellation Errors, by Study Group

Group	N	Average	Standard Deviation
Normal Aging	**18**	**0.44**	**1.25**
Medical Condition	**8**	**1.00**	**2.45**
Neuropathy	6	0.00	0.00
Orthopedic Surgery	2	4.00	4.24
Total	**26**	**0.62**	**1.68**

In-Clinic Vision Measures

Acuity. Table 25 presents the percent of participants by study group with near and far acuity at 20/20, 20/30, 20/40, and 20/50. A Fisher's Exact Test showed no significant difference in the proportion of participants with acuity at each level, as a function of study group. All participants met the South Carolina DMV vision requirements for licensure (20/70 or better in at least one eye, or if the weaker eye is less than 20/200, the stronger eye must be 20/40 or better), a criterion for participation in the study. The similarity of vision scores across groups indicates that any observed performance differences in the foot movement portion of the study would not stem from differences in acuity.

Table 25. Bilateral Near and Far Visual Acuity, by Study Group

Bilateral Visual Acuity: Near

Group	N	20/20 n (%)	20/30 n (%)	20/40 n (%)	20/50 n (%)
Normal Aging	**18**	**7 (38.9%)**	**9 (50%)**	**1 (5.6%)**	**1 (5.6%)**
Medical Condition	**8**	**1 (12.5%)**	**4 (50%)**	**3 (37.5%)**	**0 --**
Neuropathy	6	1 (16.7%)	4 (66.7%)	1 (16.7%)	0 --
Orthopedic Surgery	2	0 --	0 --	2 (100%)	0 --
Total	**26**	**8 (30.8%)**	**13 (50%)**	**4 (15.4%)**	**1 (3.8%)**

Bilateral Visual Acuity: Far

Group	N	20/20 n (%)	20/30 n (%)	20/40 n (%)	20/50 n (%)
Normal Aging	**18**	**8 (44.4%)**	**5 (27.8%)**	**2 (11.1%)**	**3 (16.7%)**
Medical Condition	**8**	**2 (25%)**	**1 (12.5%)**	**3 (37.5%)**	**2 (25%)**
Neuropathy	6	2 (33.3%)	0 --	3 (50%)	1 (16.7%)
Orthopedic Surgery	2	0 --	1 (50%)	0 --	1 (50%)
Total	**26**	**10 (38.5%)**	**6 (23.1%)**	**5 (19.2%)**	**5 (19.2%)**

Contrast sensitivity. Tables 26 and 27 summarize performance on the Pelli-Robson contrast sensitivity test (in log CS units), and show that the average log CS was similar across study groups. A t-test confirmed the absence of significant differences between study groups.

Table 26. Binocular Contrast Acuity, by Study Group

Group	N	Average (log.)	Standard Deviation (log.)
Normal Aging	**18**	**1.78**	**0.24**
Medical Condition	**8**	**1.73**	**0.20**
Neuropathy	6	1.73	0.18
Orthopedic Surgery	2	1.73	0.32
Total	**26**	**1.76**	**0.23**

Table 27. Distribution of Binocular Log Contrast Sensitivity Scores, by Study Group

		Number of Participants (%) With Log CS:			
Group	**N**	**1.05**	**1.5**	**1.65**	**1.95**
Normal Aging	**18**	**1 (5.6%)**	**1 (5.6%)**	**6 (33.3%)**	**10 (55.6%)**
Medical Condition	**8**	**0 --**	**2 (25%)**	**3 (37.5%)**	**3 (37.5%)**
Neuropathy	6	0 --	1 (16.7%)	3 (50%)	2 (33.3%)
Orthopedic Surgery	2	0 --	1 (50%)	0 --	1 (50%)
Total	**26**	**1 (3.8%)**	**3 (11.5%)**	**9 (34.6%)**	**13 (50%)**

On-Road Foot Movements

The NHTSA TOM and project team selected 10 locations along the 27-mile test route where all participants were required to brake, such as for a stop sign, and for parking and reversing out of parked positions for a detailed analysis of foot movements between the accelerator and brake. One location involved an emergency stop maneuver. This study design permitted a comparison of braking behaviors at the same point in the test route for each participant.

None of the study participants exhibited a pedal application error on the test route or during the parking or emergency stop maneuvers.

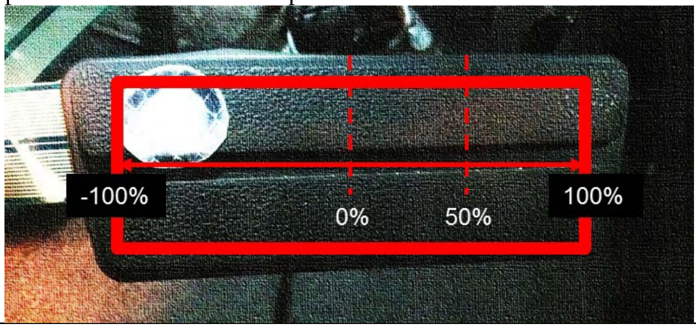
The test route is shown in the following link and in Appendix F: www.google.com/maps/d/viewer?mid=zWQrdxISD9kU.kO9aifk2oIRw. The 10 locations/maneuvers selected for analyses of foot movements are as follows:

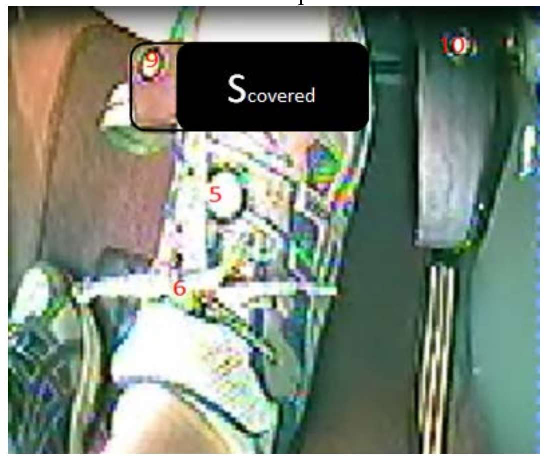
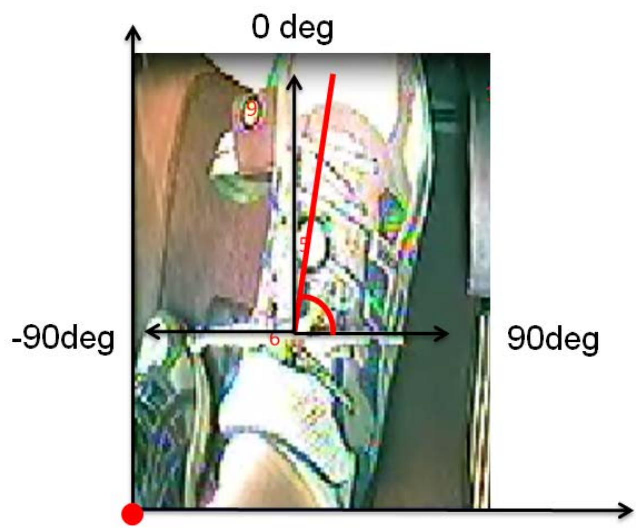
1. 3-way stop at Seven Oaks and Michaux (neighborhood portion of drive; Seven Oaks is below Location D on the map).
2. Reverse at Anthony Place (neighborhood portion of drive; Location B on the map).
3. Reverse 1 in parking garage (Location 13 on the map).

4. Reverse 2 in parking garage (location 13 on the map).
5. Reverse in parking lot (location 18 on the map).
6. Straight parking in parking lot (location 17 on the map).
7. Straight parking in parking garage (location 14 on the map).
8. Gate access when entering parking garage (location 11 on the map).
9. Gate access when entering parking lot (location 16 on the map).
10. Emergency stop (location 15 on the map).

The metrics calculated from video, Tekscan, and dot marker data that were used in the analysis of foot movements are described in Table 28. As indicated earlier, complete foot movement data were captured for 13 NA participants, 5 PN participants, and 1 OP participant. Partial foot movement data were captured for 5 NA, 1 PN, and 1 OP participant. Foot movements did not always occur for several measures described in Table 28 (such as hovers in ID N and transfers in ID B); thus, for some measures there are fewer data points than participants with complete data.

Table 28. Metrics used to Describe Foot Movements along the Test Route

ID	Metric	Units	Explanation
A	Type of foot movement from accelerator to brake (1=pivot, 2=lift)		"Pivot" refers to the type of foot transfer movements between pedals where the heel does not lift from the floor; "Lift" refers to the type of foot transfer movements between pedals where the heel lifts from the floor.
B	Foot transfer time from accelerator to brake	S	The foot transfer time starts when the accelerator travel drops below 2% of the full pedal travel and ends when the brake pedal travel increases over 10% of the full pedal travel.
C	Foot placement on brake pedal (center of force to right edge over brake pedal width)	%	Proximity to right edge of brake where center of force is applied; right edge = 100%. The percent representing foot placement is shown in the picture. 

ID	Metric	Units	Explanation
D	Average foot contact area (detected by Tekscan sensors) on brake pedal (Contact area over brake pedal size). Range = 1 to 100.	%	Foot contact area on brake pedal = Surface Covered/Pedal Size 
E	Conformance of actual foot movement path with the shortest (most direct, or linear) path from accelerator to brake. Range = 1 to 100, where 100% represents full conformance of foot movement with shortest path.	%	Conformance=[(linear path)/(actual path) (top view)+(linear path)/(actual path) (side view)]/2 
F	Average foot internal-external angle during reach & swipe (if foot is on brake)	Deg	This metric is only used for the gate access task. See metric H. This foot movement was observed during the reach and swipe period during the gate access. The start for “reach and swipe” duration was triggered when the badge crossed the window as the participant reached out of the vehicle to swipe the badge into the reader, and the end was when the badge crossed the window, as the participant brought their arm back into the vehicle.
G	Average foot internal-external angle NOT during reach & swipe (if foot is on brake). Observed as the participant slowed and stopped at the gate.	Deg	The foot internal-external angle is defined as shown on in the picture. 

ID	Metric	Units	Explanation
H	Average foot placement on brake pedal during reach & swipe (if foot is on brake)	%	This metric is only used for the gate access task: This is metric D. The start time was when the badge crossed the window as the participant reached their arm out of the vehicle (to swipe the badge to open the gate). The end time was when the badge crossed the window when the participant brought their arm back into the vehicle.
I	Average foot placement on brake pedal NOT during reach & swipe (if foot is on brake).	%	This metric is only used for the gate access task: This is metric D, observed as the participant approached the gate and moved their foot to slow and stop the vehicle.
J	Average foot contact area on brake pedal during reach & swipe (if foot is on brake)	%	This metric is only used for the gate access task: This is metric E. The start time was when the badge crossed the window as the participant reached their arm out of the vehicle (to swipe the badge to open the gate). The end time was when the badge crossed the window when the participant brought their arm back into the vehicle.
K	Average foot contact area on brake pedal NOT during reach & swipe the card (if foot is on brake)	%	This metric is only used for the gate access task: This is metric E, observed as the participant approached the gate and moved their foot to slow and stop the vehicle.
L	Average brake pedal force	lb.	(This metric is only used for the emergency stop and at the 3-way stop)
M	Maximum brake pedal force	lb.	(This metric is only used for the emergency stop and at the 3-way stop)
N	Total duration of hovering	S	The hovering movement starts when the brake pedal travel drops below 10% of its full travel range and ends when it is over 10% of its full travel range. This metric sums hovering time, if several hovers occurred during the maneuver.

The magnitude of several foot movement metrics is most certainly underrepresented; namely foot contact area on brake pedal (ID D) and brake pedal force (ID L and M). The sensitivity of the Tekscan sensor was reduced by the cover placed on the brake pedal. The Tekscan sensor was capable of capturing the full contact area *if* the participant pressed hard enough on the brake. The pedal cover was a piece of hard rubber that may have prevented the sensor from successfully capturing the full contact. This may have reduced the accuracy of the contact force reading (see Figure 14). The metric describing foot contact area on brake (ID D) across all 10 locations ranged from 1 to 45%. The Malibu's brake pedal measured 5 inches in width. Female study participants' shoe width ranged from 3.5 to 4.5 inches (average 4.1 inches), and males' ranged from 3.9 to 4.9 inches (average 4.5 inches). If the average female fully contacted the brake, the proportion of coverage would be 82%, and if the average male fully contacted the brake, the proportion of coverage would be 90%.

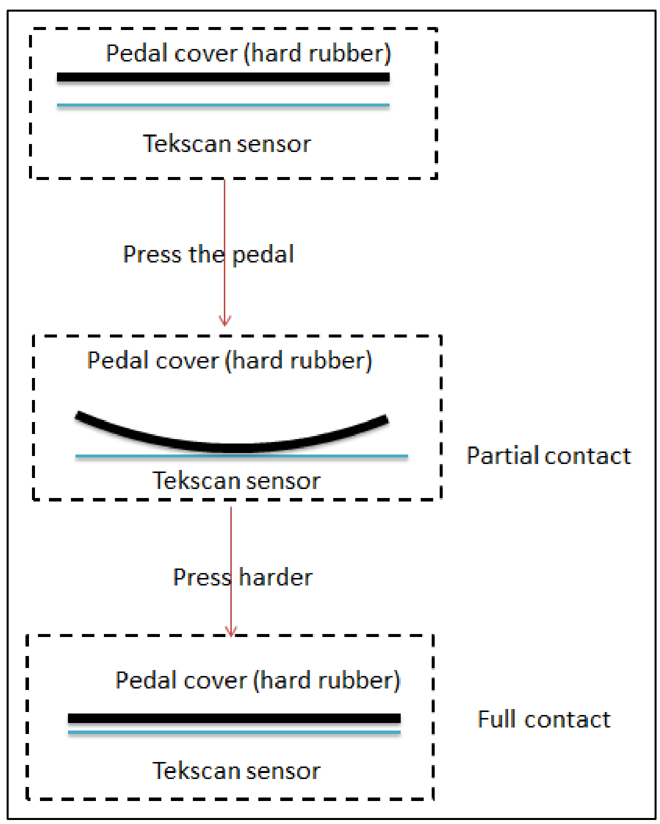


Figure 14. Potential reduction of foot contact area on brake and brake force measures.

The low recorded proportions of coverage compared to the expected proportions may be the result of (1) participants' feet hanging off the brake pedals, for example, if the left portion of the foot contacted the pedal and the right portion of the foot hung off the pedal; (2) participants not pressing hard enough for the sensor to register full contact; or (3) both (1) and (2). The team member who reduced the foot movement data from the video confirmed that participants' feet commonly did not fully contact the brake pedal (a portion of the foot hung off to the right). The metric describing foot placement on the brake describes the center of foot pressure in relation to the lateral brake center. Where this metric was captured, foot placement was most often 50% to 80% of the distance between the middle of the brake and the right edge of the brake.

Analyses were conducted within each of the 10 locations/maneuvers, using the 24-foot movement dependent measures in Table 28 where relevant to the task and where data existed for at least five participants in each analysis group to answer the following research questions:

- Did foot position and/or variability in foot movement differ by medical condition (as compared to the NA group)?
- Did foot position and/or variability in foot movement differ by sex?

Study analysts used t-tests to describe differences in the *continuous* dependent variables (measures B-O) as a function of the categorical independent variables (sex and study group). Separate t-tests examined the relationship between study groups (NA versus MC) and each of these dependent variables, and between sex and each of these dependent variables, in isolation. For any dependent variable where a significant relationship was indicated for *both* study group and sex, an ANOVA including both independent variables was performed, to address the inflation in experiment-wise error rate that could be associated with the aforementioned multiple comparisons.

Chi-square tests describe differences in the *categorical* dependent variable (measure A) as a function of sex and study group. Study analysts used conventional chi-square tests when observed counts in each cell of the contingency table were at least five, and Fisher's Exact Test when observed cell counts were smaller than five.

The researchers analyzed foot movements as a function of the following *continuous* independent variables:

- Driver anthropometry
    - Driver height
    - Shoe length
    - Femur (upper leg) length
    - Tibia (lower leg) length
    - Total leg length (femur + tibia)
- Cognitive performance
    - Trails A time
    - Trails B time
    - Letter cancellation time
    - Symbol-digit, number correct
- Physical performance
    - TUG test

- Plantar threshold (Weinstein monofilament test)
- Brake reaction time

Table 29 presents the intercorrelation matrix for these 12 independent variables. The driver anthropometry measures (height, shoe length, femur length, tibia length, and total length) were all positively and significantly intercorrelated, indicating that taller participants had longer upper and lower leg lengths and longer shoe lengths as well. Plantar threshold was positively and significantly correlated with TUG time and Trails B time, indicating the greater the loss of foot sensitivity to touch, the slower the walk time, and longer to complete Trails B. Brake RT was also positively and significantly correlated with Trails B time. Finally, and not surprisingly, several of the cognitive independent variables were intercorrelated; Trails B with Symbol Digit and Letter Cancellation; and Trails A with Symbol Digit and Letter Cancellation.

Since many of the independent variables were highly intercorrelated (e.g., r^2 for driver height and leg length [cm] = 0.782), the researchers conducted a regression analysis with backward elimination to identify the independent variables that were most closely associated with each *continuous* dependent variable. The regression models were first estimated with all the independent variables. Then variables were eliminated one at a time starting with the independent variable whose coefficient was associated with the weakest p value (or significance level). This process was continued until at least one of the independent variables was left with a p value of 0.10 or stronger. In many cases, all the independent variables dropped out, indicating that none of the independent variables were strongly associated with the dependent variables. In some cases, due to substantial instances of missing data, the independent variables were included in multiple batches (e.g., one model was run with driver height, shoe length, femur length, tibia length, and total leg length, and a second model was run using TUG time, plantar threshold, brake RT, symbol digit, letter cancellation, Trails A, and Trails B).

The regression output tables show both R-squared and adjusted R-squared statistics. Each time a predictor is added to a model, the R-squared increases, even if due to chance alone. Therefore, a model with more terms may appear to have a better fit simply because it has more terms. The adjusted R-squared is a modified version of R-squared that has been adjusted for the number of predictors in the model. The adjusted R-squared increases only if the new term improves the model more than would be expected by chance. It decreases when a predictor improves the model by less than expected by chance. The adjusted R-squared can be negative, but it's usually not. It is always lower than the R-squared.[7]

Analysts used binary logistic regression for foot movement type (pivot or lift, the only *categorical* dependent variable) and ordinary linear regression for all the other dependent variables.

[7] See http://blog.minitab.com/blog/adventures-in-statistics/multiple-regession-analysis-use-adjusted-r-squared-and-predicted-r-squared-to-include-the-correct-number-of-variables.

Table 29. Independent Variable Intercorrelation Matrix

Independent Variables		Driver Height (cm)	Shoe Length (cm)	Femur Length (cm)	Tibia Length (cm)	Total Leg Length (cm)	Plantar Threshold Log_{10} (Target $Force_{mg}$)	TUG Time (s)	Brake RT (s)	Symbol Digit (# correct)	Letter Cancellation Time (s)	Trails A Time (s)	Trails B Time (s)
Driver Height (cm)	Pearson Correlation	1	.869**	.580**	.728**	.782**	.353	.059	.282	-.280	-.032	-.111	.153
	Sig. (2-tailed)		.000	.002	.000	.000	.077	.773	.163	.165	.876	.590	.454
	N	26	25	26	26	26	26	26	26	26	26	26	26
Shoe Length (cm)	Pearson Correlation	.869**	1	.518**	.520**	.615**	.386	.050	.314	-.398*	.056	-.072	.038
	Sig. (2-tailed)	.000		.008	.008	.001	.057	.814	.126	.049	.789	.734	.855
	N	25	25	25	25	25	25	25	25	25	25	25	25
Femur Length (cm)	Pearson Correlation	.580**	.518**	1	.414*	.823**	.096	.231	.288	.024	.054	.007	.126
	Sig. (2-tailed)	.002	.008		.036	.000	.641	.256	.153	.907	.793	.972	.541
	N	26	25	26	26	26	26	26	26	26	26	26	26
Tibia Length (cm)	Pearson Correlation	.728**	.520**	.414*	1	.858**	.282	.066	.113	-.070	-.131	.084	-.003
	Sig. (2-tailed)	.000	.008	.036		.000	.163	.748	.583	.733	.522	.685	.989
	N	26	25	26	26	26	26	26	26	26	26	26	26
Total Leg Length (cm)	Pearson Correlation	.782**	.615**	.823**	.858**	1	.230	.172	.233	-.030	-.051	.056	.069
	Sig. (2-tailed)	.000	.001	.000	.000		.258	.402	.251	.883	.803	.785	.737
	N	26	25	26	26	26	26	26	26	26	26	26	26
Plantar Threshold Log_{10} (Target $Force_{mg}$)	Pearson Correlation	.353	.386	.096	.282	.230	1	.586**	.298	-.368	.167	.076	.405*
	Sig. (2-tailed)	.077	.057	.641	.163	.258		.002	.140	.064	.416	.713	.040
	N	26	25	26	26	26	26	26	26	26	26	26	26
TUG Time (s)	Pearson Correlation	.059	.050	.231	.066	.172	.586**	1	.369	-.015	.173	.035	.470*
	Sig. (2-tailed)	.773	.814	.256	.748	.402	.002		.064	.941	.397	.867	.016
	N	26	25	26	26	26	26	26	26	26	26	26	26
Brake RT (s)	Pearson Correlation	.282	.314	.288	.113	.233	.298	.369	1	-.293	.360	.263	.402*
	Sig. (2-tailed)	.163	.126	.153	.583	.251	.140	.064		.146	.071	.194	.042
	N	26	25	26	26	26	26	26	26	26	26	26	26
Symbol Digit (# correct)	Pearson Correlation	-.280	-.398*	.024	-.070	-.030	-.368	-.015	-.293	1	-.317	-.450*	-.498**
	Sig. (2-tailed)	.165	.049	.907	.733	.883	.064	.941	.146		.115	.021	.010
	N	26	25	26	26	26	26	26	26	26	26	26	26
Letter Cancellation Time (s)	Pearson Correlation	-.032	.056	.054	-.131	-.051	.167	.173	.360	-.317	1	.500**	.238
	Sig. (2-tailed)	.876	.789	.793	.522	.803	.416	.397	.071	.115		.009	.242
	N	26	25	26	26	26	26	26	26	26	26	26	26
Trails A Time (s)	Pearson Correlation	-.111	-.072	.007	.084	.056	.076	.035	.263	-.450*	.500**	1	.292
	Sig. (2-tailed)	.590	.734	.972	.685	.785	.713	.867	.194	.021	.009		.148
	N	26	25	26	26	26	26	26	26	26	26	26	26
Trails B Time (s)	Pearson Correlation	.153	.038	.126	-.003	.069	.405*	.470*	.402*	-.498**	.238	.292	1
	Sig. (2-tailed)	.454	.855	.541	.989	.737	.040	.016	.042	.010	.242	.148	
	N	26	25	26	26	26	26	26	26	26	26	26	26

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Foot movements are summarized by location in the following sections, first by study group and sex, and then by anthropometry and functional ability. Significant findings are highlighted by *italic* font. It is important to note that before the drive, the CDRS assisted each participant in adjusting the seat of the instrumented vehicle to ensure the best fit in the vehicle. Although poor fit in the vehicle was identified in Lococo, Staplin, Martell, and Sifrit (2012) study as a potential contributing factor to pedal application errors, the CDRS would not permit a driver to participate in a driving evaluation using poor seat adjustment that may have corresponded to the usual way the driver would select the seating position in his or her own vehicle.

Location 1: Three-way Stop

This section examines braking behavior at a three-way stop at Seven Oaks and Michaux as measured by the following eight dependent variables: type of foot movement from accelerator to brake pedal (A), foot transfer time (B), foot placement on brake pedal (C), average foot contact area on brake pedal (D), conformance of foot movement to most direct path (E), average brake pedal force (L) maximum brake pedal force (M), and total duration of hovering (N) Only one participant (NA male) performed this maneuver in the presence of a preceding vehicle. This may have affected the speed at which he performed the foot transfer compared to those not required to respond to a lead vehicle breaking as they approached the 3-way, stop-signed intersection.

Type of foot movement from accelerator to brake. Tables 30 and 31 describe foot movement type (pivot versus lift) as a function of study group and sex. In a pivot, the heel remains planted on the floorboard, and the ball of the foot pivots from pedal to pedal. Alternatively, in a lift the driver lifts the entire foot up from the accelerator and floorboard during the transfer from the accelerator to the brake. The lifting movement puts more strain on the thigh muscles than the pivoting movement. A Fisher's Exact Test confirmed no significant difference in foot movement type as a function of study group or sex.

Table 30. Foot Movement Type at 3-Way Stop, by Study Group

Group	N	Pivot N (%)	Lift N (%)
Normal Aging	**18**	**11 (61.1%)**	**7 (38.9%)**
Medical Condition	**8**	**5 (62.5%)**	**3 (37.5%)**
Neuropathy	6	3 (50%)	3 (50%)
Orthopedic Surgery	2	2 (100%)	0 --
Total	**26**	**16 (61.5%)**	**10 (38.5%)**

Table 31. Foot Movement Type at 3-Way Stop, by Sex

Sex	N	Pivot N (%)	Lift N (%)
Female	**10**	4 (40%)	6 (60%)
Male	**16**	12 (75%)	4 (25%)
Total	**26**	**16 (61.5%)**	**10 (38.5%)**

In performing the regression analysis for foot movement type, researchers divided the independent variables into two groups. The first group included the five anthropometric variables: driver height, shoe length, femur length, tibia length, and leg length. In this group, tibia length was the only independent variable significantly associated with foot movement type (p = 0.047). Among the five anthropometric measures, *longer tibia length was associated with increased likelihood of pivoting from accelerator to brake instead of lifting.*

The second model was estimated using data from the physical and cognitive performance variables: plantar threshold, TUG time, brake RT, Symbol Digit, Letter Cancellation, Trails A, and Trails B. From this group, only letter cancellation time (p=0.046) and Trails A time (p=0.067) were associated with foot movement type. *Longer Trails A completion time (poorer performance) was associated with increased likelihood of pivoting instead of lifting. However, longer letter cancellation time (poorer performance) was associated with decreased likelihood of pivoting rather than lifting.*

Foot transfer time from accelerator to brake. As shown in Tables 32 and 33, group differences in foot transfer time were outweighed by large variances within each group, which resulted in t-tests revealing no significant difference by medical status or sex.

Table 32. Foot Transfer Time From Accelerator to Brake, During Stop at 3-Way Stop, by Study Group

Group	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	**18**	**1.97**	**2.47**
Medical Condition	**8**	**5.67**	**7.88**
Neuropathy	6	7.02	8.82
Orthopedic Surgery	2	1.60	1.32
Total	**26**	**3.11**	**4.95**

Table 33. Foot Transfer Time From Accelerator to Brake, During Stop at 3-Way Stop, by Sex

Sex	N	Average Speed (s)	Standard Deviation (s)
Female	10	3.36	5.51
Male	16	2.95	4.76
Total	**26**	**3.11**	**4.95**

Because foot movement type (pivot or lift) could be associated with other foot movement behavior (e.g., foot movement speed, accuracy, conformance with the most linear path, foot coverage on brake, and force on the brake pedal), and the researchers were looking for patterns in the data to describe differences in foot movement behavior, several analyses included foot movement type as an independent variable. *Drivers who pivoted the foot had longer average foot transfer times (4.3 seconds) than those who lifted the foot for the transfer (1.1 second). A t-test indicated this difference approached statistical significance (t=2.11, df=15, p=0.052).*

Although a much larger proportion of females lifted and males pivoted, foot movement type was not significantly associated with sex at the 3-way stop location. However, foot movement type was significantly associated with tibia length, and since the sample of males had significantly longer legs than the sample of females, the researchers looked at how foot movement type and sex affected speed and accuracy of foot movements, even though tests of significance could not be conducted due to the small sample sizes. Table 34 shows that, among those who pivoted, females had much longer transfer times than males, while males and females who lifted their feet to transfer had similar transfer times.

Table 34. Foot Transfer Time From Accelerator to Brake, During Stop at 3-Way Stop, by Foot Movement Type and Sex.

Foot Transfer Type	Sex	N	Average Speed (s)	Standard Deviation (s)
Pivot	Female	4	6.69	8.10
	Male	12	3.56	5.40
Lift	Female	6	1.15	0.71
	Male	4	1.12	0.41
	Total	**26**	**3.11**	**4.95**

The regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length was the only independent variable strongly associated with foot transfer time**.** *Longer femur length was associated with a faster foot transfer time*. The final regression output is shown below:

IV	Coefficient	p value	Correlation with DV
Intercept	32.214	0.016	NA
Femur Length	-0.619	0.028	-0.438

Note: R^2 = 0.193; Adjusted R^2 = 0.158

Foot placement on brake pedal. For this metric, a higher positive percentage indicates that the center of force on the brake pedal is closer to the right edge of the brake pedal; a higher negative percentage indicates that the center of force is closer to the left edge of the brake; and values closer to 0% indicate that the center of force is near the lateral center of the brake pedal. The center of force is the "hot spot" captured by the Tekscan-instrumented brake pedal, indicating the point of highest force on the pedal. Tekscan did not capture data for this measure for 6 participants (all males, 2 PN and 4 NA); therefore, the sample size for this analysis is 20.

As shown in Tables 35 and 36, the average foot placement on the pedal across the sample of 20 drivers was 65.8% of the distance between the lateral center of the pedal and the right edge of the pedal. A t-test found no significant difference in average foot placement on the brake pedal by medical status. Foot position for females was closer to the lateral center of the brake than that of males across medical status groups (see Tables 37 and 38). *A t-test found a significant difference in foot positioning on the brake as a function of sex (t=2.27, df = 18, p=.036).*

Table 35. Foot Placement on Brake Pedal, During Stop at 3-Way Stop, by Study Group.

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**14**	**71.4%**	**21.6%**
Medical Condition	**6**	**52.8%**	**53.7%**
Neuropathy	4	72%	19.9%
Orthopedic Surgery	2	14.5%	94%
Total	**20**	**65.8%**	**34%**

Table 36. Foot Placement on Brake Pedal, During Stop at 3-Way Stop, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	10	50.2%	42.1%
Male	10	81.4%	11.2%
Total	**20**	**65.8%**	**34%**

Table 37. Foot Placement on Brake Pedal, During Stop at 3-Way Stop, by Study Group and Sex

Group	Sex	N	Average (%)	Standard Deviation (%)
Normal Aging	Female	7	63.4%	26.4%
	Male	7	79.3%	12.8%
Neuropathy	Female	2	55%	5.6%
	Male	2	89%	--
Orthopedic Surgery	Female	1	-52%	--
	Male	1	81%	--
	Total	**20**	**65.8%**	**34%**

As noted in the previous section, and to investigate whether sex differences in foot movement type might affect other foot movement behavior, including foot placement on the brake as hypothesized by the DRSs, the researchers again considered foot movement type as an independent variable. As shown in Table 38, it appears that foot movement type may have affected females' foot placement on the brake, whereas males' foot placement was consistent, regardless of their transfer method. The sex difference was larger among pivoters than for lifters, but the samples were too small to be reliable.

Table 38. Foot Placement on Brake Pedal, During Stop at 3-Way Stop, by Foot Movement Type and Sex

Foot Transfer Type	Sex	N	Average (%)	Standard Deviation (%)
Pivot	Female	4	35%	60.9%
	Male	7	81.7%	10.9%
Lift	Female	6	60.3%	25.5%
	Male	3	80.7%	14.4%
	Total	**20**	**65.8%**	**34%**

The linear regression analysis with backward elimination using the twelve independent variables found that shoe length and brake RT were the only measures associated with foot placement on the brake pedal. The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	-10.525	0.911	NA
Shoe length	5.825	0.087	0.274
Brake RT	-193.818	0.032	-0.433

$R^2 = 0.311$; Adjusted $R^2 = 0.225$

As the brake RT value increased, the foot placement on brake value decreased; *longer brake RT* (poorer performance) *was related to foot placement closer to the center of the brake pedal and shorter brake RT was related to foot placement closer to the right edge of the brake.* An increase in shoe length was associated with a larger foot placement on brake value; *the larger the foot, the closer placement was to the right edge of the brake.*

Average foot contact area on brake pedal. Foot contact area on the brake was calculated by dividing the area of shoe coverage (sensed by the brake Tekscan sensor material) by the brake width, presented as a percentage. As shown in Tables 39 and 40, the average percentages varied little by study group and sex. T-tests confirmed no significant differences as a function of either study group comparison or sex. Pivoters and lifters had similar areas of coverage (11.4% and 15.2%).

Table 39. Average Foot Contact Area on Brake Pedal (%) During Stop at 3-Way Stop, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**18**	**12.5%**	**9.0%**
Medical Condition	**7**	**13.6%**	**4.8%**
Neuropathy	5	11.8%	4.4%
Orthopedic Surgery	2	18%	1.4%
Total	**25**	**12.8%**	**7.9%**

Table 40. Average Foot Contact Area on Brake Pedal (%) During Stop at 3-Way Stop, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	10	13.6%	6.5%
Male	15	12.2%	8.9%
Total	**25**	**12.8%**	**7.9%**

The linear regression analysis with backward elimination using the twelve independent variables found no strong association of any of these measures with foot contact area on the brake pedal.

Conformance of actual foot movement path with the linear path. This measure represents the smoothness of foot movement from the accelerator to the brake pedal. It was used to identify what the CDRSs panelists in the earlier study described as “foot wobble” during foot transfer from accelerator to brake and to discriminate drivers with foot wobble from those who used a direct, linear path during the foot transfer. This measure was calculated using MATLAB software from the video view of the dot markers on the top and side of the right foot and involved software that counted pixels and normalized them to a distance unit. For example, the distance between two markers placed in the vehicle footwell could be 6 inches, and the number of pixels counted between these two markers in the video could be 100, so the conversion ratio of 100 pixels = 6 inches would be used. Conformance with the (direct) linear path was calculated in 3 steps: (1) dividing the top view linear path by the top view actual path; (2) dividing the side view linear path by the side view actual path; and then (3) adding the outcomes of calculations in steps 1 and 2, and dividing that by 2. If the foot moved exactly along the direct linear path, the calculation result would be 100%. Higher percentages indicated closer foot movement to the linear path (more conformance). Lower percentages indicated greater deviation in the X and/or Y planes from the linear path (less conformance).

Table 41 shows the average foot movement conformance with the linear path, by study group. T-tests found no significant differences between medical status groups. Table 42 shows foot movement conformance by sex, and Table 43 shows foot movement conformance by sex for each study group. A t-test found no significant difference in foot movement conformance as a function of sex.

Table 41. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Stop at 3-Way Stop, by Study Group.

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**18**	**56.9%**	**12.6%**
Medical Condition	**8**	**52.8%**	**18.7%**
Neuropathy	6	49.3%	18.9%
Orthopedic Surgery	2	63%	19.8%
Total	**26**	**55.7%**	**14.5%**

Table 42. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Stop at 3-Way Stop, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	10	57.8%	23.1%
Male	16	54.3%	5.0%
Total	**26**	**55.7%**	**14.5%**

Table 43. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Stop at 3-Way Stop, by Study Group and Sex.

Group	Sex	N	Average (%)	Standard Deviation (%)
Normal Aging	Female	7	58.9%	20.1%
	Male	11	55.7%	4.7%
Neuropathy	Female	2	44.5%	40.3%
	Male	4	51.8%	5.3%
Orthopedic Surgery	Female	1	77%	--
	Male	1	49%	--
	Total	**26**	**55.7%**	**14.5%**

In terms of foot movement type, those who lifted the foot had more conformance with the linear path than those who pivoted (63% versus 51%); a t-test found this difference was significant ($t=2.63$, $df=24$, $p=0.014$). Table 44 shows conformance by foot movement type and sex. These findings suggest that for males, conformance with the linear path was not affected by foot movement type, while female lifters appeared to have greater conformance than female pivoters. However, the sample was too small to support analyses.

Table 44. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Stop at 3-Way Stop, by Foot Movement Type and Sex.

Foot Transfer Type	Sex	N	Average (%)	Standard Deviation (%)
Pivot	Female	4	43%	31.7%
	Male	12	53.5%	5.3%
Lift	Female	6	67.7%	7.9%
	Male	4	56.7%	3.8%
	Total	**26**	**55.7%**	**14.5%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no strong association of any of these variables with conformance of actual foot movement path with the linear path.

Average and maximum brake force. Tables 45 and 46 describe the average brake pedal force at the 3-way stop. T-tests comparing the NA to the MC group and the male to female group failed to reach significance.

Table 45. Average Force on Brake Pedal (lb) by Study Group, During Stop at 3-Way Stop

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**17**	**3.8**	**2.2**
Medical Condition	**7**	**2.6**	**0.9**
Neuropathy	5	2.7	1.1
Orthopedic Surgery	2	2.2	0
Total	**24**	**3.4**	**1.97**

Table 46. Average Force on Brake Pedal (lb) by Sex, During Stop at 3-Way Stop

Sex	N	Average (lb)	Standard Deviation (lb)
Female	10	2.83	1.5
Male	14	3.8	2.2
Total	**24**	**3.4**	**1.97**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found brake RT to be the only independent variable with an association with average brake force. *An increase in brake RT (slower, poorer performance) was associated with a decrease in average brake force.* In other words, drivers with slower brake reaction time applied less pressure to the brake pedal. The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	7.169	0.003	NA
Brake RT	-7.635	0.094	-0.349

R^2 = 0.122; Adjusted R^2 = 0.082

Table 47 describes the maximum brake pedal force at the 3-way stop, and shows that the *NA group pressed the brake harder (about 2.5 pounds of pressure more) than the PN and OP groups. A t-test comparing the NA and the MC groups was at the margin of statistical significance (t=2.06, df=22, p=0.051).* Table 48 shows maximum pedal brake force for males and females. This difference also failed to reach statistical significance.

Table 47. Maximum Force on Brake Pedal (lb) by Study Group, During Stop at 3-Way Stop

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**17**	**7.3**	**3.0**
Medical Condition	**7**	**4.8**	**1.8**
Neuropathy	5	4.8	2.1
Orthopedic Surgery	2	4.7	0.7
Total	**24**	**6.6**	**2.9**

Table 48. Maximum Force on Brake Pedal (lb) by Sex, During Stop at 3-Way Stop

Sex	N	Average (lb)	Standard Deviation (lb)
Female	10	6.1	2.6
Male	14	7.0	3.2
Total	**24**	**6.6**	**2.9**

Of the five anthropometric and seven cognitive and physical performance measures included in the linear regression, Trails A completion time was the only independent variable associated with maximum brake force during the 3-way stop, *with poorer Trails A performance associated With Lower maximum brake force*. The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	9.408	<0.001	NA
Trails A time	-0.098	0.070	-0.335

R^2 = 0.148; Adjusted R^2 = 0.108

Hovering behavior. A hover was identified following a braking application when a participant lifted the foot off the pedal and then re-applied the brake (as in "covering the brake" but not fully depressing it). For analysis purposes, a hovering movement was defined as starting when brake pedal travel dropped below 10% of its full travel range and ending when brake pedal travel was greater than 10% of its full travel range. The interest in investigating hovering behavior and differences resulting from medical conditions or driver sex arose from the discussions with DRSs regarding foot wobble observed for drivers with mild cognitive impairment as well as the observations by Cantin, Blouin, Simoneau, and Teasdale (2004) that older drivers made more sub-movements than younger drivers when transferring the foot from the accelerator to the brake. One might hypothesize that a direct foot movement from the accelerator to the brake would result in more accurate placement on the brake than one towards the brake that begins at a point somewhere in space between the accelerator and the brake, as a direct movement would provide a reference point for the movement. The relationship between hover behavior and foot placement on the brake was not analyzed, but hover behavior was characterized by sex, medical condition, anthropometry, and functional ability.

As shown in Table 49, only five of the 18 NA participants (27.8%) performed a hover upon their approach to the 3-way stop sign, while four of the eight MC participants (50%) performed a hover. Three of the NA drivers hovered twice and two hovered once. One of the NA drivers who hovered twice had a preceding vehicle on the approach to the stop sign, which may have prompted additional brake-covering behavior. All four MC drivers hovered once. The average hover duration was similar across study groups. The proportion of males and females who hovered was similar (37.5% and 30%, respectively), as was the proportion of those who pivoted and lifted their foot when moving it from the accelerator to the brake (37.5% and 30% respectively).

Table 49. Hover Behavior, by Group, on Approach to 3-Way Stop

Group	N	Count of Participants by Number of Hovers		Hover Duration	
		0 Hovers	1 or 2 Hovers	Average (s)	Standard Deviation (s)
Normal Aging	**18**	**13**	**5**	**2.76**	**1.75**
Medical Condition	**8**	**4**	**4**	**2.32**	**2.81**
Neuropathy	6	3	3	2.67	3.33
Orthopedic Surgery	2	1	1	1.27	--
Total	**26**	**17**	**9**	**2.56**	**2.13**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that only driver height and Trails B time were associated with total hover duration. *Increases in driver height and Trails B completion time were both associated with a reduction in the total duration of hovering.* The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	33.034	0.008	NA
Driver height	-0.123	0.033	-0.454
Trails B time	-0.093	0.014	-0.619

R^2 = 0.729; Adjusted R^2 = 0.639

Location 10: Emergency stop

This section examines braking behavior during an emergency stop as measured by following seven dependent variables: type of foot movement from accelerator to brake pedal (A), foot transfer time (B), foot placement on brake pedal (C), average foot contact area on brake pedal (D), conformance of foot movement to most direct path (E), average brake pedal force (L), and maximum brake pedal force (M). The section also compares foot placement during an emergency stop (location 10) to a three-way stop (location 1) across the same participants.

Type of foot movement from accelerator to brake. As shown in Table 50, the majority of the driver sample lifted their foot, rather than pivoting it, when transferring from the accelerator to the brake during the emergency stop maneuver. This is in contrast to the findings for foot movement type at the 3-way stop (Location 1). A Fisher's Exact Test indicated that there were no significant differences in foot movement type between the NA and MC groups. Table 51 shows that the entire sample of females lifted rather than pivoted their foot during the transfer and that the majority of the male participants also lifted to transfer their foot from the accelerator to the brake. *A Fisher's Exact Test explaining the association between foot movement type and sex approached statistical significance (p=0.053).*

Table 50. Foot Movement Type During the Emergency Stop by Study Group.

Group	N	Pivot N (%)	Lift N (%)
Normal Aging	**16**	**3 (18.7%)**	**13 (81.3%)**
Medical Condition	**8**	**2 (25%)**	**6 (75%)**
Neuropathy	6	1 (16.7%)	5 (83.3%)
Orthopedic Surgery	2	1 (50%)	1 (50%)
Total	**24**	**5 (20.8%)**	**19 (79.2%)**

Table 51. Foot Movement Type During the Emergency Stop by Sex.

Sex	N	Pivot N (%)	Lift N (%)
Female	**10**	0	10 (100%)
Male	**14**	5 (35.7%)	9 (64.3%)
Total	**24**	**5 (20.8%)**	**19 (79.2%)**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that driver height was the only independent variable that was associated with foot movement type (p = 0.052). *Taller drivers showed increased odds of pivoting the foot from accelerator to brake instead of lifting the foot*.

Foot transfer time from accelerator to brake. Tables 52 and 53 show foot transfer time by study group and sex, respectively. T-tests found no significant differences in this measure by group or sex. Table 54 shows foot transfer time by both medical condition and sex.

Table 52. Foot Transfer Time From Accelerator to Brake, During Emergency Stop, by Study Group

Group	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	**16**	**0.27**	**0.20**
Medical Condition	**8**	**0.54**	**0.67**
Neuropathy	6	0.29	0.12
Orthopedic Surgery	2	1.3	1.24
Total	**24**	**0.36**	**0.43**

Table 53. Foot Transfer Time From Accelerator to Brake, During Emergency Stop, by Sex

Sex	N	Average Speed (s)	Standard Deviation (s)
Female	10	0.29	0.12
Male	14	0.41	0.55
Total	**24**	**0.36**	**0.43**

Table 54. Foot Transfer Time From Accelerator to Brake, During the Emergency Stop, by Study Group and Sex

Group	Sex	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	Female	7	0.27	0.11
	Male	9	0.27	0.27
Neuropathy	Female	2	0.31	0.18
	Male	4	0.28	0.12
Orthopedic Surgery	Female	1	0.42	--
	Male	1	2.18	--
	Total	**24**	**0.36**	**0.43**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no strong association among these variables with foot transfer time for the emergency stop maneuver.

Table 55 shows that males and females who lifted their foot had similar foot transfer times, and both more than twice the speed of the males who pivoted for the transfer.

Table 55. Foot Transfer Time From Accelerator to Brake, During the Emergency Stop, by Foot Movement Type and Sex.

Foot Transfer Type	Sex	N	Average Speed (s)	Standard Deviation (s)
Pivot	Female	0		
	Male	5	0.78	0.83
Lift	Female	10	0.29	0.12
	Male	9	0.20	0.13
	Total	**24**	**0.36**	**0.43**

Foot placement on brake. As shown in Table 56, the average foot placement on the brake, across the analysis sample, was 60% of the distance between the lateral center of the brake and the right edge of the brake. T-tests indicated no significant difference in foot placement for either the NA versus the MC group. The two OP drivers had the closest foot positioning to the center of the brake of all study groups during the emergency stop maneuver.

Foot positioning on the brake during the emergency stop was slightly closer to the center of the brake, compared to foot positioning during the 3-way stop.

Table 56. Foot Placement on Brake Pedal During the Emergency Stop by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**16**	**63.5%**	**17.3%**
Medical Condition	**7**	**53.6%**	**25.5%**
Neuropathy	5	60.2%	18.2%
Orthopedic Surgery	2	37%	42.4%
Total	**23**	**60.5**	**20.1%**

Table 57 shows similar foot placement for males and females; a t-test confirmed no significant difference as a function of sex. Table 58 shows foot placement by sex and study group, and shows that the two females with neuropathy placed their feet closest to the right edge of the brake, while males with neuropathy had the closest positioning to the brake center (with exception of the single female in the OP group).

Table 57. Foot Placement on Brake Pedal During the Emergency Stop by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	10	63%	22.7%
Male	13	58.6%	18.5%
Total	**23**	**60.5**	**20.1%**

Table 58. Foot Placement on Brake Pedal, During the Emergency Stop, by Study Group and Sex

Group	Sex	N	Average (%)	Standard Deviation (%)
Normal Aging	Female	7	68.9%	13.8%
	Male	9	59.4%	19.3%
Neuropathy	Female	2	70.5%	0.71%
	Male	3	53.3%	22.1%
Orthopedic Surgery	Female	1	7%	---
	Male	1	67%	---
	Total	**23**	**60.5**	**20.1%**

There was little difference in foot placement as a function of pivoting or lifting. Table 59 shows that the males who lifted had the closest foot placement to the center of the brake.

Table 59. Foot Placement on Brake Pedal, During the Emergency Stop, by Foot Movement Type and Sex.

Foot Transfer Type	Sex	N	Average (%)	Standard Deviation (%)
Pivot	Female	0	--	--
	Male	5	65.8%	12.5%
Lift	Female	10	63%	22.7%
	Male	8	54.1%	20.9%
	Total	**23**	**60.5**	**20.1%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that brake reaction time, Symbol Digit (number correct), and Letter Cancellation time all were associated with foot placement on the brake pedal. *An increase in the brake RT (poorer performance) was associated with foot placement closer to the center of the brake. An increase in the number of correct pairs on the Symbol Digit test (better performance) was associated with foot placement closer to the right edge of the brake. An increase in Letter Cancellation time (poorer performance) was also associated with foot placement closer to the right edge of the brake.* The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	-31.773	0.431	NA
Brake RT	-82.738	0.041	-0.402
Symbol digit modality # correct	1.665	0.005	0.487
Letter cancellation time	0.846	0.008	0.228

R^2 = 0.533; Adjusted R^2 = 0.455

Data were available for 19 participants to compare foot placement on the brake pedal during the emergency stop to foot placement on the brake during the 3-way stop. Across the sample of 19 participants, the average placement during the 3-way stop was 64.6% of the distance from the center of the brake to the right edge of the pedal, and the average placement during the emergency stop was 62.8%. A t-test confirmed no significant difference. Researchers looked at the difference scores for each participant, to determine what effect the emergency stop may have had on foot placement, as a function of study group or sex. The average change in position for the NA group during the emergency stop was just slightly closer to the center of the brake (-3% of the distance); for example, a participant who had 80% placement on the brake during the emergency stop had 83% during the 3-way stop. The average change in placement for the MC group was 0% (no change in position). A t-test confirmed this difference was not significant.

However, *the change in foot position on the brake for the emergency stop compared to the 3-way stop was significantly different for males as compared to females. The average change across the sample of 10 females was 13%; i.e., they moved their foot 13% closer to the right edge of the brake during the emergency stop compared to the 3-way stop. The average change across the sample of 9 males was -18%; (i.e., they moved the foot 18% closer to the center of the brake pedal during the emergency stop compared to the 3-way stop). A t-test confirmed that the difference between males and females was significant ($t=2.87$, $df=17$, $p=0.011$).* Researchers categorized change in foot position into the following three possibilities: (1) no change in lateral foot position on the brake during emergency stop; (2) foot positioning closer to the center of the brake during the emergency stop; and (3) foot closer to the right edge of the brake during the emergency stop. Researchers looked at counts within each category by sex. None of the participants had 0% change, 11 moved their foot closer to the center of the brake, and 8 moved their foot closer to the right edge of the brake. *A Fisher's Exact Test found a significant difference in direction of foot movement as a function of sex ($p=0.02$). Of the 10 females, 3 moved their foot closer to the center of the brake, and 7 moved it closer to the right edge of the brake. Of the 9 males, 8 moved their foot closer to the center of the brake, and 1 moved his foot closer to the right edge of the brake.*

Thus it appears that during a non-emergency braking situation, the female participants pressed on the brake (center of force) at a point significantly closer to the lateral center of the pedal compared to the male participants, who pressed the brake pedal much closer to the right edge of the pedal. In this analysis, the average foot placement for the 10 females was 50% during the 3-way stop; this compares to 81% for the 9 males. But during an emergency stop, while the average foot placement for males and females did not differ significantly, *the direction of change in foot placement* did differ significantly, as males moved their foot closer to the center of the brake pedal while females moved their foot closer to the right edge of the brake pedal.

Foot transfer type from accelerator to brake was consistent across location for 6 of the 10 women (a lift), while four of the women who pivoted at the 3-way stop lifted for the emergency stop. One might hypothesize that a change in foot movement type (from a pivot to a lift) to stop quickly might explain the findings that, as a group, women moved their foot closer to the right edge of the brake during an emergency stop, compared to foot positioning on the brake during a non-emergency stop. Three of the four women who changed their foot movement from a pivot to a lift moved their foot closer to the right edge of the brake and one moved it closer to the center of the brake; the average difference in foot placement for these four was 21.5%. Of the six women who lifted at both stop locations, four moved their foot closer to the right edge of the brake and two closer to the center of the brake. The average difference in foot placement was 7%. The single male who moved his foot closer to the right edge of the brake pedal at the emergency stop pivoted his foot during the transfer at both locations. Of the eight males who moved their foot closer to the center of the brake during the emergency stop, three changed their foot movement type (pivot to a lift), and five were consistent across location (3 consistent lifters and 2 consistent pivoters).

Average foot contact area on brake. Similar to the 3-way stop location, foot contact area on the brake during the emergency stop did not vary much as a function of medical condition or sex (see Tables 60 and 61). T-tests found no significant differences in foot contact area on the brake as a function of either study group or sex. However, foot contact area on the brake during the emergency stop was approximately double that of the area during the 3-way stop maneuver.

The average foot contact area on the brake for the 5 drivers who pivoted their foot from the accelerator to the brake was 18%, compared to 26% for the 18 drivers who lifted their foot to transfer it from the accelerator to the brake.

Table 60. Average Foot Contact Area on Brake Pedal (%) During Emergency Stop, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**16**	**22.4%**	**11.8%**
Medical Condition	**7**	**28.7%**	**5.0%**
Neuropathy	5	29.8%	4.9%
Orthopedic Surgery	2	26%	5.7%
Total	**23**	**24.3%**	**10.5%**

Table 61. Average Foot Contact Area on Brake Pedal (%) During Emergency Stop, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	10	24.5%	10.2%
Male	13	24.2%	11.1%
Total	**23**	**24.3%**	**10.5%**

Conformance of actual foot movement path With Linear path. Tables 62 and 63 show conformance by medical status group and sex, respectively. T-tests showed no significant group differences.

Table 62. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During the Emergency Stop, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**79.5%**	**17.0%**
Medical Condition	**8**	**85%**	**13.0%**
Neuropathy	6	87.5%	13.6%
Orthopedic Surgery	2	77.5%	10.6%
Total	**23**	**81.4%**	**15.7%**

Table 63. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During the Emergency Stop, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	84.4%	14.2%
Male	14	79.5%	16.8%
Total	**23**	**81.4%**	**15.7%**

Table 64 shows conformance by group and sex, and Table 65 by sex and movement type. While the sample was too small for significance testing, females in the NA and OP groups had higher conformance than males, but for those with PN, males showed higher conformance than females. Male and female lifters showed similar foot movement conformance with the linear path, and both higher than that of male pivoters.

Table 64. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During the Emergency Stop, by Study Group and Sex

Group	Sex	N	Average (%)	Standard Deviation (%)
Normal Aging	Female	6	85.5%	14.6%
	Male	9	75.5%	18.2%
Neuropathy	Female	2	81%	22.6%
	Male	4	90.7%	9.74%
Orthopedic Surgery	Female	1	85%	--
	Male	1	70%	--
	Total	**23**	**81.4%**	**15.7%**

Table 65. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During the Emergency Stop, by Foot Movement Type and Sex

Foot Transfer Type	Sex	N	Average (%)	Standard Deviation (%)
Pivot	Female	0	--	--
	Male	5	74.6%	20.2%
Lift	Female	9	84.4%	14.2%
	Male	9	82.2%	15.2%
	Total	**23**	**81.4%**	**15.7%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no strong associations among these variables with conformance of foot movement path for the emergency stop maneuver.

Average and maximum brake force. Table 66 shows little between-groups difference in the average force used on the brake pedal during the emergency stop. A t-test confirmed no significant difference between the NA and MC groups. The emergency stop produced higher average brake forces than the 3-way stop, which one would expect, based on there being no reason for a hard braking maneuver when coming to a stop at the 3-way stop location on the route. Table 67 shows average brake force by sex; a t-test indicated the differences were not statistically significant.

Table 66. Average Force on Brake Pedal (lb) by Study Group, During the Emergency Stop.

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**15**	**6.87**	**3.51**
Medical Condition	**7**	**6.44**	**2.95**
Neuropathy	5	6.76	3.31
Orthopedic Surgery	2	5.65	2.62
Total	**22**	**6.73**	**3.28**

Table 67. Average Force on Brake Pedal (lb) by Sex, During the Emergency Stop.

Sex	N	Average (lb)	Standard Deviation (lb)
Female	10	5.57	3.03
Male	12	7.7	3.28
Total	**22**	**6.73**	**3.28**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no strong associations among these variables with average brake force during the emergency stop maneuver.

Tables 68 and 69 show the maximum brake pedal force by study group and sex during the emergency stop. T-tests indicated no significant differences as a function of either group or sex.

Table 68. Maximum Force on Brake Pedal (lb) by Study Group, During the Emergency Stop.

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**15**	**13.5**	**5.60**
Medical Condition	**7**	**12.51**	**5.85**
Neuropathy	5	13.6	6.71
Orthopedic Surgery	2	9.8	2.12
Total	**22**	**13.19**	**5.56**

Table 69. Maximum Force on Brake Pedal (lb) by Sex, During the Emergency Stop.

Sex	N	Average (lb)	Standard Deviation (lb)
Female	10	10.91	5.09
Male	12	15.08	5.40
Total	**22**	**13.19**	**5.56**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found only shoe length and brake RT to be strongly associated with maximum braking force during the emergency stop. The final model output is shown below. *Longer shoe length was associated with a higher maximum brake force. Longer brake RT (poorer performance) was associated with lower maximum brake force.*

IV	Coefficient	p value	Correlation with DV
Intercept	-4.351	0.781	NA
Shoe length	1.037	0.066	0.305
Brake RT	-26.183	0.053	-0.314

R^2 = 0.267; Adjusted R^2 = 0.186

Location 2: Reverse

This section examines braking behavior during a reverse maneuver at Anthony Place (location 2) as measured by the following four dependent variables: foot transfer time (B), foot placement on brake pedal (C), conformance of foot movement to most direct path (E), and total duration of hovering (N). This section also examines the total duration of glances to the left and to the right.

Average foot transfer time. Analyses for group and sex differences are limited to descriptive statistics, because nearly half of the participants did not transfer their feet during this maneuver. The average foot transfer time for the 10 NA participants who did transfer their foot from the accelerator to the brake was 1.69 s (range = 0.43 to 4.48 s, SD = 1.27 s), and 2.19 s for the 3 PN participants who performed a foot transfer (range = 2.02 to 2.46 s, SD = 0.24 s). Neither OP participant performed a foot transfer.

The average foot transfer time for the three females who transferred their foot from the accelerator to the brake was 1.56 s (range = 1.06 to 2.46 s, SD = 0.78 s), and 1.88 s for the 10 male participants who performed a foot transfer (range =0.43 to 4.48 s, SD = 1.24 s).

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found tibia length and TUG time the only independent variables associated with foot transfer time. *An increase in tibia length was associated with longer transfer time. An increase in TUG time (poorer performance) was also associated with an increase in transfer time.* The final regression output was:

IV	**Coefficient**	**p value**	**Correlation with DV**
Intercept	-6.369	0.020	NA
Tibia length	0.120	0.059	0.540
TUG time	0.473	0.025	0.627

R^2 = 0.583; Adjusted R^2 = 0.499

Average foot contact area on brake. Table 70 presents descriptive statistics for the average foot contact area on the brake pedal during the reverse at Anthony Place maneuver, by study group, while Table 71 presents a summary of performance by sex. T-tests confirmed no statistically significant differences in this metric either as a function of study group or sex. Twenty-one of the 24 participants exhibited less than 25% contact area on the brake during the reversing maneuver.

Table 70. Average Foot Contact Area on Brake Pedal (%) During Reverse at Anthony Place Maneuver, by Study Group.

Group	**N**	**Average (%)**	**Standard Deviation (%)**
Normal Aging	**17**	**14.7%**	**9.6%**
Medical Condition	**7**	**12.1%**	**5.9%**
Neuropathy	5	10.6%	6.4%
Orthopedic Surgery	2	16%	1.4%
Total	**24**	**13.9%**	**8.6%**

Table 71. Average Foot Contact Area on Brake Pedal (%) During Reverse at Anthony Place Maneuver, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	9	17%	11.3%
Male	15	12.1%	6.2%
Total	**24**	**13.9%**	**8.6%**

The regression analysis using the anthropometric, physical, and cognitive independent variables found no strong associations with foot contact area on the brake.

Conformance of actual foot movement path with linear path. Analyses for medical status group and sex differences are limited to descriptive statistics, as nearly half of the participants did not transfer during this maneuver. The average conformance of foot movement with the linear path for the 10 NA participants who did transfer their foot was 55.9% (range = 42% to 77%, SD = 10.8%), and 57.3% for the 3 PN participants who performed a foot transfer (range = 50% to 69%, SD = 10.2%).

The average conformance for the 3 females who transferred their foot was 62% (range = 50% to 77%, SD = 13.7%), compared to 54.5% for the 10 male participants (range = 69% to 54.5%, SD = 9.1%).

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length was the only independent variable strongly associated with conformance of foot movement with the linear path. *Longer femur length was associated with less conformance*. The final regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	129.504	<0.001	NA
Femur length	-1.585	0.009	-0.688

R^2 = 0.473; Adjusted R^2 = 0.425

Total duration of hovering. Data were available for 17 participants describing the total time spent hovering during this maneuver, as 8 participants did not hover and video data were missing for a ninth participant. There was no significant difference in the proportion of those who hovered versus those who did not, as a function of study group or sex. Among the drivers who hovered, The MC group hovered frequently (3+ times) during the reversing maneuver, more often than NA participants. Table 72 presents descriptive statistics for total hover duration by group, and Table 73 presents these data by sex. T-tests found no significant differences in total hover duration as a function of study group or sex.

Table 72. Hover Behavior, by Group, for Reverse at Anthony Place.

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Normal Aging	**17**	**7**	**5**	**4**	**1**	**4.43**	**2.91**
Medical Condition	**8**	**1**	**2**	**2**	**3**	**5.05**	**2.18**
Neuropathy	6	1	1	1	3	4.12	1.80
Orthopedic Surgery	2	0	1	1	0	7.38	0.74
Total	**25**	**8**	**7**	**6**	**4**	**4.69**	**2.58**

Table 73. Hover Behavior, by Sex, for Reverse at Anthony Place.

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Females	9	1	5	1	2	5.25	2.43
Males	16	7	2	5	2	4.18	2.75
Total	**25**	**8**	**7**	**6**	**4**	**4.69**	**2.58**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that letter cancellation time was the only variable associated with total hover duration. The regression equation was:

IV	Coefficient	p value	Correlation with DV
Intercept	12.585	<0.001	NA
Letter cancellation time	-0.102	0.007	-0.544

$R^2 = 0.411$; Adjusted $R^2 = 0.369$

Longer letter cancellation time (poorer performance) was associated with shorter total hover duration.

Total duration of gazes to the left and right. As explained by Schmidt (1989), head position can influence a driver's perception of the spatial position of the (unseen) brake pedal. Moving the head or the eyes can cause large systematic biases in the direction of the aim of the foot. Movements in head position activate proprioceptive receptors in the neck which may, in turn, alter the perceived spatial position of the brake pedal with respect to the body, thereby influencing limb placement. In studies cited by Schmidt, errors ranged from 5.7 degrees to the left when the head was rotated to the right, to 4.6 degrees to the right when the head was moved to the left. A driver turning to the left while looking in the left side mirror, or reaching for the seat belt when initiating the driving sequence, may bias the perceived position of the brake pedal to the right. This bias could be sufficiently large that the driver could miss the brake and strike the accelerator.

Tables 74 and 75 present statistics describing the duration of looks to the left and Tables 76 and 77 describe the duration of looks to the right, during the reversing maneuver at Anthony Place. Looks to the left included the left mirror and left window. Looks to the right included the inside rear-view mirror, the right window, the right mirror, and to the rear. Video data were missing for one NA participant. Nine NA participants, one PN and one OP participant did not look to the left; look duration to the left for these participants was coded as "0" seconds. All participants with video data looked to the right with the exception of one NA participant, whose duration was coded as zero. T-tests indicated no significant differences as a function of medical status group or sex for duration of looks in either direction.

Table 74. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse at Anthony Place, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**17**	**3.42**	**6.28**
Medical Condition	**8**	**2.16**	**2.53**
Neuropathy	6	2.8	2.64
Orthopedic Surgery	2	0.25	0.35
Total	**25**	**3.02**	**5.34**

Table 75. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse at Anthony Place, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	4.01	7.33
Male	16	2.46	4.0
Total	**25**	**3.02**	**5.34**

Table 76. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse at Anthony Place, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**17**	**13.09**	**7.48**
Medical Condition	**8**	**15.85**	**5.78**
Neuropathy	6	16.58	6.64
Orthopedic Surgery	2	13.7	7.07
Total	**25**	**13.98**	**6.98**

Table 77. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse at Anthony Place, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	15.9	8.93
Male	16	12.89	5.65
Total	**25**	**13.98**	**6.98**

Location 3: Reverse

Similar to the analysis of the reverse maneuver at location 2, this section examines braking behavior during a reverse maneuver in a parking garage (location 3) as measured by four dependent variables: foot transfer time (B), foot placement on brake pedal (C), conformance of foot movement to most direct path (E), and total duration of hovering (N). It also examines the total duration of glances to the left and to the right.

Average foot transfer time. Analyses for group and sex differences are limited to descriptive statistics, because most of the participants did not make a foot transfer during this maneuver. The average foot transfer time for the 3 NA drivers who did transfer their foot from the accelerator to the brake was 1.66 s (range = 1.17 to 1.97 s, SD = 0.43 s). Only one PN participant performed a foot transfer (1.53 s), and neither OP participant did so.

One female performed a foot transfer (1.17 s), and the average time for the 3 males who transferred their foot from the accelerator to the brake was 1.78 s (range = 1.53 to1.97 s, SD = 0.23 s).

No linear regression analysis was performed due to the small sample size.

Average foot contact area on brake. Table 78 presents the average foot contact area on the brake pedal during the first reverse in the parking garage by study group, while Table 79 presents a summary of performance by sex. T-tests confirmed no statistically significant differences in this metric as a function of either study group or sex. Nineteen of the 21 participants exhibited less than 25% contact area on the brake during the reversing maneuver.

Table 78. Average Foot Contact Area on Brake Pedal (%) During Reverse 1 in Garage, by Study Group.

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**14**	**14.2%**	**8.6%**
Medical Condition	**7**	**11.1%**	**5.1%**
Neuropathy	5	9.4%	5.0%
Orthopedic Surgery	2	15.5%	2.1%
Total	**21**	**13.2%**	**7.7%**

Table 79. Average Foot Contact Area on Brake Pedal (%) During Reverse 1 in Garage, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	8	15.3%	10.9%
Male	13	11.9%	4.9%
Total	**21**	**13.2%**	**7.7%**

The linear regression using the five anthropometric, two physical performance, and four cognitive measures found that none of the independent variables were associated with average foot contact area on the brake pedal.

Conformance of actual foot movement path with linear path. Analyses for group and sex differences are limited to descriptive statistics because only four participants transferred their foot. The average conformance of foot movement with the linear path for the three NA drivers who did transfer their foot from the accelerator to the brake was 56.3% (range = 50% to 66%, SD = 8.5%). Only one PN participant transferred the foot, and conformance was 62%.

The average conformance of foot movement with the linear path for the three males who transferred their foot from the accelerator to the brake was 59.3% (range = 50% to 66%, SD = 8.3%). Only one female transferred her foot during the reversing maneuver with a concordance of 53%.

A linear regression was not performed with the anthropometric, cognitive, and physical performance measures because four participants is not sufficient for a meaningful analysis.

Total duration of hovering. Data for time spent hovering were available for 20 participants for this maneuver; 3 did not hover, video data were missing for 1 participant, and 2 participants did not perform the backing maneuver at this location. Table 80 presents descriptive statistics for total hover duration by medical status group, while Table 81 presents these data by sex. Similar proportions of participants across groups did not hover (approximately 13%). Among the drivers who hovered, those in the MC group hovered frequently (3+ times) more often during the reversing maneuver than NA drivers. T-tests found no statistically significant difference in total hover duration between the NA and MC group or between the NA and PN group. Table 81 shows that females and males had similar hover duration times; a t-test confirmed the absence of a significant difference.

Table 80. Hover Behavior, by Group, During First Reverse in Garage

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**2**	**1**	**5**	**7**	**4.83**	**1.30**
Medical Condition	**8**	**1**	**0**	**1**	**6**	**4.38**	**2.21**
Neuropathy	6	1	0	0	5	5.21	1.90
Orthopedic Surgery	2	0	0	1	1	2.32	1.70
Total	**23**	**3**	**1**	**6**	**13**	**4.68**	**1.63**

Table 81. Hover Behavior, by Sex, During First Reverse in Garage

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Females	9	1	0	2	6	4.45	1.71
Males	14	2	1	4	7	4.83	1.64
Total	**23**	**3**	**1**	**6**	**13**	**4.68**	**1.63**

The linear regression using the five anthropometric, two physical performance, and four cognitive measures found that only femur length and letter cancellation time were associated with total hover duration. The regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	7.667	0.105	NA
Femur length	-0.175	0.071	-0.314
Letter cancellation time	0.073	0.004	0.584

$R^2 = 0.460$; Adjusted $R^2 = 0.396$

Greater femur length was associated with shorter total hover duration, and poorer letter cancellation time was associated with longer hover duration.

Total duration of gazes to the left and right. Tables 82 and 83 present statistics describing the duration of looks to the left and Tables 84 and 85 describe duration of looks to the right during the first reverse in the parking garage. Looks to the left included the left mirror and left window. Looks to the right included the inside rear-view mirror, the right window, the right mirror, and to the rear. Video data were missing for one NA participant, and two NA participants did not perform the reverse maneuver. One NA and one PN participant did not look to the left; these participants' duration of looks to the left for were coded as zero seconds. All participants with video data looked to the right.

T-tests indicated no significant differences as a function of either study group or sex, for glance durations to the left. In terms of glance duration to the right, *the total glance duration for drivers with PN (11.72 s) was significantly longer than that of the NA drivers (9.16 s), t=-2.7, df=19, p=0.014*. There was no significant difference as a function of sex.

Table 82. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse 1 in Garage, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**3.87**	**2.38**
Medical Condition	**8**	**5.76**	**4.43**
Neuropathy	6	5.52	4.94
Orthopedic Surgery	2	6.5	3.68
Total	**23**	**4.52**	**3.27**

Table 83. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse 1 in Garage, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	5.67	3.24
Male	14	3.79	3.19
Total	**23**	**4.52**	**3.27**

Table 84. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse 1 in Garage, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**9.16**	**1.88**
Medical Condition	**8**	**12.93**	**5.27**
Neuropathy	6	11.72	2.15
Orthopedic Surgery	2	16.55	11.67
Total	**23**	**10.47**	**3.80**

Table 85. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse 1 in Garage, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	11.58	5.08
Male	14	9.76	2.67
Total	**23**	**10.47**	**3.80**

Location 4: Reverse

This section examines braking behavior during a second reverse maneuver in a parking garage (location 4) as measured by four dependent variables: foot transfer time (B), foot placement on brake pedal (C), conformance of foot movement to most direct path (E), and total duration of hovering (N). It also examines the total duration of glances to the left and to the right.

Average foot transfer time. Analyses for group and sex differences are limited to descriptive statistics, because only three participants (all NA drivers) transferred their foot from accelerator to brake during this maneuver. The average foot transfer time for these three drivers was 1.08 s (range = 0.82 to 1.42 s, SD = 0.31 s). One female performed a foot transfer (1.01 s), as did two males (0.82 s and 1.42 s).

No linear regression was performed using the anthropometric, cognitive, and physical performance measures as three participants is not sufficient for a meaningful analysis.

Average foot contact area on brake. Table 86 presents the average foot contact area on the brake pedal during the second reverse in the parking garage by study group, while Table 87 presents a summary of performance by sex. T-tests confirmed no statistically significant differences in this metric as a function of either study group or sex. Eighteen of the 22 participants exhibited less than 25% contact area on the brake during the reversing maneuver.

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables were associated with average foot contact area on the brake.

Table 86. Average Foot Contact Area on Brake Pedal (%) During Second Reverse in Garage, by Study Group.

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**14%**	**10.2%**
Medical Condition	**7**	**14.1%**	**5.15%**
Neuropathy	5	13%	5.8%
Orthopedic Surgery	2	17%	---
Total	**22**	**14%**	**8.8%**

Table 87. Average Foot Contact Area on Brake Pedal (%) During Second Reverse in Garage, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	9	13%	9.8%
Male	13	14.8%	8.3%
Total	**22**	**14%**	**8.8%**

Conformance of actual foot movement path with linear path. Analyses for group and sex differences are limited to descriptive statistics, because only three participants transferred their foot. Average conformance of foot movement with the linear path for the three NA drivers who transferred their foot from the accelerator to the brake was 64% (range = 55% to 81%, SD = 14.7%). Conformance for the two males who transferred their foot accelerator was 55% and 81%. One female transferred her foot during the reversing maneuver, with conformance of 56%.

No linear regression was performed using the anthropometric, cognitive, and physical performance due to the small sample size.

Total duration of hovering. Data were available for 20 participants describing the total time spent hovering during this maneuver; 3 participants did not hover, 2 participants did not perform the backing maneuver, and there were no video data for 1 participant at this location. Table 88 presents total hover duration by group, while Table 89 presents these data by sex. The three participants who did not hover were all NA drivers (2 males and 1 female). Among the drivers who hovered, hover frequency and total duration were similar for the MC and NA groups. T-tests found no statistically significant difference in total hover duration between the NA and MC group. Table 89shows that females hovered frequently more often than males (44% of females had 3+ hovers compared to 14% of males). Looking at the average of the total hovering time by sex, females and males had similar hover duration times; t-test results were non-significant.

Table 88. Hover Behavior, by Group, During Reverse 2 in Garage

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**3**	**5**	**3**	**4**	**4.54**	**2.02**
Medical Condition	**8**	**0**	**3**	**3**	**2**	**4.24**	**1.98**
Neuropathy	6	0	3	2	1	4.71	2.08
Orthopedic Surgery	2	0	0	1	1	2.82	0.72
Total	**23**	**3**	**8**	**6**	**6**	**4.42**	**1.96**

Table 89. Hover Behavior, by Sex, During Reverse 2 in Garage

Group	N	Count of Participants by Number of Hovers				Hover Duration	
		0 Hovers	1 Hover	2 Hovers	3+ Hovers	Average (s)	Standard Deviation (s)
Females	9	1	2	2	4	3.86	2.14
Males	14	2	6	4	2	4.80	1.82
Total	**23**	**3**	**8**	**6**	**6**	**4.42**	**1.96**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables were associated with total hover duration.

Total duration of gazes to the left and right. Tables 90 and 91 present the duration of looks to the left, and Tables 92 and 93 describe the duration of looks to the right during the second reverse in the parking garage. Looks to the left included the left mirror and left window. Looks to the right included the inside rear-view mirror, the right window, the right mirror, and to the rear. Video data were missing for one NA participant, and two NA participants did not perform the reverse maneuver. Three NA drivers and one PN participant did not look to the left; durations for these participants were coded as zero seconds. All participants who performed the maneuver and had video data looked to the right (n=23). T-tests indicated no significant differences as a function of medical status group or sex for glance durations to the right or to the left.

Table 90. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse 2 in Garage, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**3.14**	**2.88**
Medical Condition	**8**	**4.53**	**3.21**
Neuropathy	6	4.37	3.66
Orthopedic Surgery	2	5.0	2.12
Total	**23**	**3.62**	**3.00**

Table 91. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse 2 in Garage, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	3.07	2.80
Male	14	3.98	3.19
Total	**23**	**3.62**	**3.00**

Table 92. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse 2 in Garage, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**9.19**	**3.34**
Medical Condition	**8**	**9.63**	**3.33**
Neuropathy	6	8.57	2.93
Orthopedic Surgery	2	12.8	2.83
Total	**23**	**9.34**	**3.27**

Table 93. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse 2 in Garage, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	10.59	3.96
Male	14	8.54	2.58
Total	**23**	**9.34**	**3.27**

Location 5: Reverse

This section examines braking behavior during a reverse maneuver in the staff parking lot (location 5) as measured by four dependent variables: foot transfer time (B), foot placement on brake pedal (C), conformance of foot movement to most direct path (E), and total duration of hovering (N). It also examines the total duration of glances to the left and to the right.

Average foot transfer time. Table 94 presents foot transfer time by group, while Table 95 presents these data by sex. T-tests indicated no significant difference in transfer times as a function of study group or sex.

Table 94. Foot Transfer Time From Accelerator to Brake, During Reverse in Staff Parking Lot, by Study Group

Group	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	**15**	**0.90**	**0.40**
Medical Condition	**8**	**1.10**	**0.70**
Neuropathy	6	1.21	0.79
Orthopedic Surgery	2	0.75	7.78
Total	**23**	**0.97**	**0.52**

Table 95. Foot Transfer Time From Accelerator to Brake, During Reverse in Staff Parking Lot, by Sex

Sex	N	Average Speed (s)	Standard Deviation (s)
Female	9	1.03	0.66
Male	14	0.93	0.42
Total	**23**	**0.97**	**0.52**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables were associated with average foot transfer time.

Average foot contact area on brake. Table 96 presents the average foot contact area on the brake pedal during reverse in the staff parking lot by study group, while Table 97 presents a summary of performance by sex. Foot contact area was nearly equal for the NA, the MC, and the PN groups; a t-test confirmed no statistically significant differences in this metric as a function of study group. A t-test found that the difference between males and females approached, but failed to reach statistical significance (t=-2.00, df=20, p=0.059). Eighteen of the 22 participants exhibited less than 25% contact area on the brake during the reversing maneuver at the staff parking lot.

Table 96. Average Foot Contact Area on Brake Pedal (%) During Reverse in Staff Parking Lot, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**11.9%**	**10.3%**
Medical Condition	**7**	**11.6%**	**10%**
Neuropathy	5	11%	12.1%
Orthopedic Surgery	2	13%	2.83%
Total	**22**	**11.8%**	**9.96%**

Table 97. Average Foot Contact Area on Brake Pedal (%) During Reverse in Staff Parking Lot, by Sex.

Sex	N	Average (%)	Standard Deviation (%)
Female	9	16.6%	13.2%
Male	13	8.46%	5.32%
Total	**22**	**11.8%**	**9.96%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that driver height was strongly associated with foot contact area on the brake pedal. *As driver height increased, average foot contact area on brake pedal decreased.*

IV	Coefficient	p value	Correlation with DV
Intercept	112.090	0.009	NA
Driver height	-0.586	0.017	-0.500

R^2 = 0.266; Adjusted R^2 = 0.227.

Conformance of actual foot movement path with linear path. Table 98 presents foot path conformance with the linear path during the transfer from accelerator to brake during the reverse in the staff parking lot, by study group, while Table 99 presents a summary of performance by sex. The average foot conformance across group and sex approached 65%; t-tests found no significant difference in this metric as a function of medical status group or sex.

Table 98. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Reverse in Staff Parking Lot, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**64.1%**	**11.3%**
Medical Condition	**8**	**65.9%**	**8.72%**
Neuropathy	6	63.5%	8.92%
Orthopedic Surgery	2	73%	--
Total	**23**	**64.7%**	**10.3%**

Table 99. Conformance of Actual Foot Movement Path With Linear Path From Accelerator to Brake, During Reverse in Staff Parking Lot, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	64.7%	7.1%
Male	14	64.8%	12.2%
Total	**23**	**64.7%**	**10.3%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that only tibia length was associated with conformance of actual foot movement path with the linear path. *As tibia length increased, conformance decreased.* The regression output was:

IV	Coefficient	p value	Correlation with DV
Intercept	105.466	<0.001	NA
Tibia length	-1.128	0.051	-0.390

R^2 = 0.177; Adjusted R^2 = 0.136.

Total duration of hovering. Data were available for nine NA participants and three PN participants describing the total time spent hovering during this maneuver; 12 participants did not hover (seven NA, three PN, and both OP), and there were no video data for two NA participants at this location. Table 100 presents total hover duration by group, while Table 101 presents these data by sex. A larger proportion of NA drivers than MC drivers hovered (56% vs 37.5%). Among the drivers who hovered, hover duration for the NA drivers was longer than that for the MC group (average 2.43 s versus 1.67 s). No tests of statistical significance by medical status group were performed due to the small number of drivers in the MC group who hovered. Tests revealed no significant differences by sex.

Table 100. Hover Behavior, by Group, During Reverse in Staff Parking Lot

Group	**N**	**Count of Participants by Number of Hovers**				**Hover Duration**	
		0 Hovers	**1 Hover**	**2 Hovers**	**3+ Hovers**	**Average (s)**	**Standard Deviation (s)**
Normal Aging	**16**	**7**	**6**	**3**	**0**	**2.43**	**1.87**
Medical Condition	**8**	**5**	**1**	**2**	**0**	**1.67**	**0.67**
Neuropathy	6	3	1	2	0	1.67	0.67
Orthopedic Surgery	2	2	0	0	0	--	--
Total	**24**	**12**	**7**	**5**	**0**	**2.24**	**1.66**

Table 101. Hover Behavior, by Sex, During Reverse in Staff Parking Lot

Group	**N**	**Count of Participants by Number of Hovers**				**Hover Duration**	
		0 Hovers	**1 Hover**	**2 Hovers**	**3+ Hovers**	**Average (s)**	**Standard Deviation (s)**
Females	9	2	4	3	0	2.23	1.88
Males	15	10	3	2	0	2.26	1.51
Total	**24**	**12**	**7**	**5**	**0**	**2.24**	**1.66**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables was strongly associated with total hover duration.

Total duration of gazes to the left and right. Tables 102 and 103 present statistics describing the duration of looks to the left and Tables 104 and 105 describe duration of looks to the right during the reverse in the staff parking lot. Looks to the left included the left mirror and left window. Looks to the right included the inside rear-view mirror, the right window, the right mirror, and to the rear. Video data were missing for two NA participants. All other participants had durations of looking left and right greater than zero seconds. T-tests found no significant differences as a function of study group or sex for gaze durations in either direction.

Table 102. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse in Staff Parking Lot by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**16**	**3.58**	**2.33**
Medical Condition	**8**	**5.81**	**3.20**
Neuropathy	6	6.07	3.71
Orthopedic Surgery	2	5.05	1.20
Total	**24**	**4.33**	**2.80**

Table 103. Total Duration of Looking to the Left (Left Mirror and Left Window), During Reverse in Staff Parking Lot, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	4.27	2.47
Male	15	4.36	3.06
Total	**24**	**4.33**	**2.80**

Table 104. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse in Staff Parking Lot, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**16**	**7.97**	**3.23**
Medical Condition	**8**	**8.99**	**3.12**
Neuropathy	6	8.45	3.23
Orthopedic Surgery	2	10.6	2.40
Total	**24**	**8.31**	**3.16**

Table 105. Total Duration of Looking to the Right (Center Mirror, Right Window, Right Mirror, and Rear), During Reverse in Staff Parking Lot, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	7.88	3.34
Male	15	8.57	3.14
Total	**24**	**8.31**	**3.16**

Location 6: Straight parking

This section examines braking behavior during a straight parking maneuver in the staff parking lot (location 6) as measured by three dependent variables: foot transfer time (B), foot placement on brake pedal (C), and total duration of hovering (N). It also examines the total duration of glances to the left and to the right.

Average foot transfer time. Tables 106 and 107 present descriptive statistics for foot transfer time by group and sex, respectively. T-tests indicated no significant difference in transfer times as a function of medical status group. However, *males' average foot transfer time was 1.33 s longer than females'; this difference was statistically significant (t=3.0848, df = 22, p=0.005).*

Table 106. Foot Transfer Time From Accelerator to Brake, During Straight Parking in Staff Parking Lot, by Study Group

Group	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	**17**	**1.78**	**1.13**
Medical Condition	**7**	**1.94**	**1.48**
Neuropathy	6	2.10	1.55
Orthopedic Surgery	1	0.97	--
Total	**24**	**1.82**	**1.21**

Table 107. Foot Transfer Time From Accelerator to Brake, During Straight Parking in Staff Parking Lot, by Sex

Sex	N	Average Speed (s)	Standard Deviation (s)
Female	10	1.05	0.31
Male	14	2.38	1.32
Total	**24**	**1.82**	**1.21**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found driver height and brake RT to be associated with foot transfer time. *As driver height increased, there was an associated increase in foot transfer time. As brake RT increased (poorer performance), there was an associated decrease in foot transfer time (foot transfer time was faster); this association is not in the expected direction.*

IV	Coefficient	p value	Correlation with DV
Intercept	-6.734	0.106	NA
Driver height	0.065	0.015	0.398
Brake RT	-4.983	0.056	-0.243

R^2 = 0.296; Adjusted R^2 = 0.229

Average foot contact area on brake. Tables 108 and 109 present the average foot contact area on the brake pedal during straight parking in the staff parking lot by medical status group and sex, respectively. Foot contact area was nearly equal (approximately 10%) for the NA participants, the MC group, and the PN group; a t-test found there were no statistically significant differences in this metric as a function of medical status group or sex. Twenty-one of the 22 participants exhibited less than 25% contact area on the brake during the parking straight-in maneuver at the staff parking lot.

Table 108. Average Foot Contact Area on Brake Pedal (%) During Straight Parking in Staff Parking Lot, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**16**	**10.7%**	**10.4%**
Medical Condition	**6**	**10.3%**	**7.3%**
Neuropathy	5	10%	8.2%
Orthopedic Surgery	1	12%	---
Total	**22**	**10.6%**	**9.5%**

Table 109. Average Foot Contact Area on Brake Pedal (%) During Straight Parking in Staff Parking Lot, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	15%	13%
Male	13	7.5%	4.6%
Total	**22**	**10.6%**	**9.5%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables were associated with foot contact area on the brake.

Total duration of hovering. Four drivers in the NA group and three in the MC group (2 PN and 1 OP) hovered during this maneuver. Three males and one female in the NA group hovered (each with 1 hovering movement). One female and one male in the MC group hovered once and one female hovered twice.

Total hover duration by group is presented in Table 110 and by sex in Table 111. No significance testing was performed due to the small sample size.

Table 110. Hover Behavior, by Group, During Straight Parking in Staff Parking Lot

Group	N	Hover Duration	
		Average (s)	Standard Deviation (s)
Normal Aging	**4**	**0.66**	**0.35**
Medical Condition	**3**	**0.87**	**0.47**
Neuropathy	2	0.75	0.60
Orthopedic Surgery	1	1.11	---
Total	**7**	**0.75**	**0.38**

Table 111. Hover Behavior, by Sex, During Straight Parking in Staff Parking Lot

Group	N	Hover Duration	
		Average (s)	Standard Deviation (s)
Females	3	0.89	0.45
Males	4	0.65	0.36
Total	**7**	**0.75**	**0.38**

Total duration of gazes to the left and right. Only four NA drivers (two males and two females) and three MC participants (one male and one female PN participant and one female OP participant) looked to the left while performing the straight parking maneuver in the staff parking lot. Tables 112 and 113 present descriptive statistics for total duration of looks to the left, which included the left mirror and left window. There were missing data for one NA participant and one OP participant did not perform this maneuver. Gaze duration to the left was coded as zero seconds for the remaining 17 participants who did not look left. No tests of statistical significance were conducted due to the small sample size. Only one participant looked to the right (a NA male, with a duration of 2.3 s). Looks to the right included the inside rear-view mirror, the right window, the right mirror, and to the rear.

Table 112. Total Duration of Looking to the Left (Left Mirror and Left Window), During Straight Parking in Staff Parking Lot by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**17**	**0.37**	**0.75**
Medical Condition	**7**	**0.94**	**1.2**
Neuropathy	6	0.82	1.27
Orthopedic Surgery	1	1.7	---
Total	**24**	**0.54**	**0.92**

Table 113. Total Duration of Looking to the Left (Left Mirror and Left Window), During Straight Parking in Staff Parking Lot, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	10	0.61	0.88
Male	14	0.49	0.98
Total	**24**	**0.54**	**0.92**

Location 7: Straight parking

This section examines braking behavior during a straight parking maneuver in a parking garage (location 7) as measured by three dependent variables: foot transfer time (B), foot placement on brake pedal (C), and total duration of hovering (N). It also examines the total duration of glances to the left and to the right.

Average foot transfer time. Table 114 presents foot transfer time by group, while Table 115 presents these data by sex. T-tests indicated there were no significant differences in transfer times as a function of study group or sex.

Table 114. Foot Transfer Time From Accelerator to Brake, During Straight Parking in Garage, by Study Group

Group	N	Average Speed (s)	Standard Deviation (s)
Normal Aging	**14**	**2.12**	**1.65**
Medical Condition	**8**	**2.38**	**1.28**
Neuropathy	6	2.35	1.50
Orthopedic Surgery	2	2.47	0.25
Total	**22**	**2.21**	**1.50**

Table 115. Foot Transfer Time From Accelerator to Brake, During Straight Parking in Garage, by Sex

Sex	N	Average Speed (s)	Standard Deviation (s)
Female	9	2.31	1.63
Male	13	2.14	1.47
Total	**22**	**2.21**	**1.50**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that none of the independent variables were associated with foot transfer time.

Average foot contact area on brake. Table 116 presents the average foot contact area on the brake pedal during straight parking in the parking garage by group, while Table 117 presents a summary by sex. Foot contact area varied little by study group and sex, and averaged 12.4%. T-tests revealed no statistically significant differences in this metric as a function of either study group or sex. Twenty of the 22 participants exhibited less than 25% contact area on the brake during the parking straight-in maneuver in the parking garage.

Table 116. Average Foot Contact Area on Brake Pedal (%) During Straight Parking in Garage, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**11.9%**	**9.6%**
Medical Condition	**7**	**13.4%**	**5.29%**
Neuropathy	5	13%	5.57%
Orthopedic Surgery	2	14.5%	6.36%
Total	**22**	**12.4%**	**8.36%**

Table 117. Average Foot Contact Area on Brake Pedal (%) During Straight Parking in Garage, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	13.3%	10.3%
Male	13	11.8%	7.0%
Total	**22**	**12.4%**	**8.36%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that Trails B completion time was associated with foot contact area on brake. *Poorer Trails B completion time was associated with increased foot contact area on the brake pedal.*

IV	Coefficient	p value	Correlation with DV
Intercept	-7.733	0.267	NA
Trails B time	0.214	0.009	0.391

R^2 = 0.311; Adjusted R^2 = 0.275.

Total duration of hovering. Only two NA drivers (both males) hovered during this maneuver, and each of these drivers hovered only one time. In comparison, five MC drivers hovered (four PN and one OP). Among the MC group were two females (each hovering twice) and three males (each hovering once).

Total hover duration by group is presented in Table 118 and by sex in Table 119. No significance testing was performed due to the small sample size. Hover duration statistics for the NA group were largely affected by one male participant with an extended hover time compared to all other participants (6.97 s).

Table 118. Hover Behavior, by Group, During Straight Parking in Garage

Group	N	Hover Duration	
		Average (s)	Standard Deviation (s)
Normal Aging	**2**	**3.61**	**4.76**
Medical Condition	**5**	**1.07**	**0.49**
Neuropathy	4	1.15	0.52
Orthopedic Surgery	1	0.75	---
Total	**7**	**1.79**	**2.34**

Table 119. Hover Behavior, by Sex, During Straight Parking in Garage

Group	N	Hover Duration	
		Average (s)	Standard Deviation (s)
Females	2	1.26	0.01
Males	5	2.01	2.83
Total	**7**	**1.79**	**2.34**

Data were available only for seven participants, and the regression did not indicate any statistically significant associations.

Total duration of gazes to the left and right. Only one NA and one PN participant (both males) looked to the left while performing the straight parking maneuver in the parking garage. Looks to the left included the left mirror and left window. Total gaze duration to the left for the NA participant was 1.7 s, and for the PN participant 0.8 s. No study participants looked to the right during this maneuver.

Location 8: Gate access

This section examines pre-task and task behaviors at a gated access when entering a parking garage (Location 8). There were no foot movement data for six NA drivers because the gate was open (five drivers) or the camera malfunctioned (one driver). In the MC group, foot movement data could not be collected for one PN participant because the gate was already opened and for another PN participant because he stepped outside of the vehicle to perform the card swipe task. A third PN participant had partial foot movement data due to non-functioning sensors on the brake and accelerator pedal during his drive.

The dependent variables for pre-task behaviors include five “yes-no” questions about actions taken by the participant such as unbuckling a seat belt. The dependent variables for task behaviors included reach and swipe duration. And if the participant’s foot was on the brake, the dependent variables analyzed include the following:

- Average foot internal-external angle during reach and swipe

- Average foot internal-external angle NOT during reach and swipe
- Average force on the brake pedal during the reach and swipe
- Average force on the brake pedal NOT during the reach and swipe
- Average foot placement on brake pedal during reach and swipe
- Average foot placement on brake pedal NOT during reach and swipe
- Average foot contact area on brake pedal during reach and swipe
- Average foot contact area on brake pedal NOT during reach and swipe the card.

Pre-task behaviors. Participants performed the gate access task in multiple ways. Some repositioned the vehicle to get closer to the card access (two males and one female), while others put the car in park and opened the door to reach the card access; and one stepped outside of the vehicle. Some of these behaviors eliminated foot movement on the brake, while others added additional attentional demands on the drivers. These behaviors are characterized by group in Table 120. The five participants who put the car in park also unbuckled their seat belts and opened the door (three females and two males). Four of these five stepped out of the car (three females and one male). The proportion of participants engaging in each of these tasks was similar by group with the exception that a slightly higher proportion of NA drivers unbuckled their seatbelts compared to the MC group (42% versus 29%).

Table 120. Pre-Gate Access Task Behaviors, by Group, at Parking Garage Entry

Group	N	Did participant reposition car?		Did participant select parking gear?		Did participant unbuckle seatbelt?		Did participant open the door?		Did participant step out of the car?	
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Normal Aging	**12**	**2**	**10**	**3**	**9**	**5**	**7**	**3**	**9**	**2**	**10**
Medical Condition	**7**	**1**	**6**	**2**	**5**	**2**	**5**	**2**	**5**	**2**	**5**
Neuropathy	5	1	4	2	3	2	3	2	3	2	3
Orthopedic Surgery	2	0	2	0	2	0	2	0	2	0	2
Total	**19**	**3**	**16**	**5**	**14**	**7**	**12**	**5**	**14**	**4**	**15**

Reach and swipe duration. Table 121 presents the duration of reach and swipe at the gated access to the parking garage by medical status group, and Table 122 by sex. Reach and swipe began when the gate access badge crossed the plane of the vehicle window as a participant reached his/her arm out of the vehicle to swipe the badge and ended when the badge crossed the plane of the window as the participant brought his/her arm back inside of the vehicle. Three participants (all NA) had one unsuccessful swipe attempt prior to their successful swipe; researchers combined the unsuccessful and successful swipe attempt durations for a total duration of reach and swipe.

The interest in this variable lies in the potential for pedal misapplications due to a driver being out of normal driving position in the driver seat (reaching out of the window to the left), with their head turned to the left along with their gaze and attention, all possibly affecting foot positioning in the footwell. T-tests found no significant differences in total reach and swipe duration as a function of either study group or sex.

Table 121. Reach and Swipe Duration at Garage Gate Access by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**12**	**6.73**	**6.01**
Medical Condition	**6**	**4.35**	**3.24**
Neuropathy	4	4.5	3.82
Orthopedic Surgery	2	4.05	2.90
Total	**18**	**5.94**	**5.27**

Table 122. Reach and Swipe Duration at Garage Gate Access, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	6	5.4	4.10
Male	12	6.21	5.92
Total	**18**	**5.94**	**5.27**

Average foot internal-external angle during reach and swipe. This metric describes the angle that the vertical midline of the foot departs from 0 degrees in the Y-plane. A positive number indicates the toe moved toward the right (toward the accelerator) and a negative value indicates the toe moved to the left. Higher absolute values indicate the foot was further from the perpendicular (0 degree) line. Tables 123 and 124 present descriptive statistics by medical status group and sex, respectively. There was little difference between the NA and MC groups in foot internal-external angle during the reach and swipe; both groups moved their toe slightly to the right, between 12 and 14 degrees. A t-test revealed group differences were not statistically significant. While the PN group showed approximately half of the movement of the other two groups (6.1 degrees), no test was performed to determine whether this difference was significant, due to the small number of PN participants with data for this metric. A t-test indicated that the difference between males and females was not significant.

Table 123. Average Foot Internal-External Angle During Reach and Swipe (if Foot Is on Brake) at Garage Gate Access, by Study Group

Group	N	Average (deg.)	Standard Deviation (deg.)
Normal Aging	**8**	**13.9**	**8.3**
Medical Condition	**6**	**12.3**	**16.6**
Neuropathy	4	6.1	17.5
Orthopedic Surgery	2	24.6	2.1
Total	**14**	**13.2**	**12.0**

Table 124. Average Foot Internal-External Angle During Reach and Swipe (if Foot Is on Brake) at Garage Gate Access, by Sex

Sex	N	Average (deg.)	Standard Deviation (deg.)
Female	5	8.4	16.2
Male	9	15.9	8.9
Total	**14**	**13.2**	**12.0**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that shoe length, brake RT, and plantar threshold were associated with foot internal-external angle during the reach and swipe task. *Longer shoe length and longer brake RT (poorer performance) were both associated with an increase in foot internal-external angle (front of foot departs from pointing forward as it rests on brake, and angles toward accelerator). An increase in the plantar threshold (poorer foot sensation) was associated with a decrease in foot internal-external angle (foot points closer to straight ahead position on brake).*

IV	Coefficient	p value	Correlation with DV
Intercept	-101.790	0.045	NA
Shoe length	4.031	0.046	0.268
Brake RT	76.054	0.037	0.355
Plantar Threshold	-14.114	0.009	-0.142

R^2 = 0.606; Adjusted R^2 = 0.475

Average foot internal-external angle NOT during reach and swipe. This metric describes the angle that the vertical midline of the foot departed from 0 degrees in the Y-plane as the driver approached and slowed/stopped at the garage gate access, but not during the reach and swipe task. Tables 125and 126 present descriptive statistics by medical status group and by sex. As during the reach and swipe, there was little difference among the medical status groups in foot internal-external angle not during the reach and swipe. Also, the angle was similar to the angle during the reach and swipe. A t-test found no statistically significant difference between the NA and MC groups or between males and females. While the PN group showed approximately half of the movement of the other two groups (6.7 degrees), no significance testing was performed due to the small sample size.

Across the sample of 14 drivers who placed their foot on the brake during the reach and swipe task (as opposed to shifting into park), a t-test found no significant difference in foot internal-external angle before versus during the reach and swipe task. T-tests were also conducted on the difference values obtained during the two observation periods, and they found no significant difference as a function of either study group or sex.

Table 125. Average Foot Internal-External Angle NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average (deg.)	Standard Deviation (deg.)
Normal Aging	**8**	**15.4**	**10.3**
Medical Condition	**6**	**12.2**	**15.5**
Neuropathy	4	6.7	16.3
Orthopedic Surgery	2	23.3	5.4
Total	**14**	**14.0**	**12.3**

Table 126. Average Foot Internal-External Angle NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (deg.)	Standard Deviation (deg.)
Female	5	10.2	14.7
Male	9	16.2	11.2
Total	**14**	**14.0**	**12.3**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length was associated with foot internal-external angle on the brake not during the reach and swipe task. *Greater femur length was associated with increases in foot internal-external angle not during reach and swipe.*

IV	Coefficient	p value	Correlation with DV
Intercept	-68.442	0.091	NA
Femur length	1.740	0.046	0.540

R^2 = 0.311; Adjusted R^2 = 0.275.

Average force on the brake pedal during the reach and swipe. Table 127 presents the average force on the brake during the reach and swipe task at the garage (if the foot was on the brake) by study group and in Table 128 by sex. T-tests found no significant differences as a function of study group or sex.

Table 127. Average Force on the Brake Pedal During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group.

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**9**	**3.8**	**2.7**
Medical Condition	**5**	**2.1**	**1.5**
Neuropathy	3	2.7	1.8
Orthopedic Surgery	2	1.2	0.2
Total	**14**	**3.2**	**2.5**

Table 128. Average Force on the Brake Pedal During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex.

Sex	N	Average (lb)	Standard Deviation (lb)
Female	5	3.1	2.5
Male	9	3.2	2.6
Total	**14**	**3.2**	**2.5**

Regression analyses were not conducted on this dependent variable at this location.

Average force on the brake pedal NOT during the reach and swipe. Table 129 presents the average force on the brake not during the reach and swipe at the garage (if the foot was on the brake) by study group and in Table 130 by sex. T-tests found no significant differences as a function of study group or sex. Regression analyses were not conducted on this dependent variable at this location.

Table 129. Average Force on the Brake Pedal NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**9**	**3.1**	**2.9**
Medical Condition	**5**	**1.8**	**1.7**
Neuropathy	3	2.4	2.1
Orthopedic Surgery	2	1.0	0.1
Total	**14**	**2.7**	**2.6**

Table 130. Average Force on the Brake Pedal NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (lb)	Standard Deviation (lb)
Female	5	2.1	1.9
Male	9	3.0	2.9
Total	**14**	**2.7**	**2.6**

Foot placement on brake during reach and swipe. Tables 131 and 132 present the average foot placement on the brake during reach and swipe (if the foot was on the brake) at the garage gate access, by study group and sex. A t-test showed no significant difference in average foot placement of the NA and MC groups. Table 132 shows that *males' foot placement was much closer to the right edge of the brake compared to that of females (84.2% versus 70.4%). A t-test showed this difference to be statistically significant (t=3.462, df=12, p=0.005).*

Table 131. Average Foot Placement on Brake During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**9**	**80.8%**	**7.0%**
Medical Condition	**5**	**76.6%**	**14.0%**
Neuropathy	3	75.7%	18.0%
Orthopedic Surgery	2	78.0%	11.3%
Total	**14**	**79.3%**	**9.7%**

Table 132. Average Foot Placement on Brake During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	5	70.4%	9.1%
Male	9	84.2%	5.9%
Total	**14**	**79.3%**	**9.7%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that driver height and TUG time were associated with average foot placement on the brake pedal during the reach and swipe task. *Taller drivers had foot placement closer to the right edge of the brake pedal. Poorer performance in TUG time was associated foot placement closer to the center of the brake pedal.* The output of the regression was:

IV	**Coefficient**	**p value**	**Correlation with DV**
Intercept	-30.146	0.488	NA
Driver height	0.790	0.009	0.587
TUG time	-3.214	0.053	-0.391

R^2 = 0.581; Adjusted R^2 = 0.497

Foot placement on brake NOT during reach and swipe. Table 133 and 134 present descriptive statistics for average foot placement on brake not during the reach and swipe (for participants whose foot was on the brake during the reach and swipe) at the garage gate access, by medical status group and by sex. Differences between the NA and MC groups and between males and females were not statistically significant.

Table 133. Average Foot Placement on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average %)	Standard Deviation (%)
Normal Aging	**9**	**84.6%**	**3.7%**
Medical Condition	**5**	**75.4%**	**18.8%**
Neuropathy	3	73.7%	25.7%
Orthopedic Surgery	2	78.0%	8.5%
Total	**14**	**81.2%**	**11.7%**

Table 134. Average Foot Placement on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	5	74.0%	17.8%
Male	9	85.3%	3.7%
Total	**14**	**81.2%**	**11.7%**

The reach and swipe task affected lateral foot placement on the brake as follows. The majority (8 of the 14 drivers, or 57%) moved their foot *slightly* closer to the center of the brake pedal. This includes 5 NA drivers, 2 drivers with PN, and 1 OP (4 males and 4 females). Four of the 14 drivers (28.6%) moved their foot *slightly* closer to the right edge of the brake. This includes 2 NA, 1 PN, and 1 OP (3 males and 1 female). There was no difference in foot placement for 2 drivers, both NA and both males. Across the sample of 14 drivers who placed their foot on the brake during the reach and swipe task (as opposed to shifting into park), a t-test found no significant difference in foot placement on the brake before versus during the reach and swipe task. T-tests were also conducted on the difference values obtained during the two observation periods, and found no significant difference as a function of either sex or study group.

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that driver height and TUG time were associated with foot placement on the brake not during the reach and swipe task. *As driver height increased, foot placement on the brake increased (i.e., was farther toward the right edge of the brake pedal). As TUG time increased (poorer performance), foot placement decreased (i.e., was more toward the center of the brake pedal).*

IV	Coefficient	p value	Correlation with DV
Intercept	4.125	0.938	NA
Driver height	0.675	0.051	0.374
TUG time	-4.776	0.017	0.531

R^2 = 0.500; Adjusted R^2 = 0.409.

Foot contact area on brake during reach and swipe. Table 135 presents average foot contact area on brake during reach and swipe (if the foot was on the brake) at the garage gate access by study group, while Table 136 presents these data by sex. There was little difference in the average foot contact area on the brake by study group (NA versus MC); a t-test confirmed the absence of a significant difference. Eleven of the 14 participants had a coverage area on the brake less than 25%. A t-test found no significant difference as a function of sex.

Table 135. Average Foot Contact Area on Brake During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**9**	**14.9%**	**9.9%**
Medical Condition	**5**	**16%**	**8.5%**
Neuropathy	3	17%	9.8%
Orthopedic Surgery	2	14.5%	9.2%
Total	**14**	**15.3%**	**9.1%**

Table 136. Average Foot Contact Area on Brake During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	5	20%	7.9%
Male	9	12.7%	8.9%
Total	**14**	**15.3%**	**9.1%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that Symbol Digit (number correct) was associated with foot contact area on the brake during the reach and swipe task. *As the number of correct pairings increased on the Symbol Digit test (indicating better performance), there was an increase in foot contact area on the brake*.

IV	Coefficient	p value	Correlation with DV
Intercept	-15.794	0.295	NA
Symbol Digit (# correct)	0.697	0.005	0.532

$R^2 = 0.283$; Adjusted $R^2 = 0.223$.

Foot contact area on brake NOT during reach and swipe. Tables 137 and 138 present descriptive statistics for average foot contact area on brake not during reach and swipe (if the foot was on the brake) at the garage gate access, by medical status group and by sex. There was no significant difference in the average foot contact area on the brake by medical status group (NA versus MC) or by sex. Thirteen of the 14 participants had a coverage area on the brake less than 25%.

Table 137. Average Foot Contact Area on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**9**	**12.9%**	**9.1%**
Medical Condition	**5**	**13.6%**	**6.1%**
Neuropathy	3	13.7%	8.3%
Orthopedic Surgery	2	13.5%	3.5%
Total	**14**	**13.1%**	**7.9%**

Table 138. Average Foot Contact Area on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Garage Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	5	15.2%	8.0%
Male	9	12%	8.1%
Total	**14**	**13.1%**	**7.9%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that Trails B completion time was associated with foot contact area on the brake not during the reach and swipe task. *Poorer Trails B performance was associated with decreased foot contact area on the brake.*

IV	Coefficient	p value	Correlation with DV
Intercept	32.646	0.001	NA
Trails B time	-0.229	0.020	-0.614

R^2 = 0.376; Adjusted R^2 = 0.325.

Location 9: Gate access

This section examines pre-task and task behaviors at a gated access when entering the staff parking lot (Location 9). There were no foot movement data for three NA drivers because the gate was open (2 drivers) or the camera malfunctioned (1 driver). In the MC group, foot movement data could not be collected for one PN participant due to non-functioning sensors on the brake and accelerator pedal during his drive.

The dependent variables for pre-task behaviors include the same five "yes-no" questions as asked about the previous gate access location. The dependent variables for task behaviors included reach and swipe duration. And if the participant's foot was on the brake, the dependent variables analyzed included the same five measures of pedal behavior broken down into during and not during the reach and swipe.

Pre-task behaviors. There was less variability in the way participants performed the parking lot gate access task compared to the garage access. None of the participants repositioned the vehicle to get closer to the card access to the parking lot. Only one participant shifted into park (a female NA participant) and only three unbuckled their seat belt (all NA participants, 2 females and 1 male). None of the participants opened the door to reach the card access or stepped outside of the vehicle.

Reach and swipe duration. Table 139 presents the duration of reach and swipe at the gated access to the parking lot by study group and in Table 140 by sex. Four participants (three NA and one PN) had one unsuccessful swipe attempt prior to their successful swipe; researchers combined the durations for a total duration of reach and swipe. The interest in this variable lies in the potential for pedal misapplications due to a driver being out of normal driving position in the driver seat, as described for the swipe maneuver at the garage gate access. T-tests found no significant difference in total reach and swipe duration as a function of medical status group or sex.

Table 139. Reach and Swipe Duration at Parking Lot Gate Access, by Study Group

Group	N	Average (s)	Standard Deviation (s)
Normal Aging	**15**	**3.3**	**2.8**
Medical Condition	**8**	**3.8**	**3.4**
Neuropathy	6	4.1	4.0
Orthopedic Surgery	2	2.9	1.2
Total	**23**	**3.5**	**3.0**

Table 140. Reach and Swipe Duration at Parking Lot Gate Access, by Sex

Sex	N	Average (s)	Standard Deviation (s)
Female	9	4.8	4.0
Male	14	2.6	1.8
Total	**23**	**3.5**	**3.0**

Average foot internal-external angle during reach and swipe. This metric describes the angle that the vertical midline of the foot departs from 0 degrees in the Y-plane. A positive number indicates the toe moved to the right (toward the accelerator) and a negative value indicates the toe moved to the left. A higher absolute value indicates that the foot is further from the perpendicular (0-degree) line. Tables 141 and 142 present descriptive statistics by medical status group and by sex. There was no significant difference as a function of medical status or sex in foot internal-external angle during the reach and swipe.

Table 141. Average Foot Internal-External Angle During Reach and Swipe (if Foot Is on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (deg.)	Standard Deviation (deg.)
Normal Aging	**13**	**14.4**	**12.2**
Medical Condition	**7**	**14.5**	**6.0**
Neuropathy	5	14.6	7.3
Orthopedic Surgery	2	14.4	1.1
Total	**20**	**14.5**	**10.3**

Table 142. Average Foot Internal-External Angle During Reach and Swipe (if Foot Was on Brake) at Parking Lot Access, by Sex

Sex	N	Average (deg.)	Standard Deviation (deg.)
Female	8	14.7	6.8
Male	12	14.3	12.4
Total	**20**	**14.5**	**10.3**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no associations among these variables with foot internal-external angle during the reach and swipe task.

Average foot internal-external angle NOT during reach and swipe. This metric describes the angle that the vertical midline of the foot departs from 0 degrees in the Y-plane at the parking lot gate access, but not during the reach and swipe task. Tables 143 and 144 present descriptive statistics by study group and by sex. Similar to during the reach and swipe, there was no significant difference as a function of medical status or sex in this measure.

Across the sample of 20 drivers who placed their foot on the brake during the reach and swipe task (as opposed to shifting into park), a t-test found no significant difference in foot internal-external angle before versus during the reach and swipe task. T-tests conducted on the difference values obtained during the two observation periods found no significant difference as a function of either study group or sex.

Table 143. Average Foot Internal-External Angle NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (deg.)	Standard Deviation (deg.)
Normal Aging	**13**	**16.3**	**10.3**
Medical Condition	**7**	**14.9**	**5.3**
Neuropathy	5	15.0	6.5
Orthopedic Surgery	2	14.8	0.1
Total	**20**	**15.8**	**8.7**

Table 144. Average Foot Internal-External Angle NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (deg.)	Standard Deviation (deg.)
Female	8	14.7	7.0
Male	12	16.5	10.0
Total	**20**	**15.8**	**8.7**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found no associations among these variables with foot internal-external angle not during the reach and swipe task.

Average force on the brake pedal during the reach and swipe. Tables 145 and 146 present the average force on the brake during the reach and swipe at the parking lot gate (if the foot was on the brake) by study group and by sex. T-tests indicated no significant difference as a function of medical status or sex.

Table 145. Average Force on the Brake Pedal During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**15**	**3.7**	**3.7**
Medical Condition	**7**	**4.3**	**1.4**
Neuropathy	5	4.5	1.4
Orthopedic Surgery	2	3.6	1.5
Total	**22**	**3.8**	**3.1**

Table 146. Average Force on the Brake Pedal During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (lb)	Standard Deviation (lb)
Female	9	4.3	3.5
Male	13	3.6	2.9
Total	**22**	**3.8**	**3.1**

Regression analyses were not conducted on this dependent variable at this location.

Average force on the brake pedal NOT during the reach and swipe. Tables 147 and 148 present the average force on the brake not during the reach and swipe at the parking lot gate access (if the foot was on the brake) by medical status group and by sex. Similar to during the reach and swipe task, there was no significant difference in average force applied to the brake as a function of medical status or sex.

Table 147. Average Force on the Brake Pedal NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (lb)	Standard Deviation (lb)
Normal Aging	**15**	**3.2**	**4.1**
Medical Condition	**7**	**4.1**	**1.4**
Neuropathy	5	4.1	1.7
Orthopedic Surgery	2	3.9	0.8
Total	**22**	**3.5**	**3.5**

Table 148. Average Force on the Brake Pedal NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (lb)	Standard Deviation (lb)
Female	9	4.4	5.0
Male	13	2.8	1.7
Total	**22**	**3.5**	**3.5**

Regression analyses were not conducted on this dependent variable at this location.

Foot placement on brake during reach and swipe. Tables 149 and 150 present the average foot placement on brake during reach and swipe (if the foot was on the brake) at the parking lot gate access by medical status group and by sex. T-tests showed no significant differences by medical status or sex.

Table 149. Average Foot Placement on Brake During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**83.2%**	**9.3%**
Medical Condition	**7**	**79.9%**	**14.6%**
Neuropathy	5	78.6%	17.5%
Orthopedic Surgery	2	83%	5.7%
Total	**22**	**82.1%**	**11.0%**

Table 150. Average Foot Placement on Brake During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	77.8%	14.4%
Male	13	85.1%	7.1%
Total	**22**	**82.1%**	**11.0%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length and brake RT were associated with foot placement on the brake during the reach and swipe task. *Greater femur length was associated with foot placement closer to the right edge of the brake pedal. Slower/poorer brake reaction time was associated with foot placement close to the center of the brake pedal*.

IV	Coefficient	p value	Correlation with DV
Intercept	30.078	0.244	NA
Femur length	1.761	0.004	0.463
Brake RT	-61.228	0.010	-0.394

$R^2 = 0.462$; Adjusted $R^2 = 0.402$

Foot placement on brake NOT during reach and swipe. Tables 151 and 152 present descriptive statistics for average foot placement on the brake not during the reach and swipe (if the foot was on the brake) at the parking lot gate access by medical status group and sex. There was no significant difference in performance on this metric by medical status group or sex.

Table 151. Average Foot Placement on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**82.5%**	**11.3%**
Medical Condition	**7**	**82.1%**	**13.5%**
Neuropathy	5	81.4%	16.4%
Orthopedic Surgery	2	84%	2.8%
Total	**22**	**82.4%**	**11.7%**

Table 152. Average Foot Placement on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	78.4%	15%
Male	13	85.1%	8.5%
Total	**22**	**82.4%**	**11.7%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length and brake RT were associated with foot placement on the brake not during the reach and swipe task. Similar to during the reach and swipe task, *greater femur length was associated with foot placement closer to the right edge of the brake pedal, and slower/poorer brake reaction time was associated with foot placement closer to the center of the brake pedal.*

IV	Coefficient	p value	Correlation with DV
Intercept	18.447	0.506	NA
Femur length	1.917	0.004	0.499
Brake RT	-51.967	0.031	-0.291

$R^2 = 0.415$; Adjusted $R^2 = 0.353$

The reach and swipe task affected lateral foot placement on the brake as follows. Nine of the 22 drivers (41%) moved their foot *slightly* closer to the center of the brake pedal. These included five NA drivers, three drivers with PN, and one OP (six females and three males). There was no difference in foot placement for 8 of the 22 drivers (36%). This included six NA and two PN drivers (7 males and 1 female). Five of the 22 drivers (23%) moved their foot slightly closer to the right edge of the brake. This included four NA group and one OP group participants (3 females and 2 males). Across the sample of 22 drivers who placed their foot on the brake during the reach and swipe task (as opposed to shifting into park), a t-test found no significant difference in foot placement on the brake before versus during the reach and swipe task. T-tests conducted on the difference values obtained during the two observation periods found no significant difference as a function of sex or study group.

Analysts combined the counts of participants from both gate access tasks (n=36) and looked at change in foot position during the reach and swipe first by medical status group and then by sex in the following three categories: (1) no change in lateral foot position on the brake during the reach and swipe; (2) foot positioning closer to the center of the brake; and (3) foot closer to the right edge of the brake during the reach and swipe. A Fisher's Exact Test found no significant difference in foot placement as a function of study group. However, *a Fisher's Exact Test found a significant difference in foot positioning change as a function of sex (p=0.0458). Of the 15 females, 1 had no change, 10 moved the foot closer to the center of the brake, and 4 moved it closer to the right edge of the brake. Of the 21 males, 9 had no change, 7 moved their foot closer to the center of the brake, and 5 moved their foot closer to the right edge of the brake.*

Foot contact area on brake during reach and swipe. Tables 153 and 154 present descriptive statistics for average foot contact area on brake during reach and swipe (if the foot was on the brake) at the parking lot gate access by medical status group, and by sex. The differences between medical status groups and sexes failed to reach significance. Eighteen of the 22 participants had a coverage area on the brake less than 25%.

Table 153. Average Foot Contact Area on Brake During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**11.8%**	**8.6%**
Medical Condition	**7**	**17%**	**12.0%**
Neuropathy	5	15.4%	13.7%
Orthopedic Surgery	2	21%	8.5%
Total	**22**	**13.5%**	**9.8%**

Table 154. Average Foot Contact Area on Brake During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	17.8%	12.2%
Male	13	10.5%	6.7%
Total	**22**	**13.5%**	**9.8%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length and brake RT were associated with foot contact area on the brake pedal during the reach and swipe task. *Greater femur length was associated with decreased foot contact area on the brake. Poorer/slower reaction time was associated with increased foot contact area on the brake.*

IV	Coefficient	p value	Correlation with DV
Intercept	41.433	0.117	NA
Femur length	-1.089	0.059	-0.303
Brake RT	46.612	0.037	0.362

R^2 = 0.283; Adjusted R^2 = 0.207

Foot contact area on brake NOT during reach and swipe. Tables 155 and 156 present the average foot contact area on brake not during reach and swipe (if the foot was on the brake) at the parking lot gate access by medical status group and by sex. T-tests found no significant difference in the average foot contact area on the brake as a function of either group.

Table 155. Average Foot Contact Area on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Study Group

Group	N	Average (%)	Standard Deviation (%)
Normal Aging	**15**	**11.9%**	**11.4%**
Medical Condition	**7**	**13.9%**	**11.1%**
Neuropathy	5	13.2%	13.5%
Orthopedic Surgery	2	15.5%	7.1%
Total	**22**	**12.5%**	**11.1%**

Table 156. Average Foot Contact Area on Brake NOT During Reach and Swipe (if Foot Was on Brake) at Parking Lot Gate Access, by Sex

Sex	N	Average (%)	Standard Deviation (%)
Female	9	17.2%	15.1%
Male	13	9.3%	5.9%
Total	**22**	**12.5%**	**11.1%**

The linear regression analysis with backward elimination using the five anthropometric, three physical performance, and four cognitive performance measures found that femur length and brake RT were associated with foot contact area on the brake pedal not during the reach and swipe task. *Greater femur length was associated with decreased foot contact area on the brake. Slower/poorer brake reaction time was associated with increased foot contact area on the brake.*

IV	Coefficient	p value	Correlation with DV
Intercept	78.289	0.006	NA
Femur length	-1.898	0.003	-0.531
Brake RT	46.420	0.039	0.262

R^2 = 0.429; Adjusted R^2 = 0.369.

Number of Foot Transfer Movements (Trials) During Drive. Tables 157 and 158 present the number of trials for the full 27-mile route drive by study group, and by sex. For purposes of this study, a trial was defined as an accelerator activation between two consecutive brake pedal activations. This provided a measure of how many transfers from accelerator to brake each person conducted during the full drive. Variations could be the result of differing operational factors such as traffic densities or traffic signal phases, or could be indicative of driver-related factors. Inspection of these two tables indicates that average trial counts were relatively stable across medical status group and sex. T-tests found no statistically significant differences between the NA and MC groups or between males and females on this variable.

Table 157. Number of Foot Transfer Movements During On-Road Evaluation, by Study Group

Group	N	Average	Standard Deviation
Normal Aging	**18**	**137.2**	**16.0**
Medical Condition	**8**	**132.6**	**27.3**
Neuropathy	6	134.2	30.3
Orthopedic Surgery	2	128.0	24.0
Total	**26**	**135.8**	**19.7**

Table 158. Number of Foot Transfer Movements During On-Road Evaluation, by Sex

Sex	N	Average	Standard Deviation
Female	10	140.6	25.0
Male	16	132.8	15.7
Total	**26**	**135.8**	**19.7**

Overall Road Evaluation Performance

CDRS scoring protocol. The CDRS evaluation consisted of a scoring system ranging from zero to four. These scores were used to indicate competence on specific subscales within four domains of driving performance: three *tactical* sets and one *strategic* set of driving skills. A participant who had the opportunity to demonstrate the skill/behavior in question, but never did so received a score of "0". A score of "1" indicates that the participant demonstrated the skill/behavior on roughly 25% of the opportunities afforded during the on-road evaluation (between 0% and 25% of the time); a score of "2" on roughly 50% of the opportunities (between 25-50% of the time); and a score of "3" on roughly 75% of his/her opportunities (between 50 and 75%). A score of "4" indicates that a study participant consistently performed the skill/ behavior when presented with the opportunity (between 75 and 100% of the time).

It is important to note that these scores represent only ordinal, not interval or ratio level data. Although fixed evaluation routes were used as described earlier, normal variability in traffic conditions across time of day, day of week, and weather condition produced different numbers of opportunities to demonstrate skills/behaviors—both between participants on a given drive, and within participants across drives. Thus, a "4" reliably connotes better performance than a "3", a "3" than a "2", and so on; but how *much* better one score is than another varies from person to person, and from drive to drive.

Table 159 presents the number of participants who received scores of 0 through 4 on each driving skill by medical status group, while Table 160 presents the percent of each medical status group receiving these scores. Behaviors in the parking lot, parking garage, and gate access portions of the route were not included among those scored; only the on-road behaviors are reflected in the CDRS scoring metric. As shown in these two tables, most participants in both the NA and MC groups received a score of "4" on all driving behaviors, and 25% or fewer participants in each group received scores of "3." Only one participant (NA) received a score less

Table 159. Distribution of Scores (Frequency), by Study Group, for Traditional CDRS On-Road Driving Performance Scoring Method

Skill/Behavior Evaluated	Subscale Scored by CDRS	Control (n=18)						Medical Conditions (n=8)					
		Number of Subjects with Score of:					Total	Number of Subjects with Score of:					Total
		4	3	2	1	0		4	3	2	1	0	
Tactical Skills: Visual Search and Scanning Tasks	Mirror checks Low Speed Traffic	18					18	8					8
	Mirror Checks High Speed Traffic	18					18	8					8
	Scans Environment Low Speed Traffic	17	1				18	6	2				8
	Scans Environment High Speed Traffic	17	1				18	7	1				8
	Blind Spot Checks Low Speed Traffic	18					18	7	1				8
	Blind Spot Checks High speed traffic	18					18	7	1				8
	Identifies Signage Low Speed Traffic	16	2				18	6	2				8
	Identifies Signage High Speed Traffic	17	1				18	7	1				8
	Checks Cross Traffic Low Speed Traffic	18					18	8					8
	Checks Cross traffic High Speed Traffic	18					18	8					8
Tactical Skills: Vehicle Positioning Tasks	Gap Selection Low Speed Traffic	17	1				18	6	2				8
	Gap Selection High Speed Traffic	18					18	7	1				8
	Following/Stopping Distance Low Speed Traffic	12	5	1			18	7	1				8
	Following/Stopping Distance High Speed Traffic	13	5				18	8					8
	Lane Usage/Position Low Speed Traffic	16	2				18	6	2				8
	Lane Usage/ Position High Speed Traffic	16	2				18	7	1				8
	Turns into Proper Lane Low Speed Traffic	16	2				18	8					8
	Turns into Proper lane High Speed Traffic	16	2				18	8					8
	Lane Changes Low Speed Traffic	18					18	7	1				8
	Lane Changes High Speed Traffic	18					18	7	1				8
Tactical Skills: Vehicle Handling Tasks	Appropriate Speed Low Speed Traffic	15	3				18	7	1				8
	Appropriate Speed High Speed Traffic	16	2				18	8					8
	Smooth Steering Low Speed Traffic	18					18	7	1				8
	Smooth Steering High Speed Traffic	18					18	7	1				8
	Smooth Acceleration Low Speed Traffic	17	1				18	7	1				8
	Smooth Acceleration High Speed Traffic	17	1				18	7	1				8
	Smooth Braking Low Speed Traffic	17	1				18	8					8
	Smooth Braking High Speed Traffic	17	1				18	8					8
	Complete Stops Low Speed Traffic	18					18	8					8
	Complete Stops High Speed Traffic	18					18	8					8
	Turns Low Speed Traffic	16	2				18	8					8
	Turns High Speed Traffic	17	1				18	8					8
	Yields Right of Way Low Speed Traffic	18					18	8					8
	Yields Right of Way High Speed Traffic	18					18	8					8
	Turn Signals Low Speed Traffic	16	2				18	8					8
	Turn Signals High Speed Traffic	17	1				18	8					8
	Speed Maintenance Low Speed Traffic	17	1				18	7	1				8
	Speed Maintenance High Speed Traffic	17	1				18	7	1				8
Strategic Skills: Cognitive and Executive Function Tasks	Divided Attention Low Speed Traffic	15	3				18	6	2				8
	Divided Attention High Speed Traffic	16	2				18	6	2				8
	Anticipates Hazards Low Speed Traffic	16	2				18	7	1				8
	Anticipates Hazards High Speed Traffic	17	1				18	7	1				8
	Plans Ahead Low Speed Traffic	15	3				18	7	1				8
	Plans Ahead High Speed Traffic	15	3				18	7	1				8
	Decision Making Low Speed Traffic	18					18	7	1				8
	Decision Making High Speed traffic	18					18	7	1				8
	Memory Low Speed Traffic	17	1				18	8					8
	Memory High Speed Traffic	17	1				18	8					8
	Following Directions Low Speed Traffic	17	1				18	7	1				8
	Following Directions High Speed Traffic	17	1				18	7	1				8
	Speed of Processing Low Speed Traffic	15	3				18	6	2				8
	Speed of Processing High Speed Traffic	16	2				18	6	2				8
	Rules of the Road Low Speed Traffic	18					18	8					8
	Rules of the Road High Speed Traffic	18					18	8					8

Table 160. Distribution of Scores (Percent), by Study Group, for Traditional CDRS On-Road Driving Performance Scoring Method

Skill/Behavior Evaluated	Subscale Scored by CDRS	Control (n=18) Percent of Total with Scores of:					Medical Conditions (n=8) Percent of Total with Scores of:				
		4	3	2	1	0	4	3	2	1	0
Tactical Skills: Visual Search and Scanning Tasks	Mirror checks Low Speed Traffic	100%					100%				
	Mirror Checks High Speed Traffic	100%					100%				
	Scans Environment Low Speed Traffic	94%	6%				75%	25%			
	Scans Environment High Speed Traffic	94%	6%				88%	13%			
	Blind Spot Checks Low Speed Traffic	100%					88%	13%			
	Blind Spot Checks High speed traffic	100%					88%	13%			
	Identifies Signage Low Speed Traffic	89%	11%				75%	25%			
	Identifies Signage High Speed Traffic	94%	6%				88%	13%			
	Checks Cross Traffic Low Speed Traffic	100%					100%	0%			
	Checks Cross traffic High Speed Traffic	100%					100%	0%			
Tactical Skills: Vehicle Positioning Tasks	Gap Selection Low Speed Traffic	94%	6%				75%	25%			
	Gap Selection High Speed Traffic	100%					88%	13%			
	Following/Stopping Distance Low Speed Traffic	67%	28%	6%			88%	13%			
	Following/Stopping Distance High Speed Traffic	72%	28%				100%				
	Lane Usage/Position Low Speed Traffic	89%	11%				75%	25%			
	Lane Usage/ Position High Speed Traffic	89%	11%				88%	13%			
	Turns into Proper Lane Low Speed Traffic	89%	11%				100%				
	Turns into Proper lane High Speed Traffic	89%	11%				100%				
	Lane Changes Low Speed Traffic	100%					88%	13%			
	Lane Changes High Speed Traffic	100%					88%	13%			
Tactical Skills: Vehicle Handling Tasks	Appropriate Speed Low Speed Traffic	83%	17%				88%	13%			
	Appropriate Speed High Speed Traffic	89%	11%				100%				
	Smooth Steering Low Speed Traffic	100%					88%	13%			
	Smooth Steering High Speed Traffic	100%					88%	13%			
	Smooth Acceleration Low Speed Traffic	94%	6%				88%	13%			
	Smooth Acceleration High Speed Traffic	94%	6%				88%	13%			
	Smooth Braking Low Speed Traffic	94%	6%				100%				
	Smooth Braking High Speed Traffic	94%	6%				100%				
	Complete Stops Low Speed Traffic	100%					100%				
	Complete Stops High Speed Traffic	100%					100%				
	Turns Low Speed Traffic	89%	11%				100%				
	Turns High Speed Traffic	94%	6%				100%				
	Yields Right of Way Low Speed Traffic	100%					100%				
	Yields Right of Way High Speed Traffic	100%					100%				
	Turn Signals Low Speed Traffic	89%	11%				100%				
	Turn Signals High Speed Traffic	94%	6%				100%				
	Speed Maintenance Low Speed Traffic	94%	6%				88%	13%			
	Speed Maintenance High Speed Traffic	94%	6%				88%	13%			
Strategic Skills: Cognitive and Executive Function Tasks	Divided Attention Low Speed Traffic	83%	17%				75%	25%			
	Divided Attention High Speed Traffic	89%	11%				75%	25%			
	Anticipates Hazards Low Speed Traffic	89%	11%				88%	13%			
	Anticipates Hazards High Speed Traffic	94%	6%				88%	13%			
	Plans Ahead Low Speed Traffic	83%	17%				88%	13%			
	Plans Ahead High Speed Traffic	83%	17%				88%	13%			
	Decision Making Low Speed Traffic	100%					88%	13%			
	Decision Making High Speed traffic	100%					88%	13%			
	Memory Low Speed Traffic	94%	6%				100%				
	Memory High Speed Traffic	94%	6%				100%	0%			
	Following Directions Low Speed Traffic	94%	6%				88%	13%			
	Following Directions High Speed Traffic	94%	6%				88%	13%			
	Speed of Processing Low Speed Traffic	83%	17%				75%	25%			
	Speed of Processing High Speed Traffic	89%	11%				75%	25%			
	Rules of the Road Low Speed Traffic	100%					100%				
	Rules of the Road High Speed Traffic	100%					100%				

than “2” and this was for often failing to demonstrate appropriate following/stopping distance in low-speed traffic.

Following the on-road evaluation, the CDRS provided a narrative summary of the driver’s performance and her recommendations, and checked one of the following recommendations listed on the score sheet:

- Successful demonstration of driving skills;
- Adequate skills in familiar areas;
- [Number of] training hours recommended;
- Unsuccessful demonstration of safe driving skills: NO DRIVING RECOMMENDED;
- Re-assess at a later date;
- Proficient use of adaptive equipment;
- Further assess; or
- Private driving school for training or remediation.

The CDRS indicated that 73% of the sample (19 of 26 drivers) successfully demonstrated safe driving skills. This included 13 of the 18 NA participants (72%) and 6 of the 8 MC participants (75%). For the remaining seven drivers (5 NA, 1 PN, and 1 OP) the CDRS recommended driving only in familiar areas. Six of these seven drivers had Trail-Making B scores that were poorer than the median score (i.e., scores greater than 90 sec), including three participants with the poorest scores in the 26-driver sample. Examples of the CDRS’s observations and guidance provided to these drivers are presented below:

- *Passenger conversation distracted the driver and impacted ability to maintain appropriate speed.*
- *When driving in a familiar area, the driver had fewer last-minute responses, compared to driving in unfamiliar areas.*
- *Driver demonstrated safe skills in all areas except the interstate, where the driver exhibited difficulty merging on and off interstates.*
- *Although, overall the driver demonstrated adequate skills, there were instances of poor lane management and gap acceptance.*
- *Driver exhibited poor hazard management and planning ahead when conversing. The driver ran a stop sign and failed to respond to two signs indicating the lane was ending. Recommended that driver avoid distractions including conversation and cell phone use while driving.*
- *Driver’s performance was adequate for driving in familiar areas, but not in unfamiliar areas. Advised driver to increase stopping distances, choose protected left turns, and avoid distractions.*
- *Difficulties today included disorientation in familiar areas and poor attention to traffic flow, resulting in wide turns left and right, poor stopping distance, speeds 10+ over limit, and heavy take offs and stops. Recommend familiar areas only.*

- *In residential areas, the driver attended to houses versus the road, pedestrians and traffic controls.*
- *In high-speed areas the driver had difficulty attending to traffic and signage in time to allow planning.*
- *During lane changes, the driver moved the vehicle out of the lane prior to actually checking blind spots or observing signs for routes or lane drops. This forced last-minute decisions or quickly moving vehicle back into the lane.*
- *Directions had to be repeated multiple times before the driver understood them.*
- *Driver was counseled to work on attention to signage especially in unfamiliar areas and to check mirrors and blind spots prior to moving the vehicle out of the lane.*

Behaviorally-anchored rating scale (BARS). A measure of on-road driving performance, scored by a CDRS, was developed for this study. This was a complementary measure to the traditional CDRS scoring protocol described above, and it was derived from a detailed review of a driver's behavior as recorded in an instrumented vehicle using multiple video cameras to capture the driver's head movements and gaze direction (visual scanning), control movements (e.g., turn signal activation), as well as the movements of the vehicle in relation to all pertinent roadway and traffic conditions. The BARS was designed to add more depth in describing driving performance than the traditional CDRS scoring protocol and to generate scores with interval properties. The traditional CDRS scoring protocol emphasizes the presence versus absence of a skill and the ratio of behaviors to opportunities to perform the behavior. BARS goes beyond just presence and absence and characterizes how well a behavior is performed (adequate or excellent). For example if a driver used the turn signal but applied it at the last moment before the turn (e.g., less than 1 second), the driver received a BARS score of "2" (adequate) as opposed to a driver who turned on the signal well before the maneuver (e.g., approximately 3 seconds) and who was scored as "3" (excellent).

After the CDRS designed a test route in the Greenville, SC area, she, along with the research team, divided the test route into a sequence of segments or locations, each described by one or more specific maneuvers with an associated set of driving task demands. These task demands were expressed in terms of a series of required behaviors that could be observed and scored by the CDRS. The CDRS scored behaviors during 20 maneuvers as follows:

1. Lane change (Pleasantburg Road);
2. Unprotected left turn using a two-way left-turn lane (TWLTL) to turn left from a major roadway into a driveway or other minor road: with oncoming traffic in the through lanes (Laurens to NAPA Lot);
3. Unprotected left turn using a TWLTL to turn left from a major roadway into a driveway or other minor road: without oncoming traffic in the through lanes (Laurens to NAPA Lot);
4. Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic (NAPA Lot to Laurens);
5. Left turn during the protected phase (green arrow) at a signal-controlled intersection (Laurens to Washington);

6. Left turn during the unprotected phase (green ball) signal-controlled intersection (Laurens to Washington);
7. Freeway to freeway merge (385 to 85);
8. Freeway exit using a deceleration lane (85 to White Horse Road Exit);
9. Negotiating a lane drop/pavement width transition (85 to White Horse Road Merge);
10. Right turn from a channelized right-turn lane with a yield sign and no acceleration lane (Grove to Farris);
11. Gate access at parking deck;
12. Parking: left turn into a parking space (parking deck A);
13. Backing: leaving a parking space (parking deck A);
14. Parking: straight entry into a parking space (parking deck B);
15. Backing: leaving a parking space (parking deck B);
16. Gate access (staff parking lot);
17. Parking: left turn into a parking space (staff parking lot A);
18. Backing: leaving a parking space (staff parking lot A);
19. Parking: straight entry into a parking space (staff parking lot B); and
20. Backing: leaving a parking space (staff parking lot B).

The test route is presented at: www.google.com/maps/d/viewer?mid=zWQrdxISD9kU.kO9aifk2oIRw. The numbered locations on the map do not directly correspond with the numbered maneuvers described above; however, the road names may be used to identify where the maneuvers occurred on the map.

The BARS is a methodology developed in this project to assess on-road driving performance. The BARS is a 0-100 point scale, with higher scores connoting superior performance. Each discrete behavior associated with each separate location/segment along the test route is scored as '1' (fail), '2' (acceptable), or '3' (excellent). The intervals between each of these scores are equal;[8] that is, the difference between Fail and Acceptable is the same as between Acceptable and Excellent. BARS scores for each driver were calculated separately for four different driving tasks to assist in identifying where drivers with medical conditions may have performance difficulties; these were keyed to locations where pedal errors occur as reported in the literature:

- 10 on-road locations/segments (maneuvers 1, 2 or 3, 4, 5 or 6, 7, 8, 9, and 10);
- 4 parking segments (maneuvers 12, 14, 17, and 19);
- 4 backing segments (maneuvers 13, 15, 18, and 20), and
- 2 gate access segments (maneuvers 11 and 16).

Within each of the four segments, the sum was divided by the maximum number of points possible for the segment, and the resulting percentage was the BARS score.

It is important to note that, in the calculation described above, not all drivers' sums of scores were divided by the same denominator. At times, an adjustment in the maximum possible number of points for the test route was made when prevailing (beyond the control of the CDRS)

[8] Personal communication, Leah Belle, Project CDRS

traffic conditions resulted in divergent driving task demands at one or more locations. An example is the location where the driver was required to make a left turn at a signalized intersection. Two distinctly different sets of task demands are described when the driver performs this maneuver with a green arrow (protected) signal (maneuver 5 in the list above), versus a green ball (permitted) indication (maneuver 6). In the latter case, a gap judgment is necessary. The added task demand associated with the gap judgment adds to the maximum number of points that can be scored for that location, and consequently for the test route as a whole.

In the present study, two segments along the test route were characterized by divergent driving task demands – a left turn at an intersection with a green arrow (lower demand) versus a green ball (higher demand), and a turn from a center, two-way-left-turn lane (TWLTL) without opposing traffic (lower demand, maneuver 3 in the list above) or with opposing traffic (higher demand, maneuver 2). These will be described in more detail below; but the result of having divergent driving task demands at two different locations along the test route is that drivers were sorted into one of four brackets – each associated with a different maximum possible number of points – before calculating their BARS scores: (1) low demand conditions at both locations; (2) low demand for the TWLTL maneuver but high demand for the left turn; (3) low demand for the left turn but high demand for the TWLTL maneuver; and (4) high demand at both locations.

Finally, researchers applied one further adjustment, on a location-by-locations basis, when *a)* a given behavior (or series of behaviors) was not performed because the driver did not understand an instruction from the CDRS, or *b)* the behavior(s) was (were) performed but an equipment problem prevented the CDRS from viewing and scoring it. In such cases, the behaviors were removed entirely from the list of on-road performance requirements, and the maximum possible score for the test route was reduced accordingly for the affected drivers. In contrast, if a driver clearly understood the CDRS instructions but ignored or refused to comply with an instruction, each such behavior was interpreted as 'Fail' and received a score of '1.'

Backing performance. No analyses were performed for the four backing maneuvers because all participants who had the opportunity to back out of parking spaces earned the maximum score of 3 for each of the four behaviors included at each location. Backing maneuver data were missing for between 2 and 9 participants at a location because there were no available parking spaces or due to technical malfunctions.

On-road performance. Table 161 presents BARS summary statistics, by study group, for the 10 combined on-road driving tasks. A t-test indicated no significant difference in BARS scores as a function of medical status group.

Table 161. BARS Summary Statistics, by Study Group, for the 10 Combined On-Road Driving Tasks

Group	N	Average Score	Standard Deviation
Normal Aging	**18**	**95.51**	**5.86**
Medical Condition	**8**	**94.96**	**4.64**
Neuropathy	6	96.98	3.02
Orthopedic Surgery	2	88.91	2.72
Total	**26**	**95.34**	**5.43**

Parking performance. Table 162 presents BARS statistics, by medical status group, for the four combined parking tasks. *A t-test showed that the 8 MC drivers scored significantly lower (poorer performance) than the 18 NA group drivers (t=4.03, df = 9, p<.003). Additionally, the 6 PN drivers scored significantly lower (indicating poorer performance) than the 18 NA group drivers (t=2.98, df=6, p<.025). A linear regression using the BARS parking score as the dependent variable, and medical status group, sex, and the 12 independent variables used in the earlier regression analyses (five anthropometric, three physical, and four cognitive) revealed that study group was the only independent variable significantly related to parking performance (p<0.001).*

The differences between groups were isolated for the turn and spacing components during the left turn into the parking space in the parking deck, and failing to shift into park for three of the four parking maneuvers. These are described in more detail below.

Table 162. BARS Summary Statistics, by Study Group, for the Four Combined Parking Tasks

Group	N	Average Score	Standard Deviation
Normal Aging	**18**	**94.61**	**2.79**
Medical Condition	**8**	**86.55**	**5.34**
Neuropathy	6	88.38	4.85
Orthopedic Surgery	2	81.06	1.07
Total	**26**	**92.13**	**5.26**

The CDRS assigned a score of "1" (fail) for turning behavior described by BARS as "proceeds into left turn, unable to successfully determine turn radius;" a "2" (acceptable) as "proceeds into left turn; however, needs to swing wide to assist with turn radius;" and a "3" (excellent) as "able to determine appropriate turn radius and proceeds into space without hesitation." Three of the 8 MC drivers received a score lower than "3" for the turn component of the parking maneuver, while only 1 of the 18 NA drivers received a score lower than "3." The spacing component showed the same pattern by group. The CDRS assigned a score of "1" (fail) for spacing behavior described by BARS as "multiple attempts at aligning correctly for space, not aligned evenly despite multiple attempts to realign;" a "2" (acceptable) as "may need to realign once for centered space position;" and a "3" (excellent) as "does not need to readjust position, evenly positioned between lines."

Shifting into park was scored as either "1" (fail) defined as "does not shift into park, or difficulty determining parking gear," or "3" (excellent), "shifts into park without hesitation." Only one NA group driver did not shift into park, and this driver failed to do so at two of the four parking locations. In contrast, six of the eight MC drivers failed to shift into park or had difficulty doing so at two of the four parking locations, four of the eight at another parking location, and one of the eight at a fourth location.

Interestingly, the NA group drivers were more likely than the MC drivers to score lower than "3" for visual search, scanning mirrors, and surrounding environment for the pulling in straight maneuver in the lot. Drivers in all study groups tended to neglect using turn signals during left-turn parking maneuvers.

Gate access task performance. Table 163 presents BARS summary statistics, by study group, for the two combined gate access tasks. A t-test found no significant difference in BARS score as a function of study group. The slightly better scores exhibited by the MC drivers are a result of better car positioning performance at the gated lot access by all 8 MC participants. Three NA participants were scored "2" indicating "pulls up to gate, may need to position once to easily access pad."

At the parking deck gate access, drivers in both the MC and NA groups failed the vehicle positioning component, indicating "multiple attempts at positioning; may need to open door to successfully access pad."

Table 163. BARS Summary Statistics, by Study Group, for the Two Combined Gate Access Tasks

Group	N	Average Score	Standard Deviation
Normal Aging	**16**	**93.75**	**9.70**
Medical Condition	**8**	**97.22**	**7.86**
Neuropathy	6	96.30	9.07
Orthopedic Surgery	2	100	0
Total	**24**	**94.91**	**9.11**

Results: Driver-Vehicle Fit Study

Occupational Therapists and Certified Driver Rehabilitation Specialists who participated in a panel discussion addressing the overrepresentation of women in pedal misapplication crashes in the previous project (Lococo, Staplin, Martell, & Sifrit, 2012) commented that women are, on average, smaller and their "fit" in the driver's seat is often poor. Many sit with their hips stretched forward, which can cause leg cramps as well as temporary loss of sensation in their feet and legs. At CarFit events, these OTs and CDRSs have often observed women sitting too far away from the steering wheel, sitting too low, reaching for controls, and stretching with their toes. CarFit Guidelines state "drivers should not have to fully extend their leg or use their toes to press on the gas and brake pedals and push them through their full range. Full extension to reach the pedals can be tiring and cause fatigue in the leg muscles."

The Driver-Vehicle Fit Study explored, in part, the research question, "was driver height or sex related to poor driver-vehicle fit?" The study team collected measures inside of 33 drivers' vehicles upon their arrival to GHS for their in-clinic screening appointment. This sample included 24 of the 26 drivers for whom analyzable foot-movement behavior were collected and 9 additional participants with incomplete foot-movement data. The vehicle measure relating most to driver fit and pedal use was the distance they positioned themselves from their pedals ("H-point to brake"). Researchers compared this distance to their right leg functional reach to determine fit.

To measure the H-point-to-brake distance, the data collector positioned an H-point jig in the driver's seat (see Figure 15). The "H-point-to-brake" measure was the distance from the H-point to the center of the brake pedal. A research team member compared each driver's right leg functional reach to their H-point-to-brake distance to determine whether their self-selected seating position required them to stretch their leg and use their toes to operate the brake, and if so, by what amount.

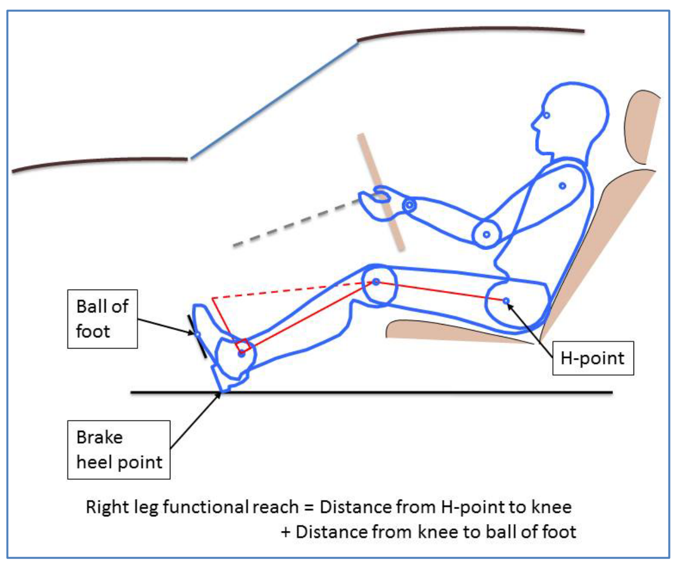


Figure 15. Dimensions used to calculate right leg functional reach length.

Right leg functional reach was calculated as follows. The OT measured each participant's right femur, tibia, and foot length (without shoe) during the in-clinic assessment. Dividing foot length by 1.307 provided the distance from the heel to the ball of the right foot (Chockalingam & Ashford, 2007). The distance from the heel to the ball of the foot provided one side of a right triangle; a second side was the knee-to-ankle (tibia) distance. These values allowed calculation of the hypotenuse of the triangle, shown as a dashed line in Figure 15, to yield an estimate of the distance from the knee to the ball of the foot. These measures supported calculations of right leg functional reach using the formula presented in Figure 15. Across the sample, right leg functional reach averaged 2 inches longer (range 1.5 to 2.6 inches, SD = 0.3) than the average tibia + femur length.

For analysis purposes, a driver's self-selected seating distance from the brake (e.g., driver-vehicle fit) was considered "poor" if his or her right leg functional reach did not exceed the measured distance from the H-point to the brake by at least 1 inch. This criterion was adopted to allow for depression of the brake pedal without stretching. The fit was deemed "acceptable" if right leg functional reach was at least one inch greater than the measured distance from H-Point-to-brake surface.[9]

It must be emphasized that the present classification of driver-vehicle fit depends upon assumptions made with respect to both the anthropometric elements included in the calculation of functional leg reach, and the extent of brake travel to be accommodated without stretching. As shown in Figure 15, the approach does not include the ankle-to-heel distance; this could add approximately two inches to an individual's functional reach calculation. At the same time, a criterion for acceptable fit that requires full depression of the brake pedal, instead of the 1 inch of brake travel adopted here as a criterion, could add another 1-2 inches to the required reach.

Sample Demographics

The 33 participants included 12 females ranging in age from 64 to 79 years (average 71.1 years, SD=4.0) and 21 males ranging from 63 to 85 years of age (average 73.0 years, SD =6.5). Table 164 presents descriptive statistics for height, femur length (upper leg from hip bone to knee), tibia length (lower leg from knee to ankle), foot length, knee-to-ball-of- foot length, right leg functional reach, as well as distance from the H-point to the center of the brake pedal, by driver sex. Female participants were on average 5.4 inches shorter than male participants, and the average right leg functional reach for females was 2.4 inches shorter than that of their male counterparts. Females positioned themselves an average of 2.3 inches closer to the brake pedal than did males.

[9] The functional reach measure did not take into account participants' shoe sole thickness, and as a result, may underestimate "functional reach" for any drivers wearing shoes with thicker soles.

Table 164. Anthropometry of Male and Female Participants in the Driver-Vehicle Fit Study

Measure	Sex	Range (in)	Average (in)	SD (in)
Height	Female (n=12)	60.0 – 68.3	63.8	2.3
	Male (n=21)	65.9 – 73.8	69.2	2.4
Femur (Upper Leg) Length	Female (n=12)	15.0 – 20.0	17.9	1.4
	Male (n=21)	14.5 – 21.2	18.6	1.6
Tibia (Lower Leg) Length	Female (n=12)	11.5 – 15.3	13.3	1.1
	Male (n=21)	11.0 – 16.6	14.9	1.3
Foot Length	Female (n=12)	8.5 – 10.2	9.3	0.5
	Male (n=21)	8.9 – 11.3	10.6	0.6
Knee to Ball of Right Foot	Female (n=12)	13.5 – 16.8	15.1	1.0
	Male (n=21)	13.6 – 18.5	16.9	1.2
Right Leg Functional Reach	Female (n=12)	28.8 – 36.1	33.1	2.2
	Male (n=21)	30.4 – 38.5	35.5	2.2
H-Point to Brake Pedal	Female (n=12)	29.4 – 34.7	31.9	1.5
	Male (n=21)	31.8 – 36.8	34.2	1.6

Self-Selected Seating Distance from Brake Pedal

Across the sample of 33 participants, self-selected seating distance from the brake pedal (fit) was “acceptable” for 20 (60.6%) and “poor” for 13 (39.4%). As shown by Table 165, drivers with acceptable fit were nearly an inch taller than those with poor fit, and had longer femurs and tibias, resulting in longer leg functional reach. Drivers with poor fit (i.e., those who had to stretch their leg to operate the brake pedal) had a right leg functional reach that was nearly 3 inches shorter than those with acceptable fit.

Table 165. Anthropometry Measures, by Driver-Vehicle Fit (Acceptable Versus Poor)

Measure	Driver-Vehicle Fit	Range (in)	Average (in)	SD (in)
Height	Acceptable (n=20)	60.0 – 72.8	67.6	3.3
	Poor (n=13)	60.7 – 73.8	66.7	3.9
Femur (Upper Leg) Length	Acceptable (n=20)	17.0 – 21.2	19.1	1.0
	Poor (n=13)	14.5 – 19.5	17.2	1.5
Tibia (Lower Leg) Length	Acceptable (n=20)	12.0 – 16.6	14.7	1.2
	Poor (n=13)	11.0 – 15.9	13.6	1.6
Foot Length	Acceptable (n=20)	8.5 – 11.3	10.1	0.9
	Poor (n=13)	8.9 – 11.0	10.1	0.7
Knee to Ball of Right Foot	Acceptable (n=20)	13.7 – 18.5	16.6	1.3
	Poor (n=13)	13.5 – 17.8	15.7	1.5
Right Leg Functional Reach	Acceptable (n=20)	31.2 – 38.5	35.7	1.9
	Poor (n=13)	28.8 – 36.4	32.9	2.2

As shown in Figure 16, fit was acceptable for just over half of the sample of males and for two-thirds of the females. Table 166 summarizes the discrepancy between right leg functional reach and H-point-to-brake distance for the four females and nine males with poor fit. Figure 17 presents the distribution of the differences between right leg functional reach and distance from the H-point to the brake in 1-inch increments, by driver sex.

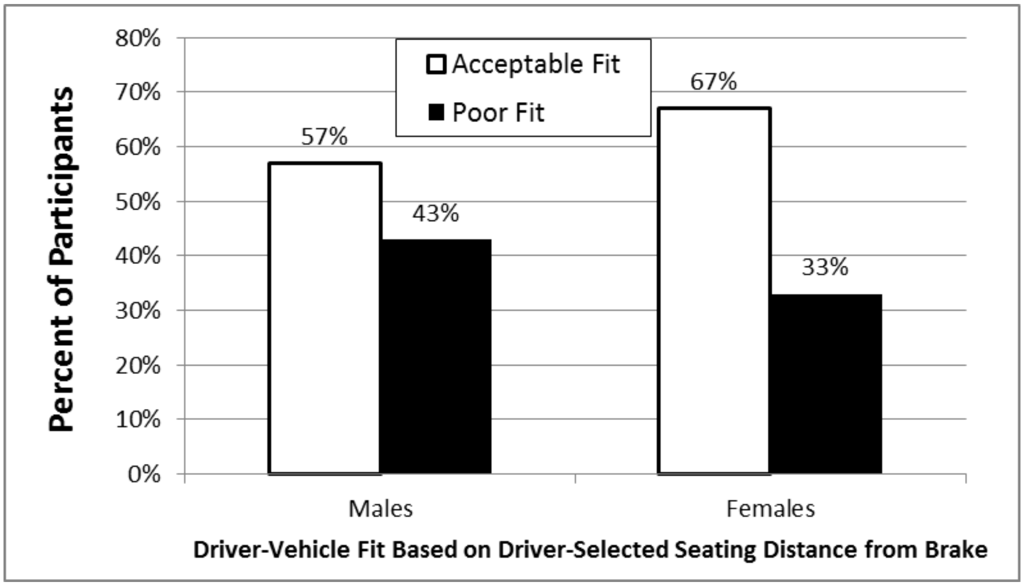


Figure 16. Driver-vehicle fit by sex.

Table 166. Discrepancy Between Leg Functional Reach and H-Point to Brake Distance, by Sex, for Drivers With Poor Fit

Sex	Number with Poor Fit	Functional Reach Minus H-Point to Brake Distance:		
		Range (in)	Average (in)	Standard Deviation (in)
Female	4	-2.2 – 0.9	-0.8	1.4
Male	9	-2.8 – 0.7	-0.8	1.5

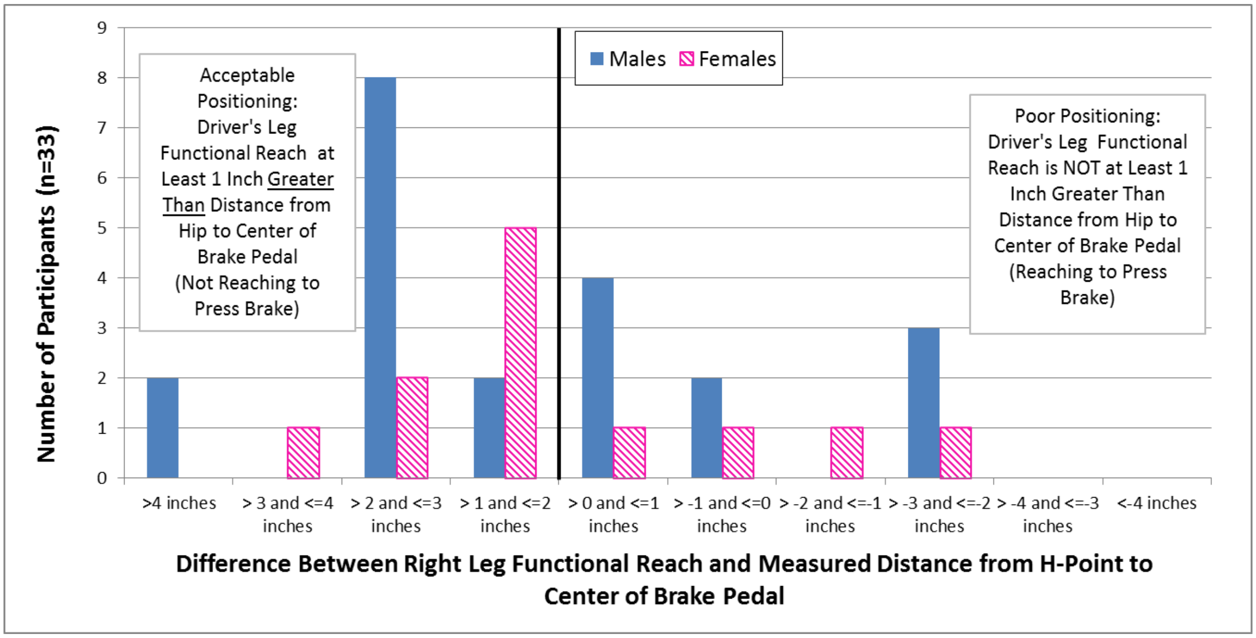


Figure 17. Distribution of the differences between right leg functional reach and distance from H-point to brake, by sex, describing acceptable and poor fit.

A measure of the *minimum* H-Point to brake distance was taken in 23 participants' vehicles, and ranged from 25.3 to 30.6 inches. This measure was available for only 8 of the 13 drivers with poor fit, due to missing data and interference in taking the measure. In these 8 cases, the vehicle seat could have been moved closer to the brake by the distance required to meet the functional reach of the right leg plus 1 inch, indicating that self-selected seating distance from the brake was not limited by the seat track length.

It is important to note that at the self-selected seating position, all 33 participants were at least 10 inches away from the airbag, the guideline for safe seating distance in the event of airbag deployment. Distance between the breastbone and steering wheel (airbag) ranged from 11 to 19.6 inches for those with acceptable H-point-to-brake fit (average 14.4 inches, SD 2.0) and from 11.6 inches to 19.1 inches for those with poor H-point-to-brake fit (average 15 inches, SD 2.4). Eleven of the 13 drivers with poor fit could move their seats to meet brake reach criteria, and still remain at least 10 inches from the air bag. However, if the two participants (females) with the shortest functional leg reach (28.7 inches and 30.5 inches) moved their seats closer to the brake by the distance required to eliminate stretching to reach the pedal, they would violate the minimum 10-inch distance from the steering wheel (9.7 and 9.8 inches, respectively). Reclining a driver's seat slightly can increase the distance from the breastbone to the steering wheel to a safe margin, for drivers comfortable operating with their seats in a more reclined position and who can still see over the steering wheel by the recommended distance.[10] One of these two participants already had reduced visibility over the steering wheel (1.9 inches). Pedal extenders

[10] A minimum distance of 3 inches 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.

might be a preferred remedy for drivers with short legs who must fully extend their legs to reach their pedals when seated 10 inches from their steering wheel.

Driver height and H-point-to-brake distance were strongly correlated (r=0.82 across the sample, r=0.69 for females, and r= 0.71 for males) while right leg functional reach and H-point-to-brake distance were moderately or weakly correlated (r=0.56 across the sample, r=0.62 for females, and r=0.27 for males). The scatter plot showing right leg functional reach on the X-axis and distance from the H-point to the brake on the Y-axis for all 33 participants, by sex is shown in Figure 18.

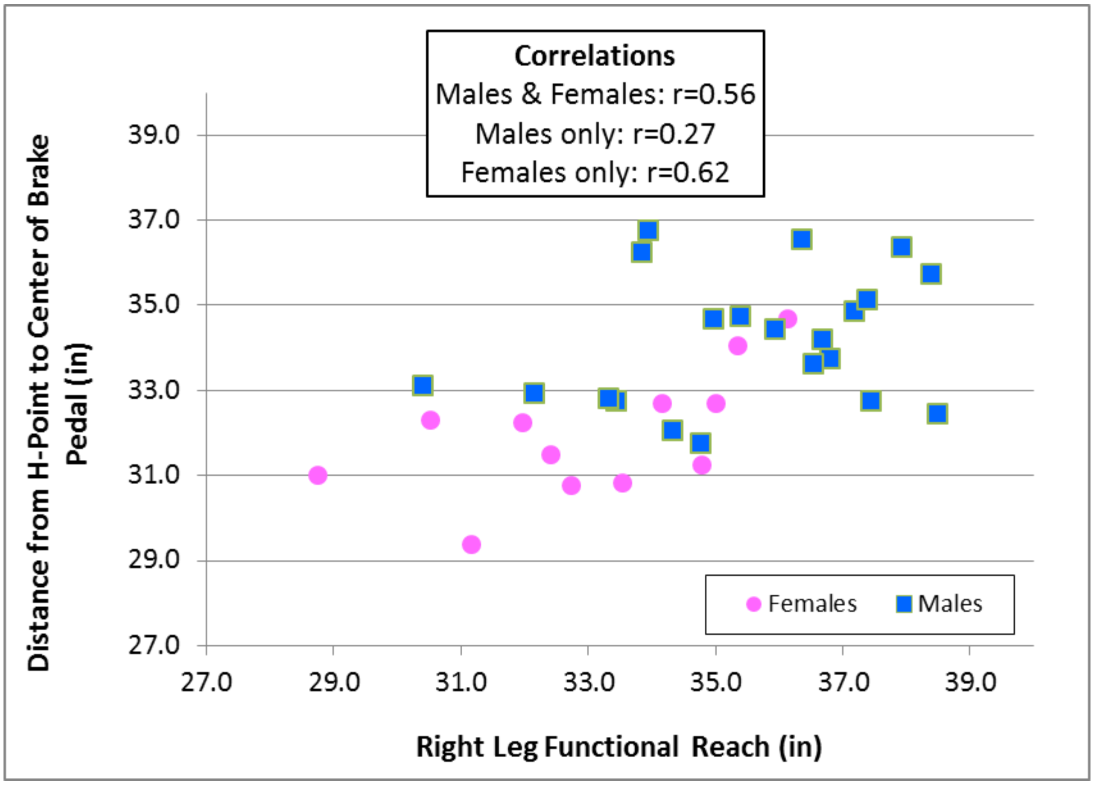


Figure 18. Scatter plot and correlations for right leg functional reach vs. H-point to brake distance, by sex, and for all participants (n=33).

There was a strong correlation between right leg functional reach and height across the sample (r=0.72); this relationship was stronger among females (r=0.82) than among males (r=0.49).A Fisher's Exact Test found no significant difference between the observed and expected proportions of participants with acceptable versus poor vehicle fit, as a function of driver sex (p=0.7188).

Binary logistic regression was used to investigate the relationship between goodness of fit and drivers' sex and anthropometry, since the dependent variable was a categorical variable with two levels (i.e., goodness of fit was either acceptable or poor). The model predicts the natural logarithm (ln) of the odds of the fit being acceptable. The independent variables included in the regression were:

- sex (male or female);
- height;
- tibia length;
- femur length;
- foot length;
- knee to ball-of-right-foot length; and
- right leg functional reach.

Not surprisingly, many of these variables were highly correlated (see Table 167). Researchers used a backward elimination regression method, starting with the complete list of independent variables and removing independent variables one at a time starting with the least significant. The final model included only the independent variables that were statistically significant at the 0.05 level and contained only two variables:

lnOdds of Acceptable Fit = -27.236 – 3.443*(Foot length) + 1.811*(Right leg functional reach)

This model demonstrates that an increase in right leg functional reach is associated with an increase in the odds that fit will be acceptable, *and* that an increase in foot length is associated with a *decrease* in the odds of the fit being acceptable. While the association between right leg functional reach and fit is consistent with the raw data (the average right leg functional reach was 35.74 for acceptable fit and 32.88 for poor fit), the association between foot length and fit is not. This outcome is also problematic considering that foot length, rounded to the nearest tenth of an inch, was identical (10.1 inches) for those with acceptable fit and those with poor fit. Regarding the anomalous results for foot length, researchers feel confident that functional leg reach was the only independent variable with an operationally significant association with goodness of fit. *As functional leg reach increased, the probability of good fit also increased*.

The model was also run using only functional leg reach to predict the odds of the fit being acceptable. The output of the model was as follows; the p value for the coefficient of right leg functional reach was 0.006:

lnOdds of Acceptable Fit = -23.118 + 0.685*(Right leg functional reach)

Table 167. Intercorrelation Matrix for Variables Used in Goodness of Fit Analysis

		Height	Tibia	Femur	Foot length	Knee to Ball of Right Foot	Right Leg Functional Reach
Height	Pearson Correlation	1	.722	.397	.770	.800	.717
	Sig. (2-tailed)		.000	.022	.000	.000	.000
	N	33	33	33	33	33	33
Tibia	Pearson Correlation	.722	1	.302	.476	.983	.765
	Sig. (2-tailed)	.000		.088	.005	.000	.000
	N	33	33	33	33	33	33
Femur	Pearson Correlation	.397	.302	1	.461	.360	.838
	Sig. (2-tailed)	.022	.088		.007	.039	.000
	N	33	33	33	33	33	33
Foot length	Pearson Correlation	.770	.476	.461	1	.628	.657
	Sig. (2-tailed)	.000	.005	.007		.000	.000
	N	33	33	33	33	33	33
Knee to Ball of Right Foot	Pearson Correlation	.800	.983	.360	.628	1	.811
	Sig. (2-tailed)	.000	.000	.039	.000		.000
	N	33	33	33	33	33	33
Right Leg Functional Reach	Pearson Correlation	.717	.765	.838	.657	.811	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	33	33	33	33	33	33

The researcher asked participants why they positioned their seat the way they did. Interestingly, drivers with acceptable fit as well as poor fit both indicated that the selected seat position allowed them to reach their pedals. Comments by drivers with *acceptable fit* included the following:

- Ability to reach the pedals; and or short legs (8 drivers);
- It's comfortable (4 drivers);
- To be far enough away from the air bag and have space between the dash and my knees;
- So I don't have to crawl out;
- Far enough away from the accelerator and brake so I don't have to lift my foot and am able to rest my foot in a neutral position;
- I have a vision problem and I need to sit close to see the controls.

Comments by drivers with *poor fit* included:

- Ability to reach the pedals; and or short legs (4 drivers);
- Far enough away from steering wheel/air bag (4 drivers);
- It's comfortable (4 drivers);
- I like to have my legs stretched out so I'm not on top of the brake;
- So I can reach the arm rest comfortably;
- Ease of getting into and out of the vehicle;
- In an emergency, I have room to move my feet;
- It allows my arms to be mostly extended.

After the research team completed each participant's vehicle measurements, the participant returned to the driver's seat of their vehicle. As a result of the researcher's measurement activity, the drivers' seats and steering wheel positions needed to be readjusted. The researcher read the CarFit Guidelines, and asked the participant to adjust his/her seat to a comfortable position keeping the CarFit Guidelines in mind. The research team took several in-vehicle measures following the driver's re-adjustment of their seat, including the H-point-to-brake measure.

Researchers compared the initial participant-selected H-point-to-brake measure (taken when the driver arrived for the study session) with the readjusted H-point-to-brake distance the participant selected after reading CarFit guidelines. Twenty of the 33 drivers (61%) moved their seats farther away from the brake and 13 drivers (39%) moved their seats closer to the brake. Two of the 20 drivers (both males) whose initial seating position was deemed acceptable based on their functional reach selected a new seating position that exceeded their right leg functional reach, degrading their fit to “poor.” None of the 13 drivers whose initial seating position was deemed poor selected a new seating position that was acceptable based on their functional leg reach. The readjustment following the CarFit education resulted in 18 drivers with acceptable fit (55%) and 15 drivers with poor fit (45%). Figure 19 presents the individual differences between right leg functional reach and distance from the H-point to the brake, as participants arrived for the study session (pre-CarFit instruction) and following the reading of the CarFit guidelines (post-CarFit instruction).

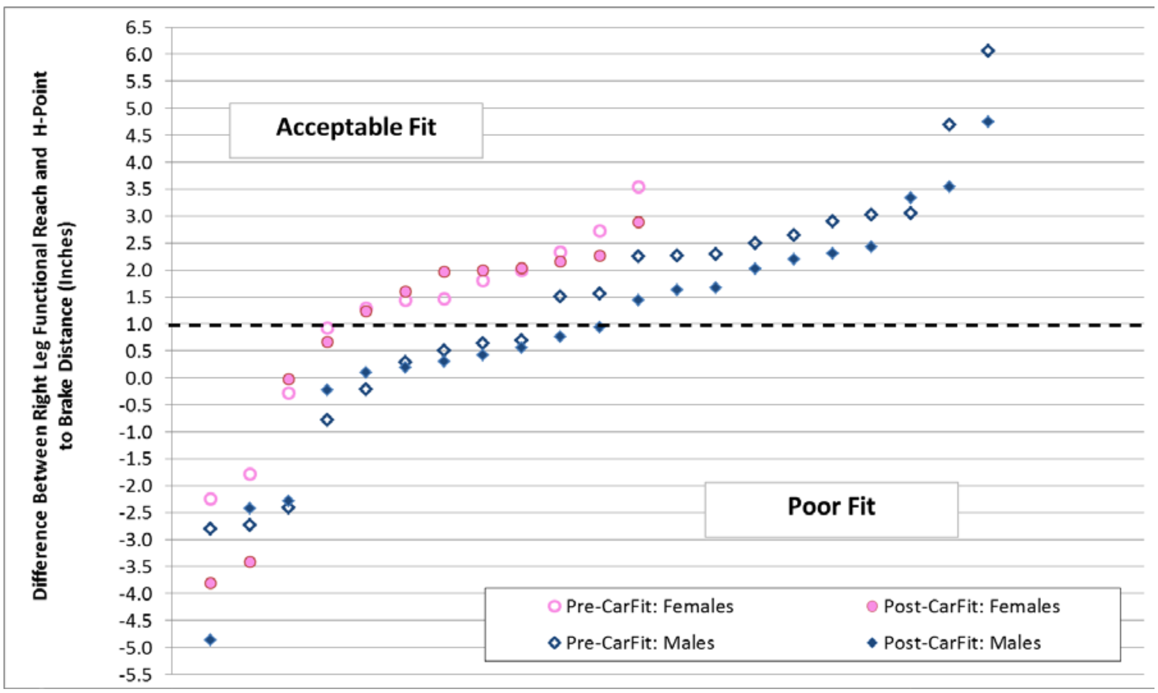


Figure 19. Participant-by-participant difference between right leg functional reach and H-point to brake distance by sex, prior to and following presentation of CarFit guidelines.

Conclusions and Discussion

The purpose of this study was to determine how drivers 60 and older control the accelerator and brake while driving and parking, and what effects driver medical status, sex, driver height and leg length, as well as the way drivers positioned their seats with respect to the brake pedal, might have on foot movements. The study also explored whether poor driver-vehicle fit was related to these variables. This information is useful for developing countermeasures to assist older drivers to properly position their seats and controls and to assist medical professionals in determining at what point their patients with peripheral neuropathy should be referred to driving rehabilitation specialists for evaluation for hand controls for accelerating and braking.

The small sample size restricted the generalizability of findings related to medical conditions and driver performance. Researchers were able to recruit eight older drivers with Medical Conditions (MC group) comprised of six drivers with PN of the feet and two drivers with a recent right hip replacement (orthopedic surgery or OP group), and a group of 18 fit Normally Aging drivers. Because of the safety concerns that could arise from permitting participants to adjust their seats in the instrumented vehicle the same way they position their seats in their own vehicles—either too close to or too far away from the pedals—the CDRS conducted the driving evaluations with participants properly positioned in the vehicle. Therefore, the team was unable to explore whether driver fit in the vehicle was related to foot movements. However, they were able to characterize participants' fit in their own vehicles as a function of driver sex, height, lower limb measures, and functional leg reach. With these limitations in mind, the relevance of the findings is discussed below, for each research question.

What was the effect of medical status on foot positioning and/or variability in foot movements?

The performance of drivers with medical conditions differed significantly from that of normal aging drivers' performance on only one foot movement measure: the maximum amount of force applied to the brake at the 3-way stop location (Location 1). Drivers in the MC group applied approximately 2.5 pounds *less* pressure on the brake than did the NA drivers (see Table 47). However, there was no significant difference in maximum brake force by group during the emergency stop at Location 10 (see Table 68).

Drivers with peripheral neuropathy or a recent right hip replacement (the MC group) took significantly longer than those in the NA group to complete the TUG test and the Trails B test in the clinic (see Tables 15 and 19). Plantar threshold was positively and significantly correlated with TUG time and Trails B time, such that poorer sensitivity to touch was associated with slower walk time and poorer Trails B performance (see Table 29).

A potential relationship between a loss of foot sensation, an increase in walk time and less pressure applied to the brake is logical. A potential relationship between increased Trails B completion time (a cognitive measure) and less brake pressure may be related to underlying diabetes in those with reduced foot sensitivity; diabetes has been found to exacerbate age-related declines in cognitive performance, particularly in the area of executive function and speed (Yeung, Fischer, & Dixon, 2009).

These declines in physical and cognitive performance may underlie the poorer performance of the MC group compared to the NA group during the parking tasks as scored with the Behaviorally Anchored Rating Scale (see Table 162). Drivers with peripheral neuropathy and recent orthopedic surgeries obtained poorer scores in gauging the turning radius for a left turn into a parking space, aligning the vehicle within the parking space, and shifting into park. Multiple attempts to realign a vehicle in a parking environment by drivers with reduced feeling in their feet could increase crash risk due to tight spacing in many parking areas. A driver who becomes startled after hitting a vehicle might hit the accelerator thinking it is the brake, resulting in a second crash, as documented in the crash narratives and media reports described by Lococo, Staplin, Martell, and Sifrit (2012).

Failing to shift into park could lead to pedal misapplications if, for example, the car moves when the driver does not expect it to. This mistake could be of particular concern when the driver is preparing to leave the vehicle, or is out of position for some other reason. A driver who is startled by the car moving unexpectedly could panic and attempt to brake, but due to improper positioning in the driver's seat, accelerate instead. In this scenario, the driver, believing the foot is on the brake, could press even harder. In the analysis of 2,411 pedal misapplication crashes identified in the North Carolina crash database, the crash narratives described 21 drivers who re-entered their vehicle to stop it from rolling after parking because they inadvertently left the vehicle in a gear other than Park. This scenario was also described for 5 of the 31drivers in the National Motor Vehicle Crash Causation Survey who hit the accelerator when they intended to brake (Lococo, Staplin, Martell, & Sifrit, 2012).

Why would drivers with peripheral neuropathy or with recent orthopedic surgery be more likely to forget to put the car in park, or have difficulty doing so more frequently than drivers without medical conditions? As discussed above, drivers with medical conditions in this study had significantly poorer Trails B performance compared to normally aging participants, so their impairment in driving performance for this task may be related to diminished divided attentional ability rather than to diminished foot sensation or sense of foot placement in the footwell (proprioception). A second possibility is that drivers with medical conditions needed to devote more attention to the vehicle control tasks necessary for parking (turning with the proper radius and positioning the vehicle in the middle of the parking space) as a result of difficulty with lower limb sensation/perception or the pain associated with their medical condition, resulting in less cognitive reserve for operational tasks such as shifting into park during the driving evaluation. Driving an unfamiliar vehicle may have disproportionately increased the cognitive demand for the MC group.

Finally, a relationship between slower Trails B time and poorer driving performance was evident among the participants receiving a CDRS recommendation to drive only in familiar areas. Trails B time was more predictive of this recommendation than was belonging to a medical conditions group, as highlighted by the fact that 5 of the 7 drivers with this recommendation were in the *NA group*. The three drivers with the longest Trails B scores among the 26-driver sample received this recommendation, and only one of these 7 drivers had a Trails B time shorter than the average score for the sample.

Was foot positioning or variability in foot movement related to driver sex?

Males' and females' foot movements differed significantly on only four measures across the 10 locations. Females may have been more likely to lift their foot during the transfer from accelerator to brake, and males more likely to pivot at both the 3-way stop and emergency stop locations; however, this finding only approached significance during the emergency stop (see Tables 31 and 51). Females had faster foot transfer time from the accelerator to the brake during one parking maneuver (Table 107), and their foot positioning on the brake was closer to the lateral center of the brake pedal during the Reach-and-Swipe task as well as during the 3-way stop. Males' foot placement was closer to the right edge of the brake (see Tables 36 and 132).

It is possible that the sex differences in foot movement type, transfer time, and foot position on the brake resulted from anthropometry. Females in the sample were shorter on average than males (see Table 8), had shorter tibias, femurs, and legs (see Table 9), and had smaller shoe lengths and widths (see Table 11). As demonstrated in the logistic regression results, some of these anthropometric variables were significantly associated with differences in foot movement; for example, pivoting between accelerator and brake was associated with being male, taller, and having a longer tibia (see the table that follows the Executive Summary on page 3). Shorter drivers with smaller feet may not have been able to pivot their foot, which may explain why larger percentages of females than males lifted their foot for the transfer. Pivoting was associated with a longer transfer time and foot placement on the brake closer to the accelerator than to the center of the brake, which could be expected to increase the risk of a crash or pedal misapplication. This foot movement type was somewhat characteristic of males in the sample, whereas Lococo, Staplin, Martell, and Sifrit (2012) found that females were more likely than males to be involved in pedal misapplication crashes. Thus, foot transfer type on its own may not affect pedal error risk, but a change in habitual foot transfer type (resulting from a startle or the need for a panic stop) might increase the risk of hitting the accelerator when intending to brake.

The analysis comparing foot placement on the brake at the 3-way stop and the emergency stop by sex may shed some light on potentially risky foot movements. Recall that a 0% foot placement is at the lateral center of the brake and 100% is at the extreme right edge of the brake pedal. Females' foot positioning was at 50% during the 3-way stop and 63% during the emergency stop. By contrast, males' average foot position during the 3-way stop was 81% versus 59% during the emergency stop (see Tables 36 and 57). During the emergency stop, males moved their foot closer to the center of the brake pedal while females moved their foot closer to the right edge of the brake pedal, compared to their positioning at the 3-way stop intersection. While the females contacted the brake at a point closer to the center of the pedal during the emergency stop than their male counterparts did during the non-emergency stop, the difference in the *direction* of foot movement (away from the center of the brake and towards the accelerator) during an emergency braking situation might help explain the over-involvement of females in pedal error crashes. Women who pivoted from the accelerator to the brake during the 3-way stop, but lifted during the emergency stop had a larger average change in direction of foot movement compared to the women who lifted their foot during both stopping maneuvers (21.1% and 7%, respectively). While the sample size was small, findings suggest that for females, a change from a habitual, practiced foot movement type when performing an emergency stop could result in more variability in foot placement.

What was the effect of height, leg length, and shoe size on foot movements?

One or more of the anthropometric variables were significantly related to every foot movement metric analyzed, and many were highly intercorrelated as well. For example, the correlation between height and leg length was 0.78 and between height and shoe length was 0.87.

Shorter stature, shorter leg length, and smaller shoe size tended to be associated with one or more of the following foot movements:

- lifting the foot (rather than pivoting) during the transfer from accelerator to brake;
- faster foot transfer times;
- foot placement closer to the center of the brake pedal;
- greater coverage area on the brake;
- longer total hover durations;
- greater conformance of foot movement with the direct path from accelerator to brake;
- foot angle on the brake more perpendicular than angled toward the accelerator during the gate access task; and
- lower maximum brake force during the emergency stop.

What was the effect of driver height, lower extremity measures, functional leg reach, and sex on driver-vehicle fit?

The research team defined driver-vehicle fit as "poor" when right leg functional reach did not exceed the H-point-to-brake distance by at least 1 inch, requiring the driver to stretch to contact and press the brake pedal. An anecdotal comment provided by DRSs in the study by Lococo, Staplin, Martell, and Sifrit (2012) was that smaller women often arrived at CarFit events sitting too far back to reach the brake pedal without stretching from their hips and reaching with their toes. This can cause fatigue in the leg muscles, and could possibly be related to women's overrepresentation in pedal error crashes. There was no significant difference in the percentage of women and men who had poor fit, and neither driver height nor any of the individual lower limb measures were significantly related to the goodness of fit, as determined by the regression analysis. However, functional leg reach (defined in Figure 15 and calculated using the lower limb measures) and goodness of fit were significantly related; as functional leg reach decreased, the odds of poor fit increased.

All drivers – those with acceptable fit and with poor fit – reported selecting seat positions that allowed them to reach their pedals, and that they positioned their seats this way because it was comfortable. After drivers were instructed in the CarFit guidelines and readjusted their seats, 45% were still positioned too far from their brake pedal. It appears that drivers heed the message to sit a safe distance away from the air bag; however, information about seat positioning for safe pedal control may be lacking. Some drivers may believe that increasing the distance from the air bag beyond 10 inches will provide an even greater margin of safety. But those with shorter functional leg reach may increase their risk of pedal errors in their efforts to decrease risk of injury from their air bag.

Findings regarding driver fit suggest the need for better or more broadly directed educational messages about proper seat positioning for effective pedal control, while reinforcing the necessity of maintaining a separation of 10 inches between the breast bone and steering wheel to prevent injury in the event of air bag inflation. Drivers may not know that reclining the seat back slightly may allow them to balance the needs for adequate distance from the air bag and appropriate distance to the pedals. Some drivers may not feel comfortable reclining their seat; four drivers specifically mentioned feeling more comfortable with the seat in the upright position, rather than reclined, so increasing seat recline to balance distance to the steering wheel with distance to the pedals does not work for everyone. For drivers in the market for a new vehicle, raising awareness of vehicle features that will help them achieve a proper and safe fit, such as power adjustable pedals, 6-way adjustable seats, and telescoping steering wheels provide methods to adjust the vehicle to a driver's size and comfort. For other drivers with a short functional leg reach who cannot reach their pedals without fully extending their legs or sitting less than 10 inches from their steering wheel, pedal extenders installed by a reputable adaptive equipment dealer may provide a safe solution.

What level of functional loss associated with peripheral neuropathy was associated With Late or abrupt braking actions?

The regression analyses found no association between loss of plantar sensation and late or abrupt braking at any of the analysis locations. Plantar sensation was significantly related to foot movement only when drivers stopped at the entrance to the parking garage and reached out the side window to swipe the parking pass. Those with poorer plantar sensation rested their foot on the brake with the foot more perpendicular to the lateral plane (i.e., their toe pointed more forward) while those with better plantar sensation rotated the foot on the brake resulting in the toe pointing rightward (toward the accelerator) (see text on page 127, below Table 124). Perpendicular foot internal-external angle would appear less likely to result in a pedal misapplication than foot rotation toward the accelerator, so this difference could be protective against pedal errors for drivers with decreased plantar sensation.

In conclusion, the sample was small, and was further reduced by missing data; both of these limitations likely contributed to the lack of significant differences in foot movement as a function of medical condition. Despite these limitations, significant differences were observed for the parking components of the driving evaluation, where those with peripheral neuropathy or a recent hip replacement received significantly poorer scores than normally aging participants. It may be argued that successful parking places a greater demand on cognitive and physical abilities compared to many of the other skills evaluated in the on-road portions of the evaluation. In any event, the confined space available for the required maneuver leaves less room for error, that is, any deviation from nominal performance results in an error score in this situation. The findings related to driver anthropometry were more robust. Driver height, leg length, and foot size affected how drivers controlled their pedals and how they positioned the driver's seat with respect to their pedals. Drivers with a shorter functional leg reach tended to sit too far away from the brake pedal, resulting in the need to extend the leg and reach with the toes to press the brake.

While educational efforts should continue to target raising all drivers' awareness of hazards of sitting too close to the air bag, complementary efforts should also be made to raise awareness of need to be within appropriate reach of the pedals. When drivers with short functional leg reach cannot move their seats close enough to their pedals for safe operation without risking injury from their air bag, and reclining the seat back slightly is not comfortable or lowers their line of sight over the steering wheel below the recommended minimum of 3 inches, pedal extenders (adaptive equipment installed by a reputable dealer) might be a preferred remedy. For vehicles with multiple operators, easily applied/removed pedal extenders may provide the most safety and convenience. Reputable adaptive equipment installers require the driver to present a prescription, written by a driver rehabilitation specialist for the specific equipment needed, before they sell and install such equipment. An evaluation (and possible training) by a driver rehabilitation specialist may be required to obtain an adaptive equipment prescription.[11] In some states, the Department of Motor Vehicles requires a driver with a recent adaptive equipment installation to undergo a road test to demonstrate his or her ability to safely control the vehicle with the adaptive equipment. As an alternative to pedal extenders, drivers in the market for a new vehicle may find that a vehicle with power adjustable pedals provides the most straightforward means of ensuring proper fit for those with short functional leg reach, particularly for vehicles driven by multiple operators. Unfortunately, at this time, few vehicle manufacturers provide power adjustable pedals as standard equipment in passenger cars, and many do not provide them even as optional equipment.

While the functional reach measure did not take into account participants' ankle angle, lateral malleolus (ankle) height, shoe plane angle, or shoe sole thickness, and may have resulted in a misclassification of goodness of fit for those who wore thick-soled shoes, it would be ill advised for drivers to try to increase their functional reach to the brake pedal by selecting shoes with thick soles. Thick soles inhibit a drivers' ability to feel the pedals and accurately judge the pressure applied. Future research including the functional leg reach measure should seek to determine which anthropometric components are both necessary and sufficient to support a goodness-of-fit criterion that is practical to implement.

CarFit education emphasizes both safety issues—distance from the steering wheel and distance from the pedals. This is of value to a broader audience than the older driver audience for whom it was developed; short functional leg reach is not restricted to the older cohort of drivers. Education that emphasizes the importance of proper positioning of the driver's seat at the beginning of each trip should highlight the need for safety over convenience (e.g., use of the arm rest or ease of exiting the vehicle). This is especially important for drivers who share a vehicle, who should reposition their seats and mirrors to accommodate their size, and for drivers who move the seat rearward at the end of each trip to provide extra space to exit the vehicle. Drivers may not realize the importance of proper seat adjustment; being out of position in the driver's seat was one of the antecedents of pedal error crashes in the literature review and crash analysis (Lococo, Staplin, Martell, & Sifrit, 2012).

---

[11] Although the National Mobility Equipment Dealers Association classifies pedal modifications as low tech, their guidelines state, "Each pedal modification shall be prescribed by the Driver Rehabilitation Specialist in conjunction with the mobility equipment dealer. (See National Mobility Equipment Dealers Guidelines, Section 8.1 www.nmeda.com/wp-content/uploads/2015/03/QAP-103-2015-Guidelines.pdf)

Finally, when CarFit technicians perform the checklist item dealing with drivers' ability to reach their accelerator and brake pedal without stretching their legs or using their toes to press through the full range, the checklist could include directions for ensuring that the driver is seated squarely in the driver's seat, with his or her lower back pressed firmly against the seat back, prior to observing his or her reach to the pedals. The driver should be sitting with weight distributed equally on the buttocks, with the hips aligned, and relaxed. Drivers' hips should not stretch away from the seat back when they demonstrate their ability to operate the pedals.

References

American College of Physicians. (2007). *Using the 10-g Semmes-Weinstein monofilament. ACP Clinical Skills Module: Diabetic Foot Ulcers*. Retrieved from http://diabetes.acponline.-org/custom_resources/tools/using_10g_monofilament.pdf?dbp.

American Diabetes Association. (2011). Standards of medical care in diabetes. *Diabetes Care*. *34* (Supplement 1). Retrieved from http://care.diabetesjournals.org/content/-34/Supplement_1/S11.full

Cantin, V., Blouin, J., Simoneau, M., & Teasdale, N. (2004). Driving in a simulator and lower limb movement variability in elderly persons: Can we infer something about pedal errors. *Advances in Transportation Studies: An International Journal, Section A & B., 12*, 39-46.

Chockalingam, N., & Ashford, R. L. (2007). Selected foot length ratios in a non-pathalogical sample. *Revista Internacional de Ciencias Podologicas, 1*(2), 25-30.

Daigneault, G., Joly, P., I Frigon, J. Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical and Experimental Neuropsychology*, *24*(2):221-38.

Daniels, K., & Worthingham, C. (1986). *Muscle testing techniques of manual examination*, 5th ed. Philadelphia: W. B. Saunders.

Dros, J., Wewerinke, A., Bindels, P., & van Weert, H. (2009). Accuracy of monofilament testing to diagnose peripheral neuropathy: A systematic review. *Annals of Family Medicine*, *7* (6), 555-558. Retrieved from www.annfammed.org/cgi/reprint/7/6/555

Fall, C. C. (1987). Comparing ways of measuring constructional praxis in the well elderly. *The American Journal of Occupational Therapy, 41*(8), 500-504.

Frese, E., Brown, M., & Norton, B. (1987). Clinical reliability of manual muscle testing: Middle trapezius and gluteus medius muscles. *Physical Therapy*, *67*, 1072-1076.

Katzman, R., Brown, T., Fuld, P., Peck, A., Schechter, R., & Schimmel, H. (1983). Validation of a short Orientation-Memory-Concentration Test of cognitive impairment. *American Journal of Psychiatry, 140*(6), 734-9.

Kendall, F. P., McCreary, E. K., & Provance, P. G. (1993). *Muscles: testing and function*. Baltimore: Williams & Wilkins.

Lococo, K. H., Staplin, L., Martell, C. A., & Sifrit, K. J. (2012). *Pedal application errors* (Report Number DOT HS 811 597). Washington, DC: National Highway Traffic Safety Administration.

Morris, J. C., Heyman, A., Mohs, R. C., Hughes, J. P., van Belle, G., Fillenbaum, G., Mellits, E. D., & Clark, C. (1989). The consortium to establish a registry for Alzheimer's disease

(CERAD). Part I. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology*, 39(9),1159-65.

Neuropathy Association (2012). About peripheral neuropathy: The facts. Retrieved from www.neuropathy.org/site/PageServer?pagename=About_Facts.

Plucknette, B. F., Brogan, M. S., Anain, J. M., and Terryberry, K. K. (2012). Normative values for foot sensation: challenging the 5.07 monofilament. *The Journal of Diabetic Foot Complications*, *4*(1), 16-25.

Schmidt, R. A. (1989). Unintended acceleration: A review of human factors contributions. *Human Factors*, *31*(3), 345-364.

Thomson, M. P., Potter, J., Finch, P. M., & Paisey, R. B. (2008). Threshold for detection of diabetic peripheral sensory neuropathy using a range of research grade monofilaments in persons with Type 2 diabetes mellitus. *Journal of Foot and Ankle Research*, *1*(1):9. Retrieved from: www.jfootankleres.com/content/1/1/9.

Appendix A: Screening Procedure for Mild Cognitive Impairment (Short Blessed Test)

Patient: ______________ **DATE:**___________
Age: __________

Short Blessed Test (SBT)[1]

"Now I would like to ask you some questions to check your memory and concentration. Some of them may be easy and some of them may be hard."

1. What year is it now?_____________ Correct (0) Incorrect (1)

2. What month is it now?____________ Correct (0) Incorrect (1)

Please repeat this name and address after me:

John Brown, 42 Market Street, Chicago

John Brown, 42 Market Street, Chicago

John Brown, 42 Market Street, Chicago

(underline words repeated correctly in each trial)
Trials to learning________(can't do in 3 trials = C)

Good, now remember that name and address for a few minutes.

3. Without looking at your watch or clock, tell me about what time it is.

(If response is vague, prompt for specific response) Correct (0) Incorrect (1)

(within 1 hour) _______

Actual time: ____________

4. Count aloud backwards from 20 to 1 — 0 1 2 Errors
(Mark correctly sequenced numerals)
If subject starts counting forward or forgets the task, repeat instructions and score one error

20 19 18 17 16 15 14 13 12 11

10 9 8 7 6 5 4 3 2 1

5. Say the months of the year in reverse order.
If the tester needs to prompt with the last name of the month of the year, one error should be scored
(Mark correctly sequenced months)

D N O S A JL JN MY AP MR F J — 0 1 2 Errors

6. Repeat the name and address I asked you to remember.
(The thoroughfare term (Street) is not required)
(John Brown, 42 Market Street, Chicago) — 0 1 2 3 4 5 Errors

_____, ______, ___, __________, ________

Check correct items **USE ATTACHED SCORING GRID & NORMS**

[1] Katzman R, Brown T, Fuld P, Peck A, Schechter R, Schimmel, H. Validation of a short orientation-memory concentration test of cognitive impairment. Am J Psyhciatry 140:734-739, 1983.

Short Blessed Test (SBT) Administration and Scoring Guidelines[2]

A spontaneous self-correction is allowed for all responses without counting as an error.

1. What is the year?
Acceptable Response: The exact year must be given. An incomplete but correct numerical response is acceptable (e.g., 01 for 2001).

2. What is the month?
Acceptable Response: The exact month must be given. A correct numerical answer is acceptable (e.g., 12 for December).

3. The clinician should state: "I will give you a name and address to remember for a few minutes. Listen to me say the entire name and address and then repeat it after me."

It is important for the clinician to carefully read the phrase and give emphasis to each item of the phrase. There should be a one second delay between individual items.

The trial phrase should be re-administered until the subject is able to repeat the entire phrase without assistance or until a maximum of three attempts. If the subject is unable to learn the phrase after three attempts, a "C" should be recorded. This indicates the subject could not learn the phrase in three tries.

Whether or not the trial phrase is learned, the clinician should instruct "Good, now remember that name and address for a few minutes."

4. Without looking at your watch or clock, tell me about what time it is?
This is scored as correct if the time given is within plus or minus one hour. If the subject's response is vague (e.g., "almost 1 o'clock), they should be prompted to give a more specific response.

5. Counting. The instructions should be read as written. If the subject skips a number after 20, an error should be recorded. If the subject starts counting forward during the task or forgets the task, the instructions should be repeated and one error should be recorded. The maximum number of errors is two.

6. Months. The instructions should be read as written. To get the subject started, the examiner may state "Start with the last month of the year. The last month of the year is_______________." If the subject cannot recall the last month of the year, the examiner may prompt this test with "December"; however, one error should be recorded. If the subject skips a month, an error should be recorded. If the subject starts saying the months forward upon initiation of the task, the instructions should be repeated and no error recorded. If the subject starts saying the months forward during the task or forgets the task, the instructions should be repeated and one error recorded. The maximum number of errors is two.

7. Repeat. The subject should state each item verbatim. The address number must be exact (i.e. "4200" would be considered an error for "42"). For the name of the street (i.e. Market Street), the thoroughfare term is not required to be given (ie. Leaving off "drive" or "street") or to be correct (ie. Substituting "boulevard" or lane") for the item to be scored correct.

8. The final score is a weighted sum of individual error scores. Use the table on the next page to calculate each weighted score and sum for the total.

---

[2] These guidelines and scoring rules are based on the administration experience of faculty and staff of the Memory and Aging Project, Alzheimer's Disease Research Center, Washington University School of Medicine, St. Louis (John C. Morris, MD, Director & PI; morrisj@abraxas.wustl.edu). For more information about the ADRC, please visit our website: http://alzheimer.wustl.edu or call 314-286-2881.

Final SBT Score & Interpretation

Item #	Errors (0 - 5)	Weighting Factor	Final Item Score
1		**X 4**	
2		**X 3**	
3		**X 3**	
4		**X 2**	
5		**X 2**	
6		**X 2**	
			Sum Total = _________ *(Range 0 – 28)*

Interpretation

A screening test in itself is insufficient to diagnose a dementing disorder. The SBT is, however, quite sensitive to early cognitive changes associated with Alzheimer's disease. Scores in the impaired range (see below) indicate a need for further assessment. Scores in the "normal" range suggest that a dementing disorder is unlikely, but a very early disease process cannot be ruled out. More advanced assessment may be warranted in cases where other objective evidence of impairment exists.

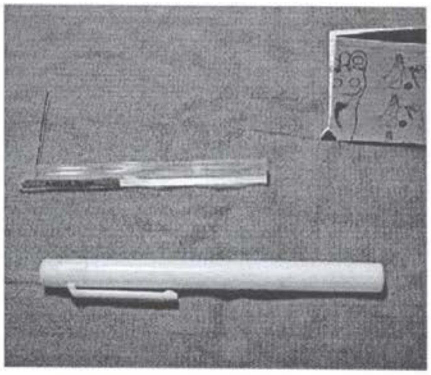
- In the original validation sample for the SBT (Katzman et al., 1983), 90% of normal scores 6 points or less. Scores of 7 or higher would indicate a need for further evaluation to rule out a dementing disorder, such as Alzheimer's disease.
- Based on clinical research findings from the Memory and Aging Project[3], the following cut points may also be considered:
  - 0 – 4 Normal Cognition
  - 5 – 9 Questionable Impairment (evaluate for early dementing disorder)
  - 10 or more Impairment Consistent with Dementia (evaluate for dementing disorder)

[3] Morris JC, Heyman A, Mohs RC, Hughes JP, van Belle G, Fillenbaum G, Mellits ED, Clark C. (1989). The Consortium to Establish a Registry for Alzheimer's Disease (CERAD). Part I. Clinical and neuropsychological assessment of Alzheimer's disease. Neurology, 39(9):1159-65.

Appendix B: Screening Procedure for Peripheral Neuropathy (Monofilament Testing)[12]

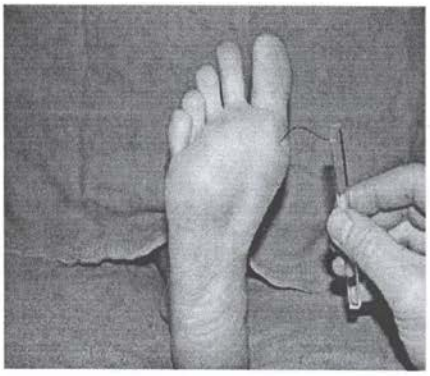
Using the 10-g Semmes–Weinstein Monofilament

The Semmes–Weinstein 5.07 monofilament exerts 10 grams of force when bowed into a C-shape against the skin for one second. Patients who cannot reliably detect application of the 10-g monofilament to designated sites on the plantar surface of their feet are considered to have lost protective sensation. That is to say, these patients cannot reliably feel discomfort on their feet and take appropriate avoidance action to prevent tissue damage. This loss of protective sensation is not equivalent to the total absence of sensation.



Patients with diabetes who have lost protective sensation as measured by standardized testing with the 10-g monofilament are at significantly increased risk to develop a foot ulcer that can lead to subsequent lower extremity amputation. Patients who have lost protective sensation are candidates for regular podiatric care, intensive foot care education, visual inspection of the feet at every office visit, and in some cases, therapeutic footwear.

Testing for quantitative vibration perception threshold with an instrument called the biothesiometer is another excellent test for protective sensation, but the equipment is seldom available in primary care settings. Some clinicians believe that testing vibration sensation with the 128-Hz tuning fork over the hallux of each foot may detect loss of protective sensation equally well as compared to 10-g monofilament testing at four plantar sites on each foot. Although this has not been proven by an adequately powered prospective study, the 2006 "Clinical Practice Recommendations" of the American Diabetes Association propose that the use of both 10-g monofilament testing and vibration sense testing at the hallux may increase diagnostic ability to detect the loss of protective sensation. Suggested techniques for 10-g monofilament testing and vibration sense testing with the 128-Hz tuning fork are detailed below.



Suggested Technique for Using the 10-g Monofilament:

1. Obtain two or more reusable monofilaments or a packet of disposable monofilaments (MFs) from one of the sites listed under "Resources For 10-g Monofilaments."
    a. Use the 10-g MF < 100 applications/day, then "rest" it for 24h – thus the need for at least 2 MFs.
    b. The accuracy of 10-g MFs obtained as samples from pharmaceutical companies is unknown.
2. Check the 10-g MF for defects. Replace if bowed, kinked, or twisted.

[12] Screening procedure was changed with IRB approval using the 8-g monofilament

3. Compress the 10-g MF twice before use each day.
4. Place the patient in the supine position for ease of testing.
5. Tell the patient that you are testing for loss of protective sensation that increases the risk for foot ulcer and amputation.
6. Demonstrate buckling of the 10-g MF on the patient's forearm or hand.
7. Have the patient close their eyes.
8. Test four sites (See diagram) on each foot in random sequence. Avoid scars, calluses, and ulcers.
    a. Test the plantar surface of each great toe.
    b. Test the plantar surfaces of the 1st, 3rd, and 5th metatarsal heads of each foot.
        - If callus, scar, or ulcer is present, test at adjacent sites on the plantar surface of the foot.
9. Hold the 10-g MF perpendicular to the test site, and then bow it to a C-shape for one second.
    a. Do not allow the 10-g MF to slide along the skin.
    b. The patient should sense the 10-g MF by the time that it bows.

10. Grade the patient's response by using the approach suggested by the International Consensus Group on the Diabetic Foot:
    a. Bow the 10-g MF at a designated site, and ask the patient, "Do you feel it touch you – yes or no?"
    b. Repeat testing twice at each site and randomly include a "sham" application in which the 10-g MF is not applied. There will be a total of three applications at each site, one of which does not touch the skin.
    c. Protective sensation is considered to be present if the patient correctly answers two or more of the three applications, one of which was a sham.
    d. If the patient correctly answers only one or none of the three applications, return and retest that site.
    e. The patient is considered to have insensate feet if they fail on retesting at just one or more sites on either foot.
11. Caveats:
    a. The feet may be falsely insensate when cold or edematous.
    b. Heel testing does not discriminate ulcer formers.
    c. Patients who have normal protective sensation should be retested annually.
    d. Technically, patients who have insensate feet need not be retested. Some clinicians believe that repeated testing of the individual with insensate feet may be a useful educational and motivational tool.

Appendix C: Standard On-Road Evaluation Form

Roger C. Peace Rehabilitation Hospital

Driver Rehabilitation Program: On Road Assessment

Therapist: ______________________________ Date: ______________________________

Time: __________________________________Vehicle:____________________________

Physician: ______________________________ Diagnosis: __________________________

SUMMARY/RECOMMENDATIONS (Refer to check off for specific details):

____

____

____

____

____

____

____

____

____

____

____

____

____ Successful demonstration of driving skills ____ Proficient use of Adaptive Equipment

____Adequate skills in familiar areas ____Further Assess (Date___________________)

____ (_______) Training hours recommended ____Private Driving School for training or remediation

____ Unsuccessful demonstration of safe driving skills **NO DRIVING RECOMMENDED**

____Re- Assess at a later date (Date________________________)

The recommendations noted previously are based on the medical information available at the time of this report and the client's performance during the period of the evaluation. If a patient's medical status changes, subsequent to this report, so that they may affect patient's driving status, this report is no longer valid. The recommendations, upon discharge, are valid for 1 year, however, should not be relied on as an absolute prediction of future performance. All results and recommendations have been developed based on education and experience of the evaluator and client's experience using existing equipment at Roger C. Peace Hospital.

____ ____

Driver Rehabilitation Specialist Date/ Time

Roger C. Peace Rehabilitation Hospital

Driver Rehabilitation Program: On Road Assessment

OPERATIONAL SKILLS

Adjusts Seat: Y N Adjusts Primary Controls: Y N

Adjusts Mirrors: Y N Locates Secondary Controls: Y N

____

____

Skill Demonstrated: 0=0% 1=0-25% 2=25-50% 3=50-75% 4=75-100% No= No opportunity to observe

TACTICAL SKILLS

VISUAL SKILLS	**Speed limit 0-45 mph**	**Speed limit 45 mph and over**
Mirror checks	0 1 2 3 4 No	0 1 2 3 4 No
Scans Environment	0 1 2 3 4 No	0 1 2 3 4 No
Blind Spot Checks	0 1 2 3 4 No	0 1 2 3 4 No
Identifies Signage	0 1 2 3 4 No	0 1 2 3 4 No
Checks Cross Traffic	0 1 2 3 4 No	0 1 2 3 4 No
VEHICLE POSITION		
Gap Selection	0 1 2 3 4 No	0 1 2 3 4 No
Following/Stopping Distance	0 1 2 3 4 No	0 1 2 3 4 No
Lane Usage/ Position	0 1 2 3 4 No	0 1 2 3 4 No
Turns into Proper Lane	0 1 2 3 4 No	0 1 2 3 4 No
Lane Changes	0 1 2 3 4 No	0 1 2 3 4 No
VEHICLE HANDLING		
Appropriate Speed	0 1 2 3 4 No	0 1 2 3 4 No
Smooth Steering	0 1 2 3 4 No	0 1 2 3 4 No
Smooth Acceleration	0 1 2 3 4 No	0 1 2 3 4 No
Smooth Braking	0 1 2 3 4 No	0 1 2 3 4 No
Complete Stops	0 1 2 3 4 No	0 1 2 3 4 No
Turns	0 1 2 3 4 No	0 1 2 3 4 No
Yields Right of Way	0 1 2 3 4 No	0 1 2 3 4 No
Turn Signals	0 1 2 3 4 No	0 1 2 3 4 No
Speed Maintenance	0 1 2 3 4 No	0 1 2 3 4 No

____

____

____

____

____

_______________________________ _________________________________

Driver Rehabilitation Specialist Date/ Time

Roger C. Peace Rehabilitation Hospital

Driver Rehabilitation Program: On Road Assessment

Skill Demonstrated: 0=0% 1=0-25% 2=25-50% 3=50-75% 4=75-100% No= No opportunity to observe

STRATEGIC SKILLS

	Speed limit 0-45 mph	Speed limit 45 mph and over
Divided Attention	0 1 2 3 4 No	0 1 2 3 4 No
Anticipates Hazards	0 1 2 3 4 No	0 1 2 3 4 No
Plans Ahead	0 1 2 3 4 No	0 1 2 3 4 No
Decision Making	0 1 2 3 4 No	0 1 2 3 4 No
Memory	0 1 2 3 4 No	0 1 2 3 4 No
Following Directions	0 1 2 3 4 No	0 1 2 3 4 No
Speed of Processing	0 1 2 3 4 No	0 1 2 3 4 No
Rules of the Road	0 1 2 3 4 No	0 1 2 3 4 No

Adaptive Equipment: □HAND CONTROLS (PR, PRA, PP, R) □SPINNER KNOB □NOT APPLICABLE

□TURN SIGNAL EXTENSION □PEDAL GUARD □LEFT FOOT ACCELLERATOR

________________________________ _____________________________________ Driver Rehabilitation Specialist Date/ Time

Appendix D: Behaviorally Anchored Rating Scale

Task	Component	Action	Fail	Acceptable	Excellent
Pleasantburg					
Lane Changes	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Lane Changes	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to
Lane Changes	5	Maneuver vehicle from one lane to another (lane change) in traffic	Not able to change lanes without causing receiving lane drivers to alter speed or path of travel	Changes lanes without causing receiving lane drivers to alter speed or path of travel, but hesitates or straddles lane during maneuver	Changes lanes without hesitation, moves to center of lane, and does not cause receiving lane traffic to adjust speed or path of travel.
Lane Changes	4	Turn Signal Off	Never turns off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
Laurens to NAPA lot					
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to maneuver
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)			IF THERE IS ONCOMING TRAFFIC		

Task	Component	Action	Fail	Acceptable	Excellent
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	9	Maneuver vehicle from lane to TWLTL	Never able to move into TWLTL if another stationary opposing vehicle occupies the lane less than 5 seconds away, and/or hesitates or slows significantly (below the speed of traffic flow) before moving into TWLTL, or straddles the line	Able to move into TWLTL with or without another stationary opposing vehicle occupying the lane. Smoothly decelerates to turn location. Does not hesitate or straddle line.	Able to move into TWLTL with or without another stationary opposing vehicle occupying the lane. Can maneuver vehicle into tight gap if another vehicle occupies TWLTL. Able to determine the need to be in front of or behind the other vehicle without hesitation. Moves at or near speed of traffic flow until beginning transition into TWLTL.
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	38	Gap judgment	Chooses a gap that requires opposing drivers to alter speed or path of travel to avoid a collision	Accepts gap where oncoming traffic reaches turning path < 3 seconds after driver completes turn	Accepts gap allowing driver to complete turn 3 seconds or more before opposing traffic crosses turning path

Task	Component	Action	Fail	Acceptable	Excellent
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	11	Turn Movement	Driver fails to complete maneuver with vehicle properly positioned in lane or driveway.	Driver must alter speed or path during turn but ends with vehicle properly positioned in lane or driveway.	Executes turn without speed or path correction, ending with vehicle properly positioned in lane or driveway.
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)			IF THERE IS NO ONCOMING TRAFFIC		

Task	Component	Action	Fail	Acceptable	Excellent
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	11	Turn Movement	Driver fails to complete maneuver with vehicle properly positioned in lane or driveway.	Driver must alter speed or path during turn but ends with vehicle properly positioned in lane or driveway.	Executes turn without speed or path correction, ending with vehicle properly positioned in lane or driveway.
Unprotected left against oncoming traffic (Using a TWLTL to turn left from a major roadway into a driveway or other minor roadway)	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
NAPA to Laurens					
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	16	Implied stop (leaving parking lot)	Does not stop at implied stop. Proceeds on to TWLTL.	Stops only if cross traffic approaching.	Stops at implied stop regardless of cross traffic.
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	19	Checks cross traffic (TWLTL maneuver)	Does not check cross traffic in both directions.		Checks cross traffic in both directions prior to moving into TWLTL.

Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	20	Moves into TWLTL	Does not stop in TWLTL, proceeds into lane change without slowing	Slows in TWLTL, moves vehicle into position for a lane change	Stops in TWLTL. Moves vehicle into position for a lane change.
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to maneuver
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	5	Maneuver vehicle from one lane to another (lane change) in traffic	Not able to change lanes without causing receiving lane drivers to alter speed or path of travel	Changes lanes without causing receiving lane drivers to alter speed or path of travel, but hesitates or straddles lane during maneuver	Changes lanes without hesitation, moves to center of lane, and does not cause receiving lane traffic to adjust speed or path of travel.
Unprotected left turn from driveway or other minor road into a TWLTL on a major road, then merging with same-direction traffic	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
Laurens to Washington					
Left turn at protected/permitted signal-controlled intersection	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Left turn at protected/permitted signal-controlled intersection	12	Checks cross traffic	Does not check cross traffic	Only checks cross traffic immediately before turn	Checks cross traffic during approach to intersection and again immediately before turn
Left turn at protected/permitted signal-controlled intersection			IF SIGNAL PHASE IS PROTECTED (GREEN ARROW)		
Left turn at protected/permitted signal-controlled intersection	36	Understands right-of-way conveyed by left-turn green arrow	Stops or hesitates prior to maneuver (in the absence of a queue or lead vehicle slowing)		Proceeds into intersection on proper trajectory without hesitation
Left turn at protected/permitted signal-controlled intersection	15	Proper lane	Follows improper trajectory and/or fails to end maneuver in correct receiving lane		Follows proper trajectory to end turn in correct receiving lane.
Left turn at protected/permitted signal-controlled intersection	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off
Left turn at protected/permitted signal-controlled intersection			IF SIGNAL PHASE IS PERMITTED (GREEN BALL)		
Left turn at protected/permitted signal-controlled intersection	37	Understands right of way conveyed by green ball	Does not slow or stop when oncoming traffic is present, or stops in the absence of oncoming traffic		Slows or stops as needed to determine safe gap if oncoming traffic is present; or proceeds without stopping (may slow) in the absence of oncoming traffic.

Task	Component	Action	Fail	Acceptable	Excellent
Left turn at protected/permitted signal-controlled intersection	38	Gap judgment	Chooses a gap that requires opposing drivers to alter speed or path of travel to avoid a collision	Accepts gap where oncoming traffic reaches turning path < 3 seconds after driver completes turn	Accepts gap allowing driver to complete turn 3 seconds or more before opposing traffic crosses turning path
Left turn at protected/permitted signal-controlled intersection	15	Proper lane	Follows improper trajectory and/or fails to end maneuver in correct receiving lane		Follows proper trajectory to end turn in correct receiving lane.
Left turn at protected/permitted signal-controlled intersection	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
385 to 85					
Merge	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Merge	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to maneuver
Merge	3	Maneuver vehicle from one lane to another (merge) in traffic	Not able to merge without hesitating, stopping, using the shoulder, or causing receiving lane drivers to alter speed or path of travel	Completes merge without requiring receiving lane drivers to alter speed or path of travel, but hesitates due to difficulty adjusting to speed of traffic	Modulates speed according to the rate of traffic flow. Can merge without hesitation and without causing drivers in receiving lane to alter speed or path of travel.
Merge	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
85 to White Horse road					
Freeway exit using deceleration lane	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Freeway exit using deceleration lane	8	Lane change onto deceleration lane	Has to make multiple lane changes to get to deceleration lane at last minute.	Is prepared in the right lane position but slows and/or does not move into deceleration lane at beginning of lane.	Has prepared to enter deceleration lane by positioning in the right lane, then moves into deceleration lane prior to reducing speed.
Freeway exit using deceleration lane	4	Turn Signal Off	Never turns off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
85 to White Horse road					
Negotiating lane drop (pavement width transition)	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Negotiating lane drop (pavement width transition)	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to maneuver
Negotiating lane drop (pavement width transition)	35	Maneuver vehicle from one lane to another to avoid physical barrier ahead (lane ends)	Not able to change lanes without causing receiving lane drivers to alter speed or path of travel, or must stop at end of lane before executing maneuver	Changes lanes without causing receiving lane drivers to alter speed or path of travel, but hesitates or straddles lane during maneuver	Changes lanes without hesitation, moves to center of lane, and does not cause receiving lane traffic to adjust speed or path of travel. Completes lane change maneuver more than 2.5 seconds before lane ends.
Negotiating lane drop (pavement width transition)	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
Grove to Faris					
Right with yield; no acceleration lane	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Right with yield; no acceleration lane	2	Visual search- Scans mirrors and blind spot checks	Does not check mirrors or blind spots	Checks mirrors and blind spots just prior to maneuver (~1 second)	Checks mirrors and blind spots well before maneuver (~ 3 seconds) regardless of traffic density and just prior to maneuver
Right with yield; no acceleration lane	17	Dynamic visual search	Unable to divide attention between approaching traffic and controlling vehicle (speed and/or path) while moving into yield position. Must stop, and then check traffic.	Must significantly reduce speed to effectively divide attention, between controlling vehicle and searching for a gap on approach to yield sign.	Divides attention between vehicle control and search for gap on approach to yield sign without significantly reducing speed.
Right with yield; no acceleration lane	18	Maneuvers vehicle from yield position into lane of travel	Can not merge into receiving lane of traffic without causing other drivers to alter speed or path of travel.	Accomplishes merge without causing receiving lane drivers to alter speed or path of travel, but only under low-density conditions.	Merges into traffic at rate of flow, without causing drivers in receiving lane to alter speed or path of travel.
Right with yield; no acceleration lane	4	Turn Signal Off	Does not turn off signal		Turns off signal / signal automatically turns off

Task	Component	Action	Fail	Acceptable	Excellent
GATE ACCESS: deck					
Gate access	21	Positions car	Multiple attempts at positioning; may need to open door to successfully access pad.	Pulls up to gate, may need to reposition once to easily access pad.	Stops at appropriate position at first attempt.
Gate access	22	Reach pad	Unable to coordinate lowering window and reaching pad to swipe badge, with foot on the brake.		Able to coordinate holding brake while lowering window and using badge to swipe pad.
Gate access	23	Clears gate	Proceeds before gate clears top of vehicle or runs through gate, or moves in reverse.		Waits for gate to clear top of vehicle before proceeding forward.

Task	Component	Action	Fail	Acceptable	Excellent
PARKING LEFT: deck					
Parking, turning left into space	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Parking, turning left into space	25	Visual search- scans mirrors, blind spots and surrounding environment (parking lot)	Never checks mirrors or blind spots. Does not scan for pedestrians or potential vehicle movement		Checks mirrors and blind spots prior to turn regardless of traffic density. Checks for potential vehicle movement/pedestrians in area surrounding parking space.
Parking, turning left into space	26	Turn	Proceeds into left turn, unable to successfully determine turn radius.	Proceeds into left turn however needs to swing wide to assist with turn radius.	Able to determine appropriate turn radius and proceeds into space without hesitation.
Parking, turning left into space	27	Spacing	Multiple attempts at aligning correctly for space, not aligned evenly despite multiple attempts to realign.	May need to realign once for centered space position.	Does not need to readjust position, evenly positioned between lines.
Parking, turning left into space	28	Stop	Speed inappropriate for smooth stopping, or impacts curb/ barrier when stopping.		Slows to an acceptable speed and comes to a smooth stop without impacting curb or parking barrier.
Parking, turning left into space	29	Shifts into park	Does not shift into park, or difficulty determining parking gear.		Shifts into park without hesitation.

Task	Component	Action	Fail	Acceptable	Excellent
BACKING: A deck					
Leaving parking space (Backing)	30	Shifts into reverse	Does not shift into reverse or difficulty determining reverse gear. Does not maintain foot on brake		Shifts into reverse without hesitation with no difficulty maintaining foot on brake.
Leaving parking space (Backing)	31	Visual search- scans mirror and over the shoulder checks (parking lot)	Does not scan mirrors or perform over the shoulder checks.	Uses mirrors primarily however would perform over the shoulder check if cued with peripheral information to verify safety.	Performs mirror checks and over the shoulder checks to verify safety.
Leaving parking space (Backing)	32	Backing into proper lane	Speed inappropriate for smooth backing or too fast for safety; or unable to back into appropriate lane to allow for forward movement into correct path of travel.		Smoothly modulates speed and backs into correct lane.
Leaving parking space (Backing)	33	Plan for forward movement	Does not shift into drive or has difficulty determining drive gear; or does not maintain foot on brake.		Shifts into drive without hesitation; maintains foot on brake without difficulty.

Task	Component	Action	Fail	Acceptable	Excellent
PARKING STRAIGHT: deck					
Parking straight	25	Visual search- scans mirrors, blind spots and surrounding environment (parking lot)	Never checks mirrors or blind spots. Does not scan for pedestrians or potential vehicle movement		Checks mirrors and blind spots regardless of traffic density and prior to turn. Checks for potential vehicle movement/pedestrians in area surrounding parking space.
Parking straight	34	Entry	Excessive speed when entering parking space (over 10 mph).		Speed appropriate for entry into parking space (10 mph or below).
Parking straight	27	Spacing	Multiple attempts at aligning correctly for space, not aligned evenly despite multiple attempts to realign.	May need to realign once for centered space position.	Does not need to readjust position, evenly positioned between lines.
Parking straight	28	Stop	Speed inappropriate for smooth stopping, or impacts curb/ barrier when stopping.		Slows to an acceptable speed and comes to a smooth stop without impacting curb or parking barrier.
Parking straight	29	Shifts into park	Does not shift into park, or difficulty determining parking gear.		Shifts into park without hesitation.

Task	Component	Action	Fail	Acceptable	Excellent
BACKING: B deck					
Leaving parking space (Backing)	30	Shifts into reverse	Does not shift into reverse or difficulty determining reverse gear. Does not maintain foot on brake		Shifts into reverse without hesitation with no difficulty maintaining foot on brake.
Leaving parking space (Backing)	31	Visual search- scans mirror and over the shoulder checks (parking lot)	Does not scan mirrors or perform over the shoulder checks.	Uses mirrors primarily however would perform over the shoulder check if cued with peripheral information to verify safety.	Performs mirror checks and over the shoulder checks to verify safety.
Leaving parking space (Backing)	32	Backing into proper lane	Speed inappropriate for smooth backing or too fast for safety; or unable to back into appropriate lane to allow for forward movement into correct path of travel.		Smoothly modulates speed and backs into correct lane.
Leaving parking space (Backing)	33	Plan for forward movement	Does not shift into drive or has difficulty determining drive gear; or does not maintain foot on brake.		Shifts into drive without hesitation; maintains foot on brake without difficulty.

Task	Component	Action	Fail	Acceptable	Excellent
GATE ACCESS: lot					
Gate access	21	Positions car	Multiple attempts at positioning; may need to open door to successfully access pad.	Pulls up to gate, may need to reposition once to easily access pad.	Stops at appropriate position at first attempt.
Gate access	22	Reach pad	Unable to coordinate lowering window and reaching pad to swipe badge, with foot on the brake.		Able to coordinate holding brake while lowering window and using badge to swipe pad.
Gate access	23	Clears gate	Proceeds before gate clears top of vehicle or runs through gate, or moves in reverse.		Waits for gate to clear top of vehicle before proceeding forward.

Task	Component	Action	Fail	Acceptable	Excellent
PARKING LEFT: lot					
Parking, turning left into space	1	Turn Signal On	Does not use turn signal	Uses turn signal at last moment (~ 1 second)	Turns on signal well before maneuver (~ 3 seconds)
Parking, turning left into space	25	Visual search- scans mirrors, blind spots and surrounding environment (parking lot)	Never checks mirrors or blind spots. Does not scan for pedestrians or potential vehicle movement		Checks mirrors and blind spots prior to turn regardless of traffic density. Checks for potential vehicle movement/pedestrians in area surrounding parking space.
Parking, turning left into space	26	Turn	Proceeds into left turn, unable to successfully determine turn radius.	Proceeds into left turn however needs to swing wide to assist with turn radius.	Able to determine appropriate turn radius and proceeds into space without hesitation.
Parking, turning left into space	27	Spacing	Multiple attempts at aligning correctly for space, not aligned evenly despite multiple attempts to realign.	May need to realign once for centered space position.	Does not need to readjust position, evenly positioned between lines.
Parking, turning left into space	28	Stop	Speed inappropriate for smooth stopping, or impacts curb/ barrier when stopping.		Slows to an acceptable speed and comes to a smooth stop without impacting curb or parking barrier.
Parking, turning left into space	29	Shifts into park	Does not shift into park, or difficulty determining parking gear.		Shifts into park without hesitation.

Task	Component	Action	Fail	Acceptable	Excellent
BACKING: A lot					
Leaving parking space (Backing)	30	Shifts into reverse	Does not shift into reverse or difficulty determining reverse gear. Does not maintain foot on brake		Shifts into reverse without hesitation with no difficulty maintaining foot on brake.
Leaving parking space (Backing)	31	Visual search- scans mirror and over the shoulder checks (parking lot)	Does not scan mirrors or perform over the shoulder checks.	Uses mirrors primarily however would perform over the shoulder check if cued with peripheral information to verify safety.	Performs mirror checks and over the shoulder checks to verify safety.
Leaving parking space (Backing)	32	Backing into proper lane	Speed inappropriate for smooth backing or too fast for safety; or unable to back into appropriate lane to allow for forward movement into correct path of travel.		Smoothly modulates speed and backs into correct lane.
Leaving parking space (Backing)	33	Plan for forward movement	Does not shift into drive or has difficulty determining drive gear; or does not maintain foot on brake.		Shifts into drive without hesitation; maintains foot on brake without difficulty.

Task	Component	Action	Fail	Acceptable	Excellent
PARKING STRAIGHT: lot					
Parking straight	25	Visual search- scans mirrors, blind spots and surrounding environment (parking lot)	Never checks mirrors or blind spots. Does not scan for pedestrians or potential vehicle movement		Checks mirrors and blind spots regardless of traffic density and prior to turn. Checks for potential vehicle movement/pedestrians in area surrounding parking space.
Parking straight	34	Entry	Excessive speed when entering parking space (over 10 mph).		Speed appropriate for entry into parking space (10 mph or below).
Parking straight	27	Spacing	Multiple attempts at aligning correctly for space, not aligned evenly despite multiple attempts to realign.	May need to realign once for centered space position.	Does not need to readjust position, evenly positioned between lines.
Parking straight	28	Stop	Speed inappropriate for smooth stopping, or impacts curb/ barrier when stopping.		Slows to an acceptable speed and comes to a smooth stop without impacting curb or parking barrier.
Parking straight	29	Shifts into park	Does not shift into park, or difficulty determining parking gear.		Shifts into park without hesitation.

Task	Component	Action	Fail	Acceptable	Excellent
BACKING: B lot					
Leaving parking space (Backing)	30	Shifts into reverse	Does not shift into reverse or difficulty determining reverse gear. Does not maintain foot on brake		Shifts into reverse without hesitation with no difficulty maintaining foot on brake.
Leaving parking space (Backing)	31	Visual search- scans mirror and over the shoulder checks (parking lot)	Does not scan mirrors or perform over the shoulder checks.	Uses mirrors primarily however would perform over the shoulder check if cued with peripheral information to verify safety.	Performs mirror checks and over the shoulder checks to verify safety.
Leaving parking space (Backing)	32	Backing into proper lane	Speed inappropriate for smooth backing or too fast for safety; or unable to back into appropriate lane to allow for forward movement into correct path of travel.		Smoothly modulates speed and backs into correct lane.
Leaving parking space (Backing)	33	Plan for forward movement	Does not shift into drive or has difficulty determining drive gear; or does not maintain foot on brake.		Shifts into drive without hesitation; maintains foot on brake without difficulty.

Appendix E: Data Sheet for Driver Seat Position and Interior Vehicle Measurements Study

Revised: 06.17.2014 Participant #:________

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 our occupational therapist, we would like to take some measurements of you in your vehicle. Do you have any questions about the study before we get started?

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: ________

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

Was the car purchase new or used? ________ Shoe Size: ________ M or F

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: ________

VIN: ________

Transmission type: Automatic or Manual

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

Initial Seat Position (Participant 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 Restraint

Move tools and mat out of the way for the Participant

Please get out of your vehicle so we can take a few measurements of you vehicle's seat. You are welcome to sit in this chair.

Initial Seat Position (Participant out of Vehicle)

B1		Seat Height at Front
B2		Seat Track Length
B3		Brake Pedal to Seat
B4		H-point to Brake
B5		Brake Pedal Height above accel. Pedal:
B6		Accel. Pedal to center console:
B7		Brake Pedal to Left Footwell Wall:

1 of 2

(Clear all hand tools out of vehicle at this time.)

Please have a seat back in your vehicle. After I read a list of recommendations for your considerations, we are going to readjust the position of your seat and steering wheel until you are comfortable. Let me know when you're ready to proceed.

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.	

	Final Seat Position (Participant in Vehicle)	
C1	Ground to Eye Level	
C2	Top of Leg to Steering Wheel Bottom	
C3	Top of Steering Wheel to Eye Level	
C4	Steering Wheel to Breast Bone	
C5	Top of Head to Roof	
C6	Back of Head to Head Restraint	

Move tools and mat out of the way for the Participant

Please get out of your vehicle so we can take a few last measurements. You are welcome to sit in this chair.

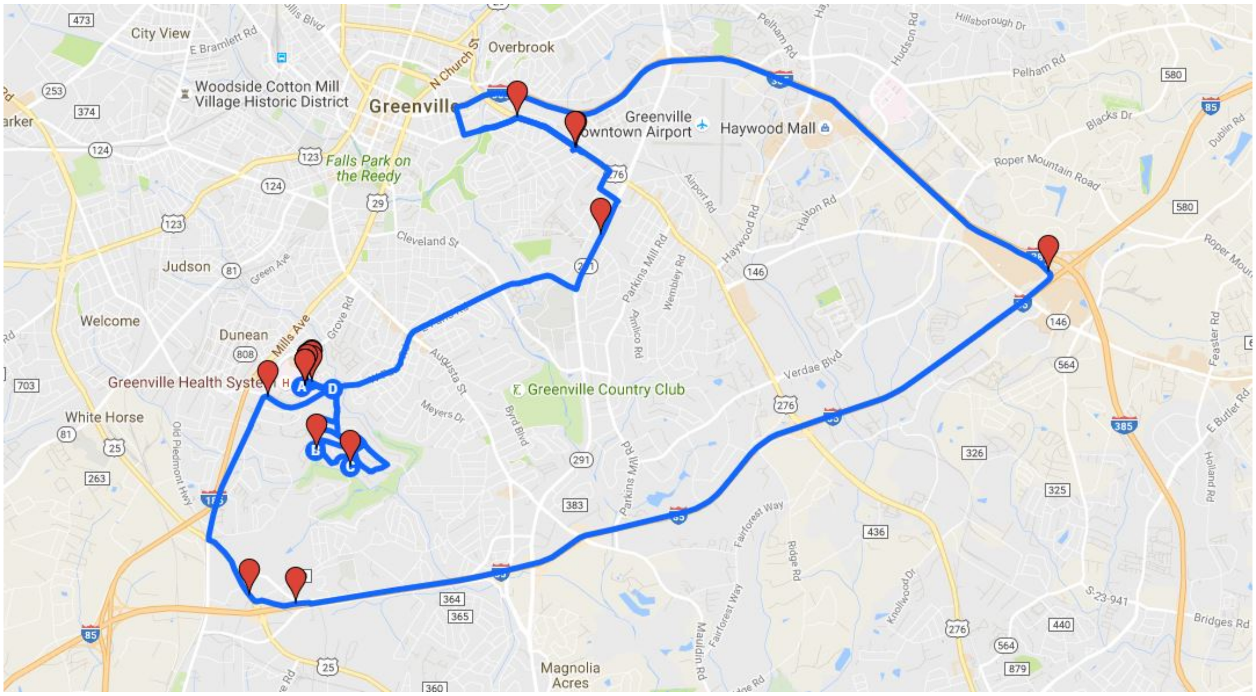
Final Seat Position (Participant out of Vehicle)

D1		Seat Height at Front
D2		Seat Track Length
D3		Brake Pedal to Seat
D4		H-point to Brake

Clean up all tools

Thank you for your participation let me introduce you to ________ the occupational therapist that will be working with you.

Appendix F: On-Road Evaluation Test Route



Interactive map showing numbered locations, names, and driving tasks may be found at:
www.google.com/maps/d/viewer?mid=1kAhIcwzHiEbe81VPTE-XhfbTndk

DOT HS 812 431
July 2017

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

12910-062217-v2