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Understanding the Automotive Pedal Usage and Foot Movement Characteristics of Older Drivers

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UNDERSTANDING THE AUTOMOTIVE PEDAL USAGE AND FOOT MOVEMENT CHARACTERISTICS OF OLDER DRIVERS

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ABSTRACT

The purpose of this study was to understand the pedal usage characteristics of older drivers in various driving tasks using an instrumented vehicle. This study stemmed from the prevalence of the pedal application errors (PAEs) and the older drivers' overrepresentation in crashes caused by PAEs.

With the population increasing and becoming older, it is estimated that in 2020 there will be 40 million drivers over the age of 65 in the United States. Compared with their younger counterparts, older drivers are facing declining cognitive and physical abilities, such as impaired vision, slower reaction time and diminishing range of limb motion. Because these abilities are closely associated both with the driving task and the ability to recover from a crash, older drivers are overrepresented in vehicle crash involvement rate, and they are especially vulnerable to injuries caused by the crashes.

Pedal misapplication crash is a type of crash preceded by a driver mistakenly pressing the accelerator pedal. Recently, the National Highway Traffic Safety Administration issued a report on PAE. The report reveals that older drivers are overrepresented in pedal misapplication crashes and that several driving tasks are overrepresented, such as emergency stopping, parking lot maneuvers and reaching out of the vehicle to interact with a curb-side device such as a card reader, mailbox, or ATM. Existing research has investigated the PAEs from different perspectives, but questions remain as to why older drivers are more likely to commit PAEs in these driving tasks.

The current study investigated the pedal usage characteristics of 26 older drivers in driving tasks, such as startle-braking, forward parking and reaching out from the vehicle, which are scenarios associated with higher risk of PAEs. Ten stopping tasks were also investigated as baseline tasks. The study was conducted on-road using an instrumented vehicle. The data collected by the instrumented vehicle included pedal travel (potentiometer), force applied on the pedals (Tekscan sensor), and video recordings of each driver's upper body and his or her foot movement.

The study findings include the following: a) There are significantly positive correlations between a driver's stature and the percent of foot pivoting, as well as between the shoe length and the percent of foot pivoting, which means the taller the driver or the longer the driver's shoe, the more likely the driver will use foot pivoting instead of foot lifting in the baseline stopping tasks; b) In the startle-braking task, the driver is more likely to use foot lifting than that in the baseline tasks; c) The foot movement strategy is not found to affect lateral foot placement in either the baseline stopping tasks or the startle-braking task; d) When reaching out of the driver's window to swipe a card at a card reader, the lateral foot placement on the brake pedal will bias rightward, compared with the lateral foot placement prior to reaching out; e) Approaching a gated access or parking in a dark, relatively confined parking space does not significantly slow down a driver' foot transfer from the accelerator pedal to the brake pedal; f) Stature of a driver does not significantly affect the time required to successfully complete a card-swiping task.

A driver's pedal operation characteristics are associated with many factors, among which four factors are identified to be relevant to the driver's pedal operation: stature, shoe length, startle stimuli and reaching out of the driver's window. To identify the direct causes of PAEs, future research should investigate the pedal operation characteristics in a more controlled environment. For example, an eye-tracking device can be used to study the relationship between gaze direction and foot movement. Other driving scenarios, such as reversing, should be studied as well. In addition, a study with a larger sample size and novice drivers is necessary to validate the findings of the current study and to understand the PAEs among the population with little driving experience.

The current study has both clinical and engineering implications. For occupational therapists and driving rehabilitation specialists, factors such as stature, leg length, footwear, vehicle type and pedal configuration may provide information about driver's foot behaviors. For example, drivers with flat-soled shoes may tend to use foot lifting and drivers with wedged shoes may tend to use foot pivoting. Drivers with very wide shoes may get the shoe caught under the brake pedal when pivoting from the accelerator pedal to the brake pedal. Drivers with short leg length may be able to use foot pivoting when driving a sports vehicle, but they would have to use foot lifting when driving a large truck. Drivers tend to use foot lifting when the pedals are higher above from the vehicle floor and drivers tend to use foot pivoting when the pedals are lower above the vehicle floor. An in-clinic test of a driver's lower extremity functions prior to on-road assessment helps to select the appropriate test vehicles. For example, it is recommended that shorter drivers with weaker lower extremity functions use vehicles of which the pedals are lower above the vehicle floor. To reduce the chance of a driver's foot slipping off the brake pedal, engineers should consider redesigning the pedal pad to increase the friction coefficient of shoe-pedal contact. For example, using tread width of 2mm produces higher friction values. In addition, Automatic Vehicle Identification can be implemented so that the drivers do not have to reach out of the window to swipe card and to enter a gated access. Other driver assistance systems such as Autonomous Emergency Braking and Automated Parking System can either mitigate the damage or eliminate the chance of a human error.

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NOTATION

ACC	Adaptive Cruise Control
ANOVA	Analysis of Variance
ADAS	Advanced Driver Assistance System
BFI	Brake Feel Index
BoF	Ball-of-Foot
BOFRP	Ball-of-Foot Reference Point
CDRS	Certified Driver Rehabilitation Specialist
C/L	Centerline (of)
CU-ICAR	Clemson University International Center for Automotive Research
DOT	Department of Transportation
FAA	Federal Aviation Administration
FMVSS	Federal Motor Vehicle Safety Standards
HVI	Human Vehicle Interface
ISO	International Organization for Standardization
MCI	Mild Cognitive Impairment
NHTSA	National Highway Traffic Safety Administration
NMVCCS	National Motor Vehicle Crash Causation Survey
OECD	Organization for Economic Co-operation and Development
OP	Orthopedic

Notation (Continued)

PAE	Pedal Application Error
PN	Peripheral Neuropathy
RCP	Roger C. Peace Rehabilitation Hospital
RTK	Real Time Kinematic
SgRP	Seating Reference Point
SPA	Shoe Plane Angle
TRAID	Canadian Traffic Accident Information Databank
TUG	Timed Up and Go
UNECE	United Nations Economic Commission for Europe
VMT	Vehicle-Mile of Travel
WP29	The UNECE World Forum for Harmonization of Vehicle Regulations

CHAPTER ONE

INTRODUCTION

1.1 **Study Objectives**

Older drivers in the United States are overrepresented in pedal misapplication crashes. The objective of this research is to advance the understanding of the pedal operation characteristics of older drivers as they performed a series of driving tasks that are associated with a higher risk of pedal misapplication errors. In the study, older adult drivers, ages 60 and above, completed driving tasks on a pre-defined route and performed (a) stopping in front of 10 stop signs, (b) stopping in response to a startle (emergency) cue, (c) transferring the foot rapidly between the accelerator and brake pedals, (d) reaching out of the driver's side window to swipe a gate access card, and (e) forward parking in both a parking deck and an open parking lot. An instrumented test vehicle, equipped with data acquisition apparatus, such as Dewetron and Tekscan, was used to record the data of older drivers' foot placement and movement on the pedals. Specifically, the current study investigated how each older driver, in the driving scenarios mentioned above, transferred the foot from the accelerator pedal to the brake pedal, placed the foot on the brake pedal, and how long it took them to reach out of the vehicle to complete the card-swiping task. Because the target population was older drivers over the age of 60, the research hypotheses center around older drivers, and the phrase "older drivers" is not mentioned specifically.

1.2 Motivation, Background and Scope

Over the past four decades, the United States has experienced a steady growth of the population, licensed drivers, and registered vehicles. It is estimated that the number of licensed drivers over age 65 will be about 40 million in 2020 (Dellinger, Langlois, & Li, 2002). As people age they become more fragile, and they typically experience diminishing cognitive and physical functionalities (e.g., vision, reaction time and range of motion in the lower limbs) that may have an effect on their ability to drive safely. As a result, not only are older drivers more likely to be involved in crashes, they are also more vulnerable to crash injuries.

Among various types of crashes involving older adults, the pedal misapplication crash is a type of crash where drivers depress the accelerator pedal when they intended to depress the brake pedal. In 2012 the National Highway Traffic Safety Administration (NHTSA) published a study that investigated the prevalence of the pedal application errors (PAEs), using crash databases and media reports. Findings of this study reveal that the older drivers and parking maneuvers are overrepresented in the PAE crashes. The NHTSA report provides the ratio of the percentage of older drivers involved in PAE crashes to the percentage of licensed drivers in the US (U.S. Department of Transportation, 2012). As age exceeded 65 years, the ratio became greater than one, which indicates that the drivers over 65years of age are overrepresented in pedal misapplication crashes. The report also shows that some driving tasks are associated with higher risk of the PAE, such as parking, executing an emergency stop, and reaching out of the vehicle. Other research has also focused on the PAE and its causes (Cantin et al., 2004; Schmidt,1989; Vernoy &

Tomerlin, 1989). However, the pedal usage characteristics of older drivers in various driving tasks, performed in an on-road, realistic environment, is unknown.

The current study focused on drivers over the age of 60. The goal of the study was to understand the risks that older drivers may experience as a result of their pedal usage characteristics.

1.3 Overview of the Dissertation

Chapter Two of this dissertation is a review of existing literature. To achieve the objectives of understanding older drivers' pedal usage characteristics, one needs to understand both the pedal design and the characteristics of older drivers. Section 2.1 provides a brief history of automotive foot controls. Section 2.2 reviews the existing design guidelines and standards on automotive pedal design. It is followed by a section on research studies that are related to pedal design which is organized by different aspects of pedal design, such as pedal position and pedal size. Note that section 2.2 and section 2.3 are similar because one can find pedal design recommendations, such as how far the brake pedal and the accelerator pedal should be apart from each other, in both sections. The difference between the two sections is that the section 2.2 is a review of official documents issued by a government or an international organization that either carry legal forces or are so important that they are followed by most of the manufacturers. Section 2.3 is a review of recommended practice from resources such as a research paper or a design handbook. These practices are recommended because they are proven to promote drivers' safety or comfort through experiments. However, they are not mandated by governments, making noncompliance easier to defend in courts. Section 2.4 through section 2.6 describes older drivers from different aspects, such as the driving population (section 2.4), travel patterns (section 2.5), as well as crash and fatality rates (section 2.6). Section 2.7 reviews the factors related to older drivers' involvement in crashes, and section 2.8 delves deeper on the topic of the PAE as a cause of crashes involving older drivers.

Chapter Three discusses the research gaps that were identified based on an extensive review of existing literature. In addition research questions and hypotheses address the absent literature. Chapter Four is a thorough description of research methods which includes participants, their driving route and driving tasks, the instrumented vehicle, experiment procedures and data processing. Chapter Five presents the results of the data analyses. This includes both descriptive data and results of statistical tests for each of the hypotheses. Chapter Six discusses the implications of the results, lessons learned, limitations and future research.

CHAPTER TWO

REVIEW OF THE LITERATURE

This chapter encompasses necessary background information about automotive foot pedal design as a factor in driver performance and drivers' pedal application characteristics. Section 2.1 traces the evolution of the foot controls as an essential starting point for examining current foot pedal design. Section 2.2 reviews relevant portions of several design guidelines and standards for foot controls. Section 2.3 of this chapter is a thorough examination of existing studies and design recommendations related to automotive pedals. Section 2.4 through section 2.6 provides statistics related to older drivers in the United States, travel patterns of older drivers and their crash rates. Section 2.7 is a review of factors related to crashes involving older drivers, and section 2.8 reviews studies relevant to the Pedal Application Error (PAE).

2.1 Evolution of Foot Controls

In order to understand current automotive pedal design and why the pedals look like they do today, it is helpful to have an understanding of the origins and development of foot controls in early automobiles and modifications that have occurred over time. The birth of the automobile was not accompanied by the birth of foot controls. The means by which people accelerate and decelerate automobiles have been through great changes since the late 19th century when automobiles were invented. In 1886, the Benz patent motor car was the first commonly acknowledged automobile (Figure 1). It was operated mainly by a hand lever located on the left side of the vehicle and a tiller steering mechanism, and there were no foot controls.

The first known automotive foot control was introduced in 1890 when the French manufacturer, Panhard, adopted a foot pedal clutch to operate the gearbox (Figure 2).

Figure 1. Benz Patent Motor Car 1886 (Daimler Group, 2014).

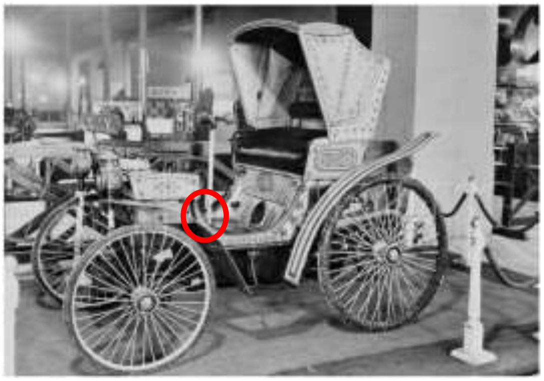


Figure 2. 1890 Panhard (The red circle indicates the position of the pedal ("Album photographique," 2014).

Early forms of foot controls were not necessarily well-received by most drivers or manufacturers, as foot controls began to assume functions formerly performed by hand controls. Evidence of unfavorable reactions to foot controls occurred in frequent discussions that appeared in an early car magazine, *The Motor-Car Journal* (Richardson, 1904). Nevertheless, in the early stages of automotive design, driving functions like acceleration continued to migrate to foot controls in the forms of pedals or buttons. In addition, some foot controls had more than one control level, such as the clutch pedal in the Ford Model T which had three levels: neutral, low gear and high gear.

In 1912 Cadillac introduced the first foot-operated starting motor (Kettering, 1915). The first foot-operated headlight dimmer button was introduced in 1927 and was located in the foot pan for about 50 years, until it was moved to the steering column (Motorera, 2012). Other functions, such as the windshield washer, were also once controlled by the driver's foot. Examples of these foot controls can be seen in Figure 3 and Figure 4. Foot controls in early automobiles had two main features. First, there were more functions that needed to be operated by foot than those in modern cars. Second, the foot controls existed in different forms (such as a button) other than pedals as we see nowadays.

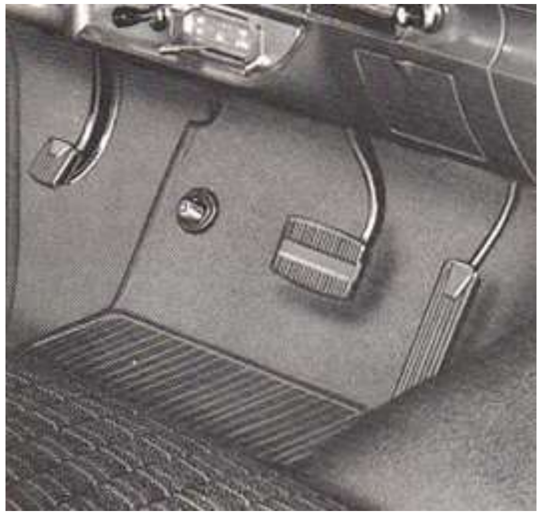


Figure 3. Foot-controlled headlight dimmer switch in a 1960 Ford (Ford Motor Company, 1960).

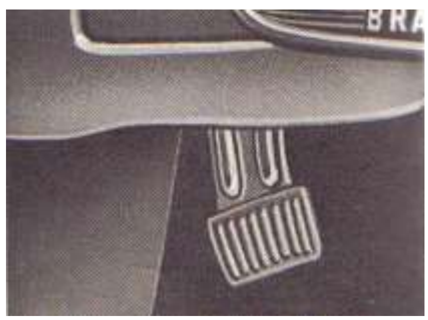


Figure 4. Windshield washer control in 1963 Mercury Comet and S-22 (Ford Motor Company, 1963).

2.1.1 Combined brake-accelerator pedal.

Historically in foot control design, there were several attempts to combine the brake pedal with the accelerator pedal. The reasons for this combined pedal design included reducing the braking reaction time (Konz, Wadhera, Sathaye and Chawla, 1971) and reducing the likelihood of depressing an unintended pedal (Matsunaga, Naruse, Muto, & Kitamura, 1996). A combined pedal mechanism was developed and patented by Winkelman in 1959 (U.S. Patent No. 2878908). The accelerator was engaged if depressed at the front of the pedal using the toes, and the brake was engaged if depressed at the rear using the heel (Figure 5).

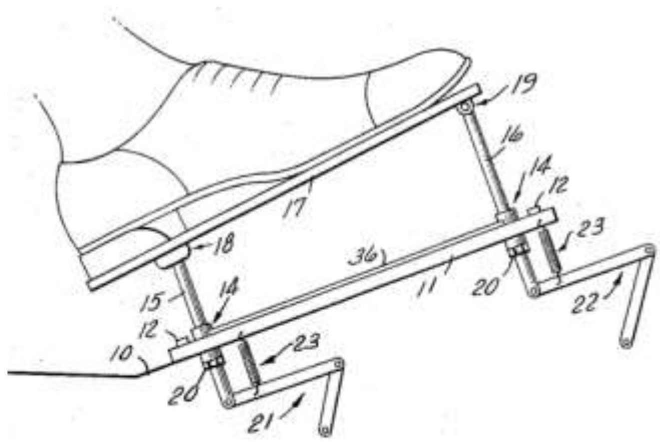


Figure 5. Winkelman patented combined pedal design (U.S. Patent No. 2878908). According to Konz et al. (1971), this pedal mechanism reduced the reaction time by 0.2 s compared to conventional pedal configurations.

Another combined pedal design was developed in 1991 by Naruse (Figure 6). When the foot was rotated to the right to actuate the lever, the accelerator was engaged, and when the pedal was depressed, the brake was engaged. Matsunaga et al. (1996) compared the foot transfer time from the accelerator to the brake pedal and the stopping distances, using both the conventional pedals and the Naruse pedal system. The experiment examining foot transfer time was carried out using the KM choice reaction time measuring software. Two females (21 and 48 years old) participated in the experiment.

The mean foot transfer time using the Naruse pedal system was 0.16 s less than that using the conventional pedal system. The experiment examining stopping distance had seven participants (18 to 64 years old, six males and one female) drive at 40km/h on the track of a driving school and respond to a red traffic light, using both a conventional pedal system and Naruse's pedal system. The stopping distance using the Naruse pedal was reduced by 1.6 m (5.2 ft), compared to the stopping distance using the conventional pedal system.

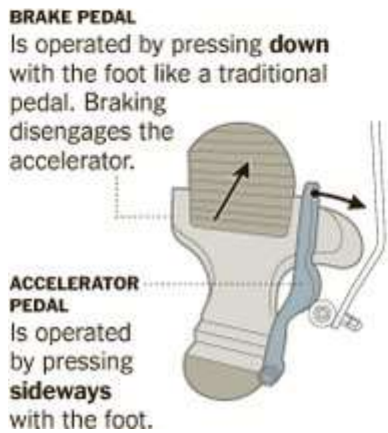


Figure 6. The operation of Naruse's pedal (Tabuchi, 2010).

2.2 Design Guidelines and Standards for Automotive Pedals

Over many decades, various guidelines or standards have been issued by governments, international or national standards organizations, professional associations and other institutions. Those included in this section are influential and are specialized for passenger cars.

In 1958, the United Nations Economic Commission for Europe (UNECE) developed a framework, known as the '1958 Agreement', to harmonize the standards for automobiles that are related to safety, environment, energy and anti-theft issues (United Nations Economic Commission for Europe, 1993). The World Forum for Harmonization of Vehicle Regulations (WP.29) is a component of the UNECE's Inland Transport Committee. Based on the 1958 Agreement, the WP.29 developed a series of vehicle regulations. Among these regulations, regulation No. 35 (*Uniform Provisions Concerning the Approval of Vehicles with Regard to the Arrangement of Foot Controls*) provides requirements for foot control placement in passenger cars, including both manual and automatic transmissions. According to the standards, the brake pedal and the accelerator pedal in a passenger car with automatic transmission should be separated by 50 to 100 mm (2 to 3.9 in.). The distance from left wall of the footwell to the left edge of the brake pedal should be at a minimum of 120 mm (4.7 in.). The distance from the right edge of the brake pedal to the right wall of the footwell should be a minimum of 130 mm (5.1 in.).

The Federal Motor Vehicle Safety Standards (FMVSS) was developed by the National Highway Traffic Safety Administration (NHTSA), an operating administration under the U.S. Department of Transportation. The first FMVSS standard (*Standard 209 Seat Belt Assemblies*) became effective in 1967, and more standards became effective subsequently (U.S. Department of Transportation, 1999). Vehicle and equipment manufacturers must conform and certify compliance. Failure to comply with the FMVSS can result in fines and mandatory recalls (Green, 2008). FMVSS Standard No. 105 (*Hydraulic and Electric Brake Systems*) specifies requirements for hydraulic and electric brake systems and parking brake systems. The 'spike stop' test, one component of brake test procedure, allows up to 890 N (200 lb) of force applied on the brake pedal in 0.08 s (National Highway Traffic Safety Administration, 1968). Standard No. 124 (*Accelerator Control System*) requires that when the foot force is released from the accelerator pedal, the throttle should return to the idle position (National Highway Traffic Safety Administration, 1973).

The Society of Automotive Engineers (SAE) is a worldwide, professional organization and has developed numerous standards in the field of automotive engineering. SAE standards are recommended practices and do not carry legal force, but failure to comply with them may make defending noncompliance in U.S. courts very difficult (Green, 2008). SAE J1100 (*Motor Vehicle Dimensions*) was first developed in 1973 and defines a set of measurements and standard procedures for motor vehicle dimensions (Figure 7 to Figure 11, Table 1).

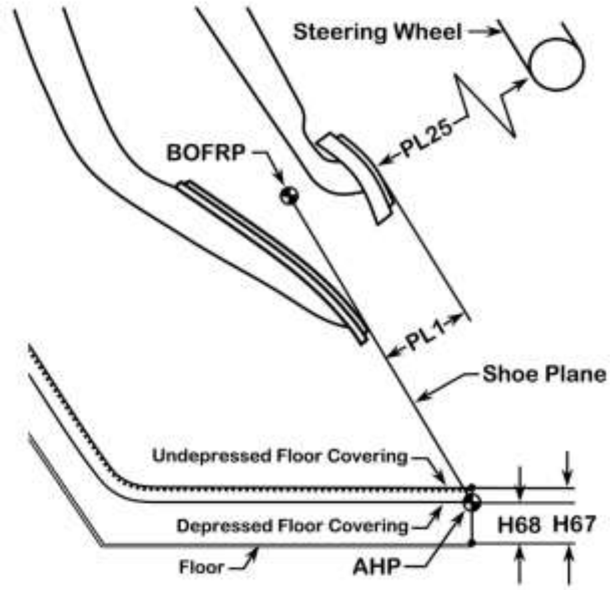


Figure 7. Pedal clearances (SAE International, 2009).

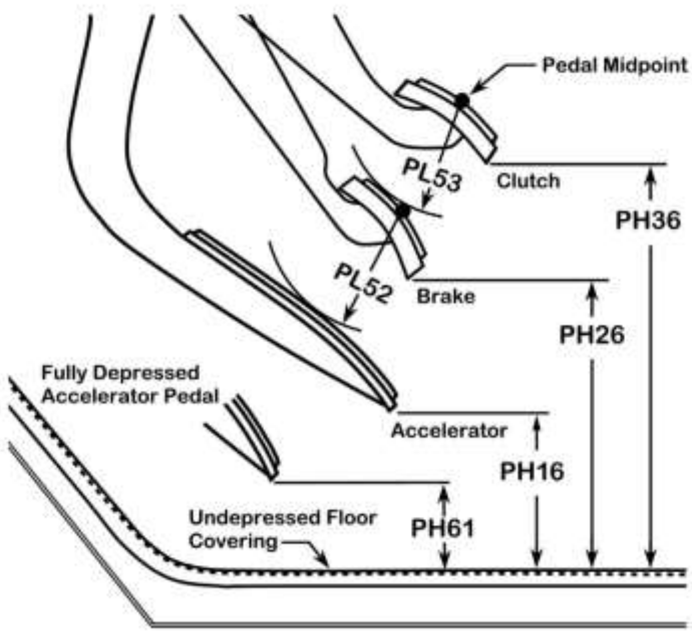


Figure 8. Pedal height and clearances (SAE International, 2009).

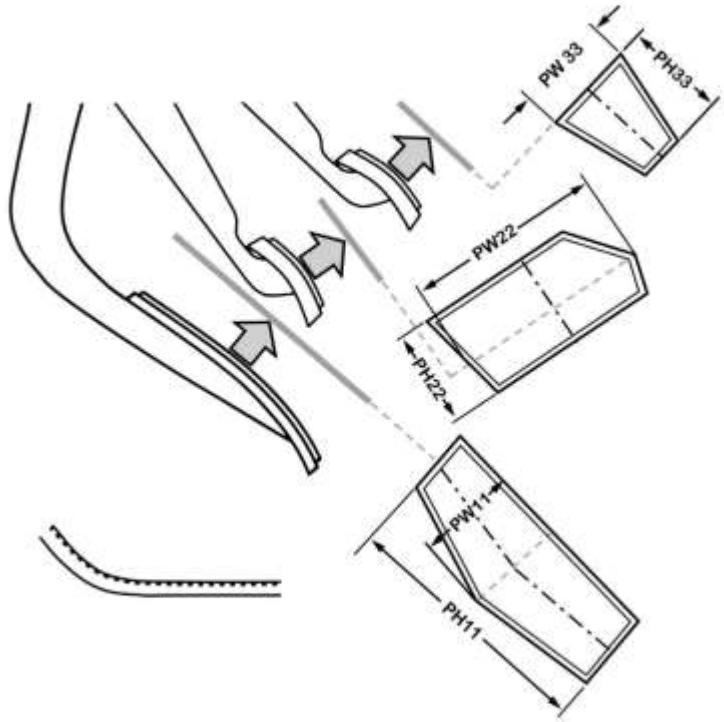


Figure 9. Pedal surface dimensions (SAE International, 2009).

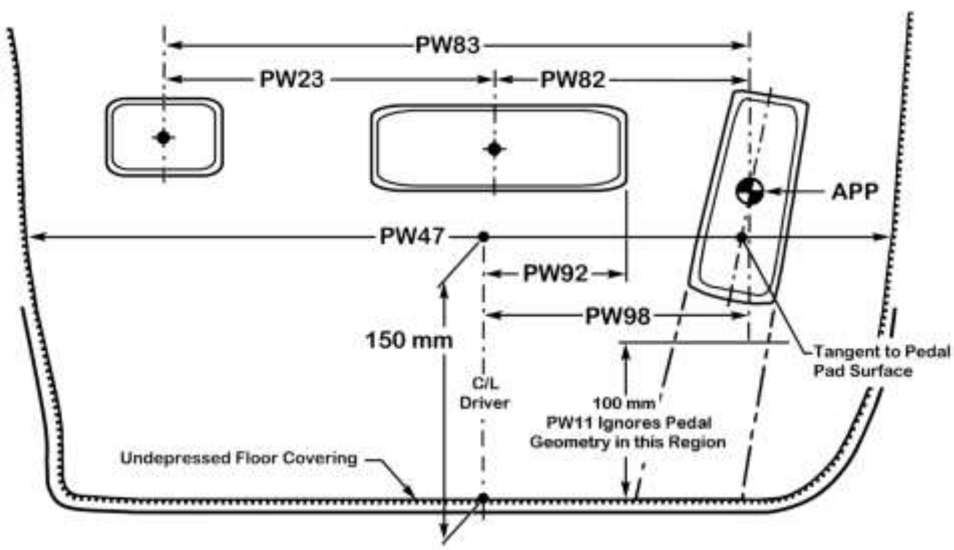


Figure 10. Pedal separation and relationship to driver (SAE International, 2009).

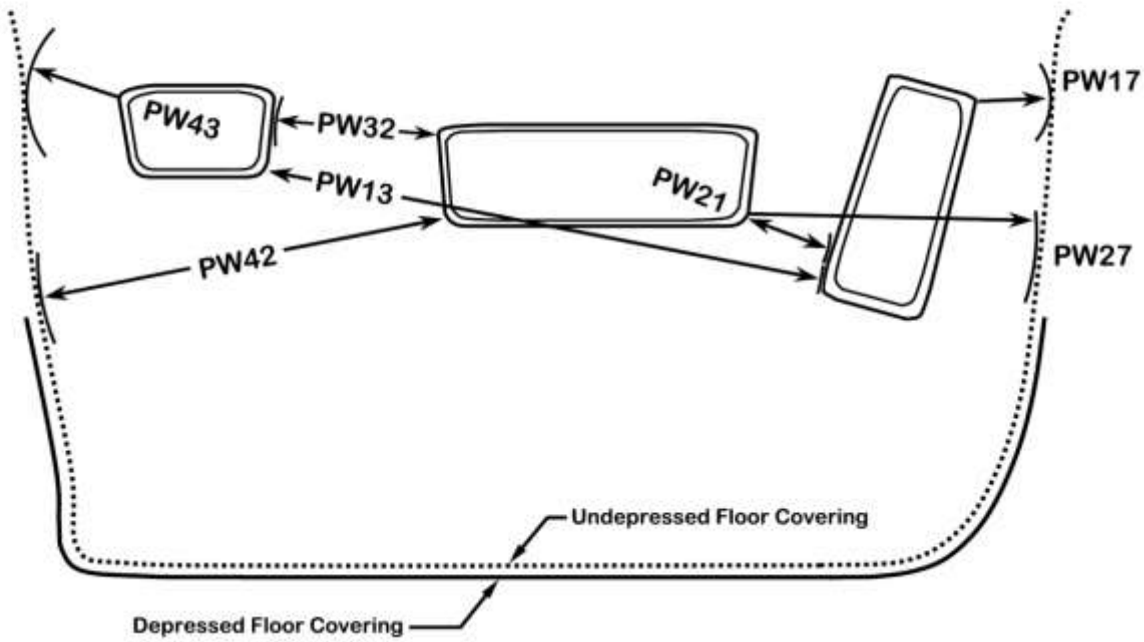


Figure 11. Pedal separation (SAE International, 2009).

Table 1. Pedal Dimension Code Used in the SAE Standards (SAE International, 2009).

Code	**Dimension**
PL1	Accelerator to brake lift off (step over)
PL52	Brake to accelerator offset
PL53	Clutch to brake offset
PW11	Accelerator pedal width
PW13	Brake space
PW17	Accelerator to right side
PW21	Brake to accelerator separation
PW22	Brake pedal width
PW23	Brake to clutch lateral offset
PW27	Accelerator space
PW32	Clutch to brake separation
PW33	Clutch pedal width
PW42	Brake to left side

PW43	Clutch to left side
PW47	Driver footwell width
PW82	Ball of Foot Reference Point (BOFRP) to Centerline of (C/L) brake
PW83	BOFRP to c/l clutch
PW92	C/L driver to right edge of brake
PW98	C/L driver to BOFRP
PH11	Accelerator pedal height
PH16	Accelerator clearance to floor
PH22	Brake pedal height
PH26	Brake clearance to floor
PH33	Clutch pedal height
PH36	Clutch clearance to floor
PH61	Accelerator travel, clearance height

Among all pedal-related measurements, the pedal spacing dimensions are based on International Organization for Standardization (ISO) standard 3409 (SAE International, 2009). However, this standard does not make any specific recommendations as to how much these dimensions (such as pedal spacing) should be. For example, SAE J1100 specifies how the dimension of the lateral separation between the brake pedal and the accelerator pedal should be measured (Figure 10 and Figure 11), but it does not provide information as to how much the lateral separation should be. Additionally, SAE J135 (*Service Brake System Performance Requirement*) presents minimum performance requirements for the brake system of passenger cars and trailers (SAE International, 2013). Some tests, such as the Emergency Brake System Test, allow up to 890 N (200 lb) of pedal force. SAE J4004 (*Positioning the H-Point Design Tool—Seating Reference Point and Seat Track Length*) describes the method of positioning the H-point Design Tool (a physical representation of the seated driver) and the methods of establishing important design references, such as seating reference point (SgRP), which is a unique H-point used to position many design tools such as head clearance contours. Among them, the driver shoe plane angle (SPA) equation is highly related to the accelerator pedal design. This SPA equation is used to define the side-view angle of the shoe plane from horizontal, and the shoe tool (a physical representation of the driver's shoe) is positioned based on the SPA equation. The position of the shoe tool can be established either before or after the pedal is designed. If the pedal is designed after the shoe tool is defined, the lateral centerline of the pedal surface should contact but should not protrude through the driver shoe plane while the heel of the shoe has constant contact with the depressed floor covering.

The ISO has developed a large number of voluntary, international standards for products, services and practices. Vehicle manufacturers comply with ISO standards both because "some countries require 'type certification' for vehicles to be sold which includes compliance with ISO standards" and because "global manufacturers find that producing ISO-compliant, globally marketable vehicles is less costly than producing non-compliant, country-specific vehicles" (Green, 2008, p.448). Among these standards, the ISO 3409 (*Passenger Cars-Lateral Spacing of Foot Controls*) was developed by Technical

Committee 22/Subcommittee 13 (*Road Vehicles / Ergonomics Applicable to Road Vehicles*) in 1975. Similar to SAE J1100 standards, ISO 3409 specifies several measurements in the footwell but does not provide numeric values as to how pedals should be designed (International Organization for Standardization, 1975).

The Alliance of Automobile Manufacturers (AAM), a trade association of U.S. automobile manufacturers, also developed voluntary and publicly available guidelines. The main incentive to comply with AAM guidelines is the "potential negative outcome of a product liability action" (Green, 2008, p.448). AAM recommends removing its guidelines related to pedal design and allowing NHTSA sufficient time to determine whether rulemaking is warranted.

2.3 Pedal Design Recommendations and Research Studies

The review of the literature revealed an abundance of recommendations relevant to the pedal design that exists in design handbooks, peer-reviewed articles and government reports. In addition, there have been numerous research efforts to provide insight into drivers' pedal application behaviors, although these studies did not make pedal design suggestions for automobiles.

Pedal mechanisms have been used in a variety of applications other than automobiles such as airplanes, farm machinery and industrial settings (e.g., a textile mill). Because the interactions between the operators and the pedals in different environments are comparable, it is worth giving attention to the pedal studies that apply to environments other than the automobile. In fact, much information about automobile pedal designs from today's design books originated from studies conducted for pedals used in airplanes (Gough & Beard, 1936; Hertel, 1930). However, just because some early pedal design recommendations were derived for different types of human machine interactions, one needs to be careful when applying these recommended practices to automobile pedal design. For example, the maximum leg force exerted on airplane pedals cannot be used as a reference when looking for the desired resistance for automobile pedals because the operators' physical capabilities may be different. , With many airplane studies, the maximum leg force data were obtained from young, healthy and well-trained pilot populations, whereas the automobile drivers encompass those persons whose legs may not be as strong.

Although early studies of pedal design can be traced back to 1930s (Gough & Beard, 1936; Hertel, 1930), the burgeoning research efforts on automobile pedals came in the 1960s (Davies & Watts, 1969; Rebiffé, 1966; Trombley, 1966). The Joint Army-Navy-Air Force Steering Committee sponsored the preparation of a human factors handbook, *Human Engineering Guide to Equipment Design* (Van Cott & Kinkade, 1972), which was first published in 1963. It contributed to the human engineering knowledge of equipment design by providing data, principles and practices, as well as a comprehensive bibliography. Black's book, *Man and Motor Cars: An Ergonomic Study*, is one of the early works on automotive ergonomics (Black, 1966). For automobile pedals, Black makes comprehensive design recommendations from perspectives such as pedal travel, resistance, and position. Most importantly, Black explains the considerations behind each recommendation in detail.

Another important information resource is the Department of Defense Design Criteria Standard, *Military Standard 1472 (MIL-STD-1472).* MIL-STD-1472 was established in February 1968 and presents a compilation of a large number of standards published by U.S. Army Human Engineering Laboratory. It serves as the base document for many guidelines, handbooks and standards, such as the *Human Factors Design Guide* from the Federal Aviation Administration (FAA) (Poston, 2003). The current version is the MIL-STD-1472G. Lockett (2012) presented an evolution of this military standard from the 1980s.

Two additional data resources related to pedal design are *Humanscale,* organized by Henry Dreyfuss Associates (Dreyfuss, 1973) and *Human Factors Design Handbook: Information and Guidelines for the Design of Systems, Facilities, Equipment, and Products for Human Use* (Woodson, 1981).

In 1989, the National Highway Traffic Safety Administration (NHTSA) issued a technical report, *Human Factor Analysis of Automotive Foot Pedals* (Brackett, Pezoldt, Sherrod, & Roush, 1989). In addition to a review of existing literature on pedal design, the report proposed a set of design recommendations for automobile pedals based on field measurements and experiments. Different from most of the existing studies, the researchers derived the design recommendations by capturing the participants' expected and preferred pedal location. The authors maintained that if the pedals were placed where the drivers preferred or expected the pedals, pedal misapplication errors may be mitigated. Unfortunately, the participants' performances using the recommended pedal configuration were not significantly superior to their performances using other pedal configurations.

Many other design books also provide useful information for automobile pedal design or pedal design for general purposes, such as *Human Factors in Engineering and Design* (Sanders & McCormick, 1993) and *Ergonomic Design for People at Work* (Eastman Kodak Company, 1983). While these books provide useful resources, engineers need to review the rationale (e.g., experiments) behind each recommendation to evaluate whether the recommendation is applicable for the current purpose. For example, the recommendations for pedal resistance may only include data from experiments involving young and healthy participants. When designing a pedal system for the civilian driving population, including both younger and older individuals, the pedal resistance recommendations from those earlier studies may not be appropriate.

Unfortunately, many recommendations from the above resources, especially from those handbooks or standards that are intended for quick reference, do not state clearly either the corresponding rationale or the data sample. In addition, some recommendations are based on unpublished work. Therefore, the literature reviewed in the following sections focuses primarily on those recommendations where the rationale and methodology are clearly described (e.g., from journal articles). For the comprehensiveness of this literature review, pedal design recommendations without corresponding background studies are also listed.

2.3.1 Pedal type.

Pedal type can be categorized in many ways, but it mainly refers to the pedal fulcrum (around which the pedal arm rotates) position and the pedal moving path when being depressed. According to Black (1966), there are three types of accelerator pedals: piston, pendulum and the organ-type pedal. See Figure 12. The piston pedal has a translatory motion and moves along a straight line. The pendulum pedal has a fulcrum above and forward to the pedal plate so that it moves through a curve convex towards the driver. The organ-type pedal has a fulcrum below and forward to the operator's heel; thus, the pedal has a moving path concave towards the driver.

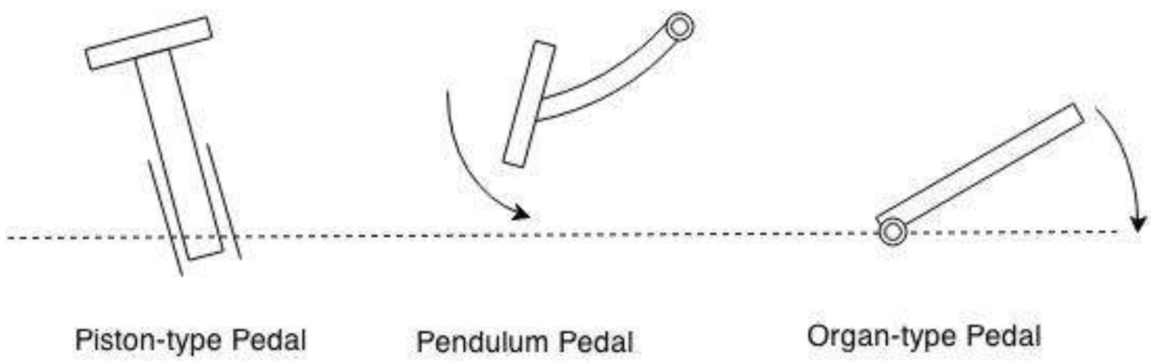


Figure 12. Three types of accelerator pedals discussed in Black (1966).

Black recommended that the accelerator pedal should be an organ-type pedal. The conclusion was based on the author's literature review, but no specific studies were cited in the book. For the brake pedal, Black suggested the pedal movement should raise the heel from the floor to allow for powerful and controlled leg action.

Van Cott and Kinkade (1972) also categorized pedals into three types: rotary (a pair of pedals such as bicycle pedals), reciprocating (a pair of connected pedals like two ends of a seesaw: when one is pressed down, the other one will lift up) and translatory (the same as the Black's 'piston pedal') (See Figure 13).

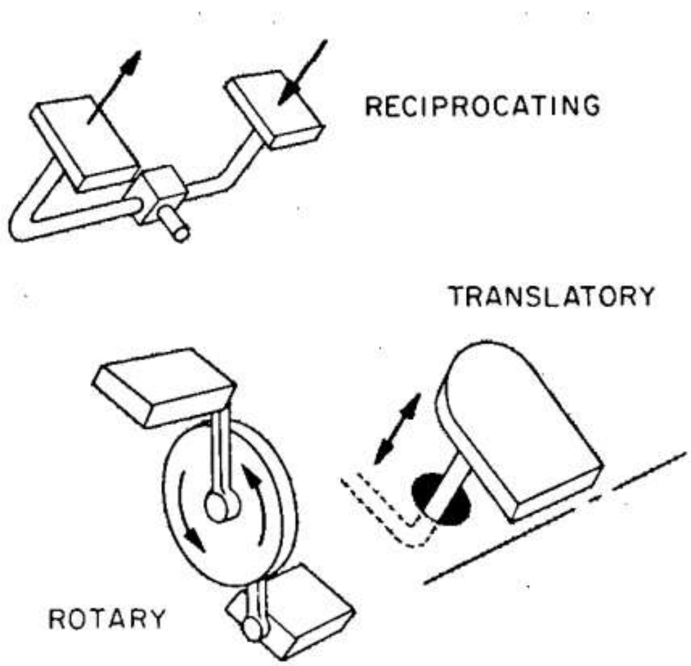


Figure 13. Three types of pedals discussed in Van Cott and Kinkade (1972).

However, unlike Black (1966), Van Cott and Kinkade did not suggest pedal types for the automotive brake pedal and the accelerator pedal.

Woodson (1981) recommended pedal types based on the automobile seat height. For the accelerator pedal, both a flat rectangular pedal with one end hinged on the floor and a small curved hanging pedal would be satisfactory (Woodson, 1981).

In addition to categorizing a pedal by its fulcrum location and moving path, some authors categorized a pedal as ‘operated by leg’ and ‘operated by ankle’, or as ‘one foot random’ and ‘one foot sequential’ (U.S. Department of Defense, 2012). ‘One foot random’ refers to the foot movement that is independent of each other. In other words, each foot movement (its direction, force, amplitude, etc.) is not affected by other foot movements. ‘One foot sequential’ refers to the foot movement among several targets (accelerator pedal and brake pedal in the case of operating an automobile).

2.3.2 Pedal position.

Pedal position is measured in three dimensions (Figure 14). The position of the pedal may relate to the driver’s safety and comfort in an automobile. Pedal positioning is dependent upon factors such as a driver’s leg length, foot length and seat position, as well as vehicle footwell size. The review of the literature establishes that the exact reference points, chosen to quantify the pedal position, vary among researchers.

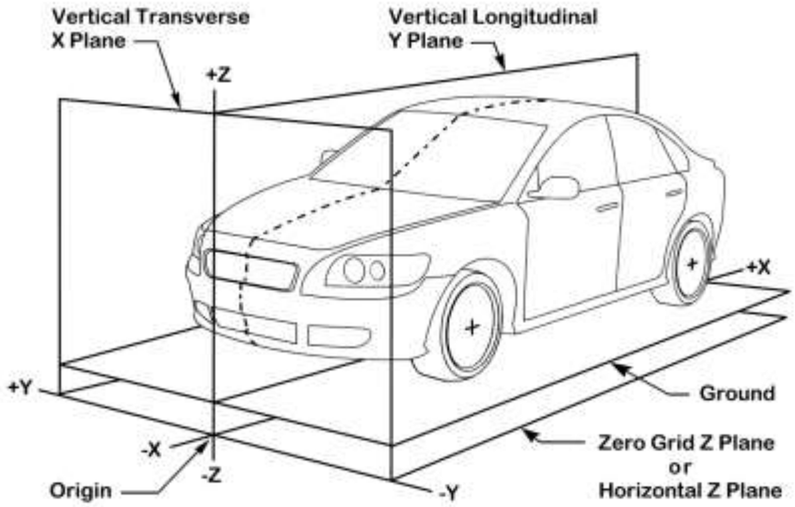


Figure 14. Vehicle coordinate system (SAE International J182, 2009).

Longitudinal position.

Black (1966) recommended that the brake pedal should be 940 mm (37 in.) forward of the backrest of the driver's seat to allow for full depression of the brake pedal without locking the knee joint. The knee joint angle in this case was 160 degrees.

Brackett et al. (1989) suggested that the longitudinal distance between brake pedal and the seating reference point (SgRP) should be 876 to 1080 mm (34.5 to 42.5 in.), and thus, the seat should have 203 mm (8 in.) of track. The purpose for this recommendation was to accommodate the leg reach of the 5th percentile female to 95th percentile male when the knee angle was approximately 160 degrees.

Freeman and Haslegrave (2004) used the simulation software, JACK, to derive the optimal accelerator pedal position when the seat height ranges from 150 mm (5.9 in.) to 250 mm (9.8 in.). The simulation was aimed at improving joint comfort of 1st percentile female to 99th percentile male. The accelerator pedal position was quantified using the distance from the hip point to the pivot of the accelerator pedal.

Lateral position.

Black (1966) suggested that a brake pedal should be in line with the center plane of the driver's right leg. Based on the pelvis width and leg angle, the brake pedal was recommended to be 127 mm (5 in.) to the right of the center line of the driver's body. Black made no recommendations for the accelerator pedal. Van Cott and Kinkade (1972) recommended that the accelerator pedal should be 127 to 178 mm (5 to 7 in.) to the right of the driver's centerline. However, the rationale for this recommendation was not found in the citation list in the Van Cott and Kinkade (1972).

Brackett et al. (1989) recommended that the brake pedal should be at least 203mm (8 in.) wide, and the right edge of the brake pedal should be 102 mm (4 in.) right to the steering wheel centerline. These specifications are based on the preferred brake pedal locations captured in their study. In addition, the left edge of the accelerator pedal was suggested to be 165mm (6.5 in.) to the right of steering wheel centerline, using brake pedal position and minimum lateral separation between the brake pedal and accelerator pedal.

According to Woodson (1981), when using an automatic transmission, the brake pedal should be placed on the driver's centerline, and when using the accelerator pedal, the right foot heel should be 140 mm (5.5 in.) to the right of the driver's centerline.

***Vertical position*.**

Black (1966) suggested that the brake pedal should be 127 mm (5 in.) below the seat to maximize the driver's leg force. According to Black, a brake pedal as high as the seat pan would cause fatigue on the hip, although no more details were provided regarding this statement. Brackett et al. (1989) made the same recommendation as Black because this height would allow drivers to apply the right amount of force on the pedal, and this pedal position aligned with the results of their empirical studies. Brackett et al. identified that the accelerator pedal position should be determined using the brake pedal position and vertical separation between the two pedals.

Dreyfuss (1973) suggested that the accelerator pedal height (vertical distance from the floor to the top of inclined pedal) should be 76 mm (3 in.), and that the elevation of the accelerator pedal (vertical distance from the floor to the bottom of pedal) should be 25 mm (1 in.). For the brake pedal, the height should be within the range from 152 mm (6 in.) to 254 mm (10 in.) with an optimal value of 203 mm (8 in.).

Woodson (1981) recommended two types of accelerator pedal. If a small, curved, hanging pedal is used, it should accommodate the ball of foot height from 76 mm (3 in.) to 114 mm (4.5 in.). The driver should always be able to rest his or her heel while holding or depressing the pedal. Similar comments about heel rest were also made in the military standard MIL-STD-1472G (U.S. Department of Defense, 2012).

2.3.3 Separation between accelerator pedal and brake pedal.

In daily driving, a driver's foot transfers frequently from one pedal to the other. This is especially true in traffic scenarios, such as following a slow car. Because there are no visual cues for drivers to know which pedal the foot is currently hovering above, the separation between pedals may play a significant role in helping drivers to differentiate between the two pedals. The separation is also closely related to foot fatigue, especially when the foot transfer is very frequent. Pedal separation can be further categorized as lateral separation and perpendicular separation. The lateral separation is the distance measured on the pedal plane as shown in Figure 15. The perpendicular separation is the distance measured perpendicularly from one pedal to the other. The perpendicular separation is set to be positive when the brake pedal is above the accelerator pedal. Vertical separation is used when referring to the vertical distance from one pedal to the other (Figure 16). Because the foot movement time between the brake and the accelerator pedals plays an important role in determining the appropriate pedal separations, the studies on foot transfer between pedals are also included in this section.

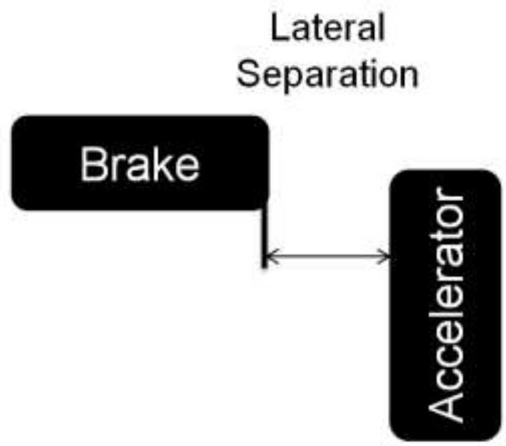


Figure 15. Pedal lateral separation.

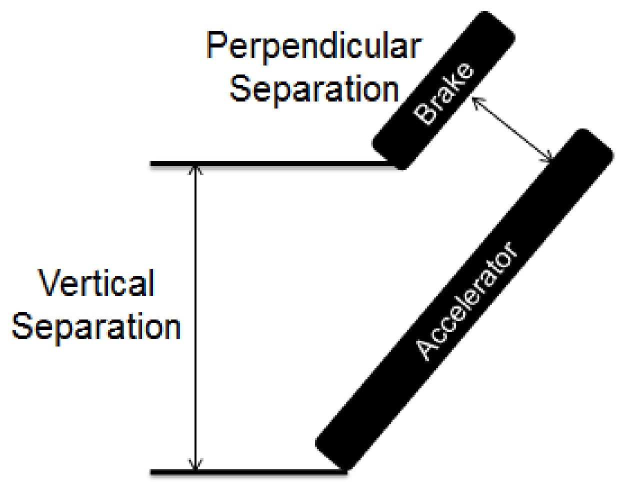


Figure 16. Pedal perpendicular and vertical separation.

Black (1966) suggested that the top of the accelerator pedal should be 76mm (3 in.) from the right margin of the brake pedal. This distance allows for the driver's maximum shoe width and full contact with the brake pedal with minimum risk of inadvertently depressing both pedals. Black also noted that the brake pedal should be 13 mm (0.5 in.)

below the top of accelerator pedal at three-quarters throttle. According to Black's experiments, the braking movements are the most frequent when the throttle is three-quarters opened.

Davies and Watts (1969, 1970) compared foot movement time between pedals using two pedal configurations: the brake pedal level with the accelerator pedal, and the brake pedal higher than the accelerator pedal. The authors identified that when two pedals were coplanar with each other, the foot movement time was significantly less than that when the brake pedal was above the accelerator pedal.

Snyder (1976) measured foot movement time using three pedal configurations: one configuration with a combination of lateral (64 mm/2.5 in.) and perpendicular (51 mm/2 in.) separations, and two configurations with only lateral separations (102 mm/4 in. and 152 mm/6 in.). He identified that pedal configuration with perpendicular separation produced significantly longer movement time. Pedal configuration with lateral separation of 152 mm (6 in.) was recommended by the author to avoid simultaneous depression of both pedals.

Glass and Suggs (1977) tested drivers' foot movement time between the two pedals using a variable, conventional pedal design and two new pedal designs. The conventional pedal design has 11 perpendicular separation settings from the brake pedal being 102 mm (4 in.) lower than the accelerator pedal to it being 152 mm (6 in.) vertically above the accelerator pedal (in 25 mm/1 in. increments). In the first new pedal design, two pedals were placed adjacent to each other and in the same plane when no force was applied. The brake pedal and the accelerator pedal were combined to be one pedal in the second new design. The acceleration was controlled by pivoting the pedal about a central axis, and the braking was controlled by depressing the pedal. A significant reduction of foot movement time was identified when the brake pedal was 25 mm (1 in.) and 50 mm (2 in.) below the accelerator pedal. The two new pedal designs showed obvious reduction of foot movement time up to 74%. The authors noticed that when the brake pedal was higher than the accelerator pedal in the conventional pedal design, the driver's foot could get caught on the brake pedal when moving from the accelerator pedal. However, Glass and Suggs still recommended the conventional pedal design.

A study by Sexton and Koppa (1980) measured the foot movement time (from the accelerator pedal to the brake pedal) and choice reaction time using a timing device which started and finished recording automatically. The choice reaction time was measured by having the driver's foot move to either the accelerator (when the green stimulus was seen) or the brake (when the red stimulus was seen). Four pedal configurations (with different lateral and perpendicular separations, pedal sizes and lateral positions with regard to the steering column) were tested. Two groups of female drivers (five in each) with an average age of 23.8 and 44.2 years old were included. According to the authors, there was no significant difference in foot movement time between the younger group and the older group. In addition, there was no significant difference in choice reaction time among the four pedal configurations.

Glaser and Halcomb (1980) measured the foot movement time between the brake pedal and the accelerator pedal using one of 18 pedal configurations, and identified the brake width as the factor that significantly affects foot movement time. They were also trying to predict the foot movement time using Fitt's Law and its revision, which are used widely to model the movement between two objects.

In an attempt to optimize the brake pedal location, Morrison, Swope and Halcomb (1986) also measured the foot movement time between the two pedals. Six spatial relationships between the brake pedal and the accelerator pedal were tested. The six spatial relationships were combinations of three brake depths (brake pedal being 51 mm/2 in. above or below, or coplanar with the accelerator pedal) and two lateral separations (brake pedal being 51 mm/2 in. or 133 mm/5.2 in. from the accelerator pedal). The authors concluded that foot movement time can be improved by placing the brake pedal coplanar with or lower than the accelerator pedal.

Casey and Rogers (1987) pointed out that the foot movement time should not be used as the only factor when determining the pedal separation. They discussed a series of other factors that should be taken into account which include reaction time, actuation errors, control dynamics, anthropometry, pedal travel, kinesthetic feedback and control modulation. The authors concluded that placing the brake pedal above the accelerator pedal is still desired.

Brackett et al. (1989) used the drivers' preferred pedal location to determine the pedal lateral location. According to the authors, the lateral separation between accelerator and brake pedal should be 64 mm (2.5 in.) to 114 mm (4.5 in.). The minimum lateral separation of 64 mm (2.5 in.) was chosen so that simultaneous activation of both pedals can be avoided, even if a 95th percentile male presses on the left edge of the accelerator pedal. The maximum separation of 114.3 mm (4.5 in.) was chosen because it was consistent with their measurement of the subject vehicles, and separation greater than that may increase foot movement time from pedal to pedal. As to the perpendicular separation, they recommended coplanar pedal configuration because non-coplanar pedals would not accommodate foot movement between pedals that are relatively closer to each other.

In addition, three other resources provided recommendations for pedal separations without indicating clearly what these recommendations were based on. According to Dreyfuss (1973), the pedal lateral separation should be 51 to 152 mm (2 to 6 in.) if the pedals are operated by using the leg, and greater than 51 mm (2 in.) if the pedals are operated by using the ankle. In both the military standard, MIL-STD-1472G (U.S. Department of Defense, 2012), and the book by Van Cott and Kinkade (1972), the pedal lateral separation was discussed as ‘one foot random’ and ‘one foot sequential’. For ‘one foot random’, the separation should be between 100 mm (4 in.) and 150 mm (6 in.); for ‘one foot sequential’, the separation should be between 50 mm (2 in.) and 100 mm (4 in.).

A summary of the design recommendations on pedal lateral separation is shown in Figure 17.

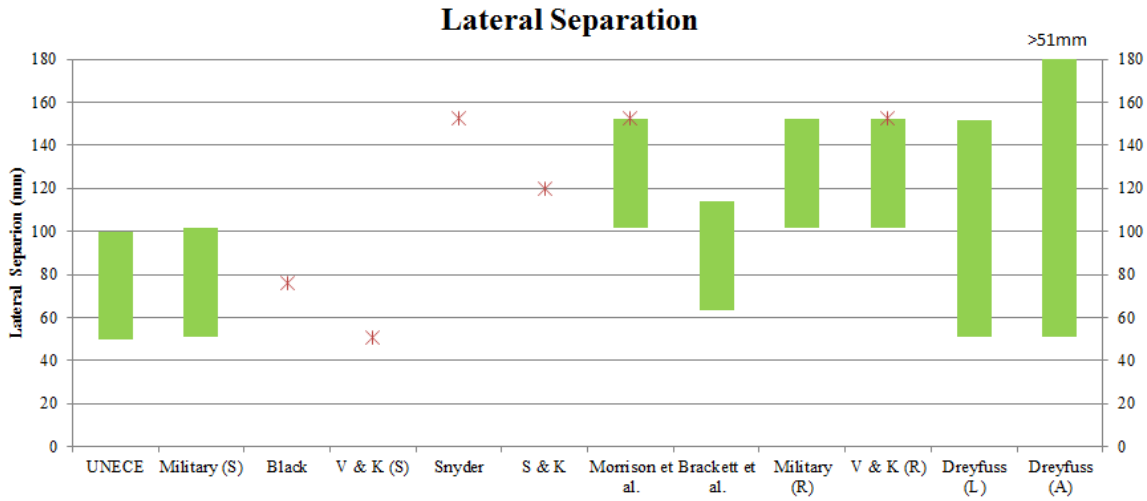


Figure 17. Summary of pedal design recommendations-lateral separation. (The asterisk indicates the preferred lateral separation; "S" stands for sequential operation and "R" stands for random operation; "L" stands for leg-operated and "A" stands for ankle-operated.)

2.3.4 Pedal Size.

Appropriate pedal size will afford comfortable foot contact and help provide distinguishable feelings of different pedals.

Pedal length.

Black (1966) determined that the accelerator pedal length should be equal to the mean length from the driver's heel to the ball of the foot, which is 229 mm (9 in.). The brake pedal was recommended to be 61 mm (2.4 in.) long to maximize the foot contact. The accelerator pedal length recommendation by Black aligned with that from Van Cott and Kinkade (1972). In addition, Van Cott and Kinkade suggested that the pedals that are used intermittently or for short period of time be 76 mm (3 in.), and the pedals that are used continuously or for a long period of time be 279 to 310 mm (11 to 12 in.). Dreyfuss (1973) recommended that a standing (hinged on the floor) accelerator pedal should be from 229 mm (9 in.) to 305 mm (12 in.), and the optimal length should be 254 mm (10 in.). According to Dreyfuss, the brake pedal length should be between 25 mm (1 in.) and 305 mm (12 in.), and preferably be 76 mm (3 in.). Woodson (1981) mentioned two recommended accelerator pedal lengths. If the accelerator pedal is flat and hinged on the floor, the pedal length should be 279 mm (11 in.); if the accelerator pedal has a curved surface and is hinged from above, a pedal length of 76 mm (3 in.) could provide equally satisfactory accelerator control. The military standard MIL-STD-1472G (2012) only required that the pedal length should be greater than 25 mm (1 in.) (U.S. Department of Defense, 2012).

A summary of the design recommendations on pedal length is shown in Figure 18.

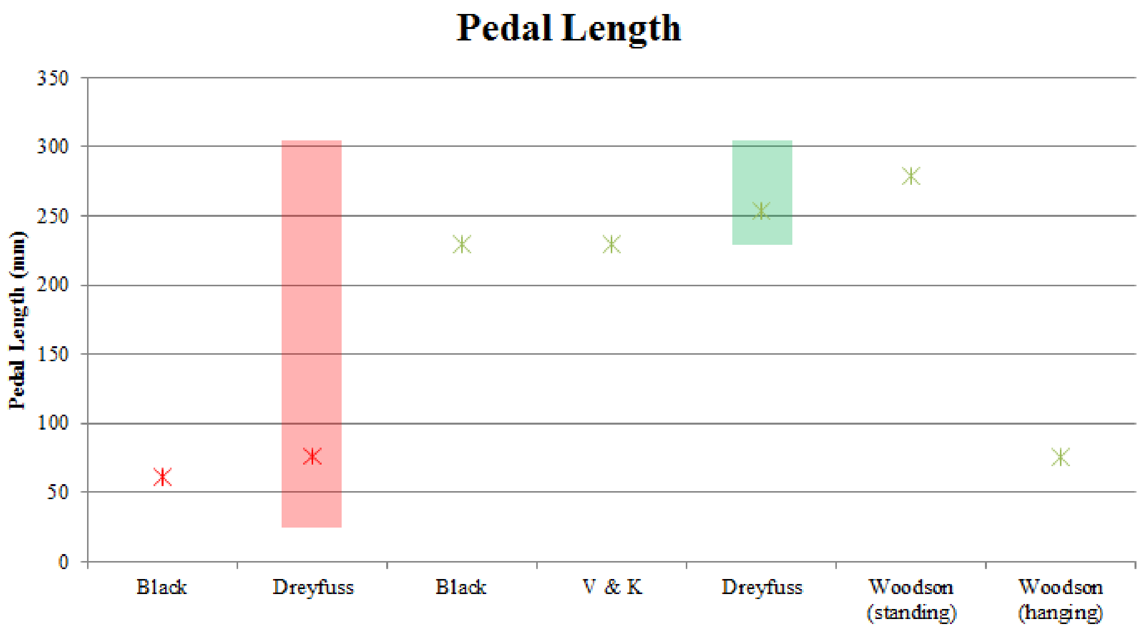


Figure 18. Summary of pedal design recommendations-pedal length. (The asterisk indicates the preferred pedal length; recommendations for the brake pedal are in red and recommendations for the accelerator pedal are in green.)

Pedal width.

Black (1966) suggested that the accelerator pedal should be semicircular in shape with a diameter of 25 mm (1 in.). Black stated that the pedal should allow variable foot contact. The curved pedal surface and the flat shoe surface will create a desirable line of contact. Compared with point contact, a line contact between the pedal and the shoe can reduce the likelihood of the foot slipping off the pedal. It can also help the drivers to distinguish brake and accelerator pedals, given that the two pedals have similar surface friction. At the same time, Black suggested the brake pedal width should be 305 mm (12 in.) so that both feet can operate it.

Van Cott and Kinkade (1972) had conflicting recommendations. They suggested that the minimum pedal width should be as wide as the shoe sole width which, according to them, is 89 mm (3.5 in.). As long as there is sufficient clearance with adjacent pedals (authors did not reveal how much the ‘sufficient clearance’ should be), the maximum pedal width is not limited. However, in another chapter dedicated for road vehicle controls arrangement, the authors suggested an accelerator pedal width of 51 mm (2 in.).

Dreyfuss (1973) suggested that for a standing accelerator pedal (hinged at the floor), the pedal width should be 51 to 114 mm (2 to 4.5 in.) and optimally be 89 mm (3.5 in.). The brake pedal width should be 76 to 108 mm (3 to 4.3 in.) and optimally be 102 mm (4 in.). Woodson (1981) suggested that the pedal should be big enough so that drivers with different sizes of feet can press the pedal with the ball of the foot (BOF). According to Woodson, the width of the accelerator pedal should be 76 mm (3 in.) if it is flat and hinged at the floor, or 51 mm (2 in.) if it is hanging from above and has a curved surface. To make sure that the driver can press the brake pedal with either foot, Woodson’s recommended brake pedal width is 152 to 203 mm (6 to 8 in.).

As pointed out previously in the Pedal Design Recommendations section, the NHTSA report by Brackett et al. (1989) made pedal design recommendations based on driver’s natural foot placement data. The width recommendation for the accelerator pedal was 32 to 76 mm (1.3 to 3 in.), based on the measurement of the vehicles used in the study. The type and brand of the vehicles measured were not revealed. For the brake pedal, the width was recommended to be greater than 203mm. The military standard MIL-STD-1472G

(U.S Department of Defense, 2012) only required that the pedal width be greater than 76 mm (3 in.).

A summary of the design recommendations on pedal width is shown in Figure 19.

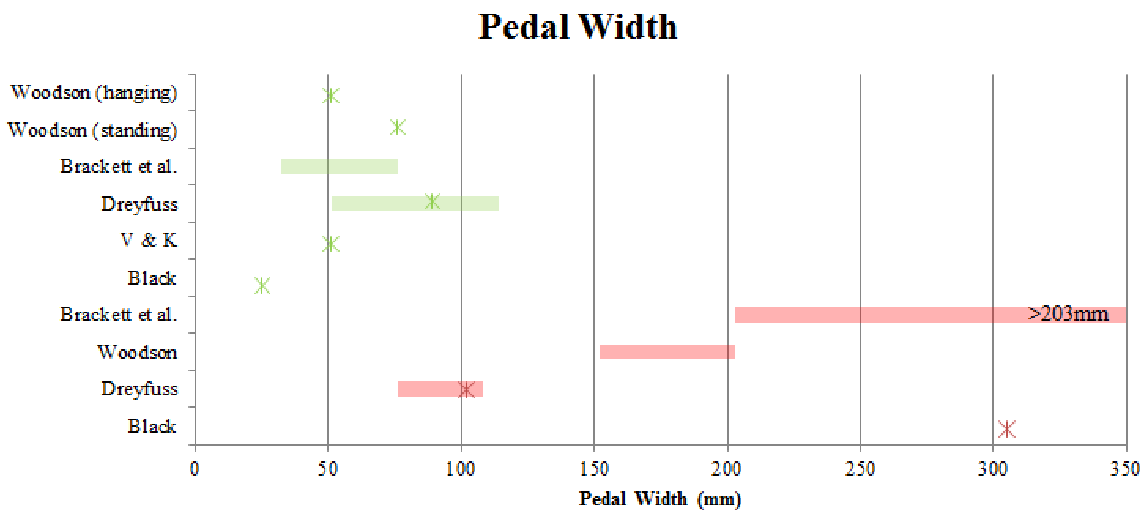


Figure 19. Summary of pedal design recommendations-pedal width. (The asterisk indicates the preferred pedal width; recommendations for the brake pedal are in red and recommendations for the accelerator pedal are in green.)

2.3.5 Pedal travel.

Pedal travel in the literature is also referred to as 'pedal displacement' or 'pedal stroke'. It normally refers to the pedal translatory travel, but because pedals are also moving in a curved path, the pedal travel can also be described by the pedal's angular travel or the shape of the travel path.

Black (1966) suggested that the accelerator pedal travel should be 20 degrees or 76 mm (3 in.) at the pedal top to provide adequate comfort. As for the brake pedal, Black suggested that the pedal travel should be 38 mm (1.5 in.) not considering the wheel lockup issue, although no reference was provided. The author also stated that the maximum pedal travel should occur at 3.5 in. before the leg is straight to allow for movement at the knee and the hip, assuming that a knee angle of 160 degrees will provide large foot force without discomfort.

Van Cott and Kinkade (1972) suggested that the brake pedal should have 102 to 178 mm (4 to 7 in.) of travel. They also noted that an ankle-operated pedal should not have 51 mm (2 in.) of travel or 10 degrees angle. Due to the limit of ankle movement, the angular range of an ankle-operated pedal should not exceed 30 degrees. To achieve an optimal range for force application on the pedal, the range of pedal travel should be 20 to 40 degrees from vertical for a leg- operated pedal, or 90 to 130 degrees from vertical for an ankle- operated pedal. With heavy foot gear, 0.5 in. of travel should be added.

Dreyfuss (1973) stated that for an accelerator pedal, the travel should be less than 20 degrees, and when the foot is resting on the accelerator pedal, the pedal displacement should be less than 5 degrees. As for a brake pedal, the normal travel should be between 127 to 178 mm (5 to 7 in.) with an optimal range of 51 to 152 mm (2 to 6 in.). If the driver is wearing boots, the normal travel should be 25 to 178 mm (1 to 7 in.) with the same optimal range as that for normal footwear.

According to Woodson (1981), accelerator pedal angular travel should be 15 degrees. The desirable brake pedal travel is dependent upon the seat height (Figure 20).

- If the seat is higher than 432 mm (17 in.), the brake pedal moving path should be straight downward and forward (piston type).

- If the seat is about 300 mm (13 in.) high, the brake pedal moving path should be curved, downward and forward.
- If the seat is lower than 152 mm (6 in.), the brake pedal moving path should be curved and forward.

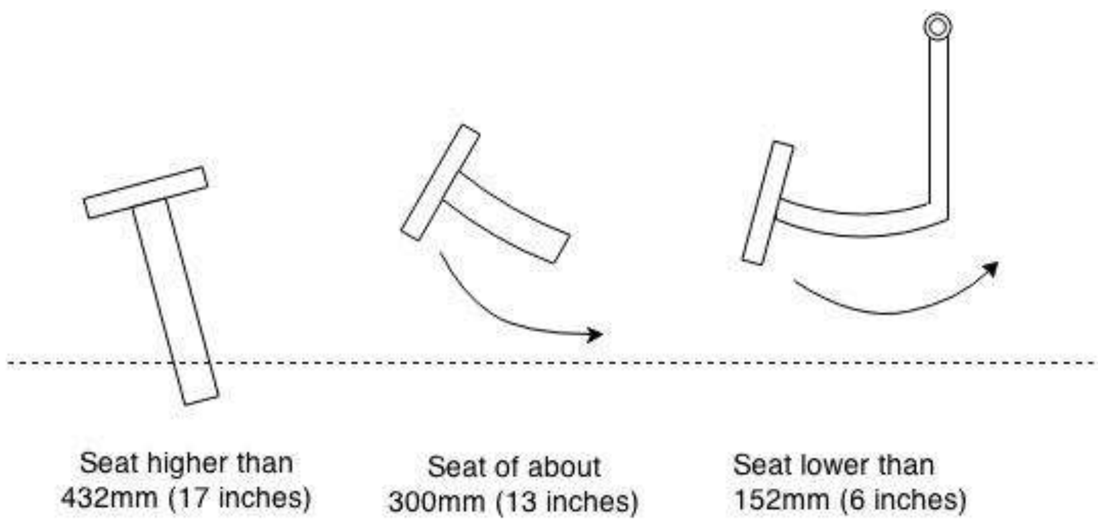


Figure 20. Brake pedal moving path recommendations by Woodson (1981).

According to Brackett et al. (1989), the brake pedal travel should be less than 89mm (3.5 in.), and the accelerator pedal travel should be less than 76mm (3 in.).

The military standards MIL-STD-1472G (U.S. Department of Defense, 2012) specify the pedal travel recommendation for four types of pedals (Table 2). However, the standard does not elaborate on the difference among ‘normal operation’, ‘ankle operated’ and ‘leg operated’.

Table 2. Recommended Pedal Travel by MIL-STD-1472G (U.S. Department of Defense, 2012)

	Normal operation	**Heavy boots**	**Ankle operated**	**Leg operated**
Min	13 mm (0.5 in.)	25 mm (1 in.)	25 mm (1 in.)	25 mm (1 in.)
Max	65 mm (2.5 in.)	65 mm (2.5 in.)	65 mm (2.5 in.)	180 mm (7 in.)

A summary of the design recommendations on brake pedal travel is shown in Figure 21, and the recommendations on accelerator pedal travel are shown in Figure 22.

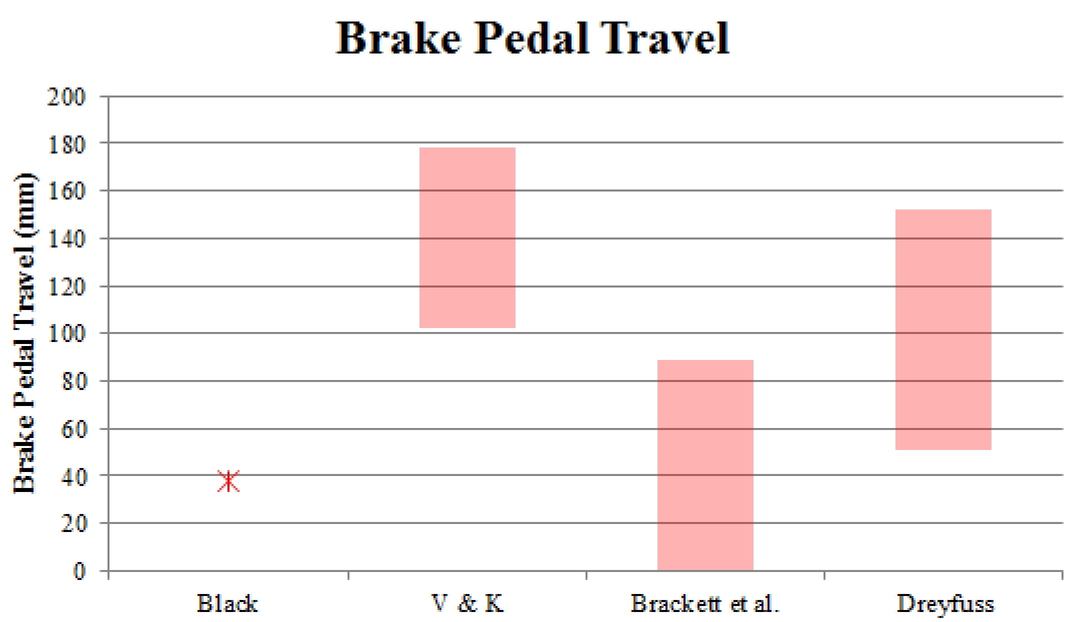


Figure 21. Summary of pedal design recommendations-brake pedal travel. (The asterisk indicates the preferred brake pedal travel.)

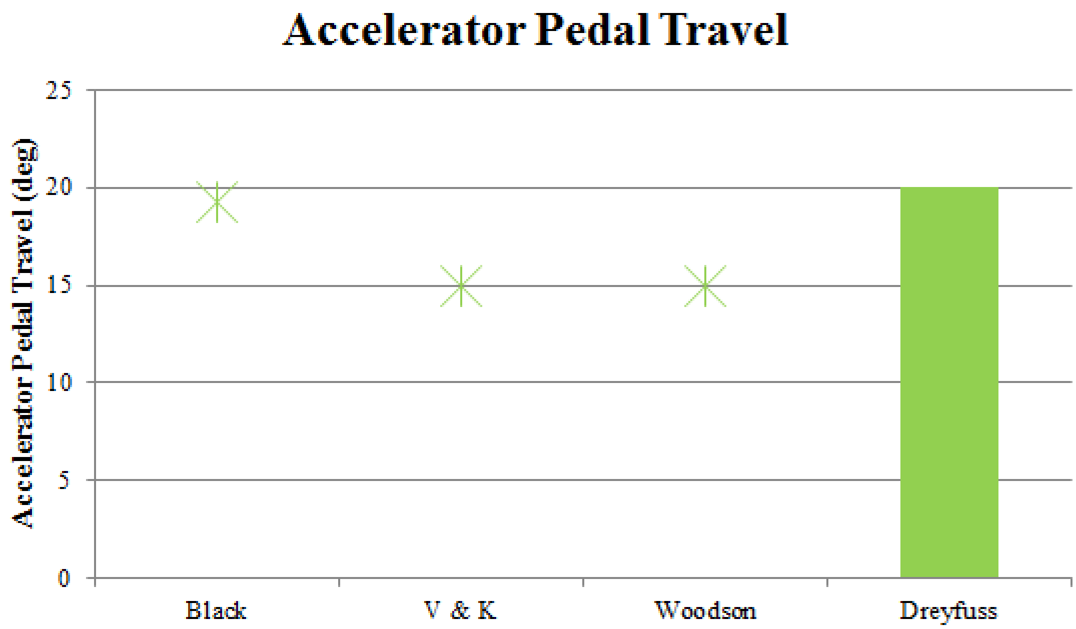


Figure 22. Summary of pedal design recommendations-accelerator pedal travel, (The asterisk indicates the preferred accelerator pedal travel.)

2.3.6 Pedal angle.

The pedal angle (or pedal orientation) refers to the angle formed by the pedal surface and the vehicle floor. The pedal angle determines the foot angle, so it relates to ankle comfort. Black (1966) recommended that the accelerator pedal angle should be 60 degrees from the floor by summing up the angle at each joint (i.e., knee joint, ankle joint, etc.).

Hertzberg and Burke (1971) suggested that an angle of 15 to 35 degrees past vertical should be used for pedals. The foot force was measured from 100 pilots in a cockpit mock-up. The researcher set the pedal at 11 angular positions (from 5 to 55 degrees past vertical at 5 degree increments). Two leg postures (neutral and extended) and three cock-pit sizes (940 mm/37 in., 999 mm/39.3 in. and 533 mm/21 in.) were also used, producing 66 measures for each participant. In addition, the subjective comfort evaluation was obtained from 86 out of the 100 participants. The results showed that the maximum foot force was obtained at 15 to 35 degrees past vertical. This angular range was also associated with higher comfort ratings. Although the study was conducted with pilots using an aircraft setting, the authors concluded that the recommendation apply to other foot controls, such as the automotive pedals.

According to Woodson (1981), the accelerator pedal angles should be (from horizontal): 45 degrees if the seat is 152 mm (6 in.) or lower (such as in a sports car); 35 degrees if the seat height is less than 432 mm (17 in.); or 15 degrees if the seat height is 432 mm (17 in.) or higher. The recommendations were based on driver comfort; if the pedal angle is too steep, the ankle will be fatigued easily when the driver releases the pedal.

In addition, some other design guidelines provide suggested pedal angles. However, no rationale was included by the authors. Van Cott and Kinkade (1972) recommended that the accelerator pedal should be 28 degrees from horizontal when the foot is resting on the pedal. Instead of providing pedal angle recommendations, Dreyfuss (1973) suggested that the maximum travel angle should be 20 degrees. The MIL-STD-1472G (U.S. Department of Defense, 2012) states that the pedal angle should be less than 60 degrees from the floor.

A summary of the design recommendations on pedal angle is shown Figure 23.

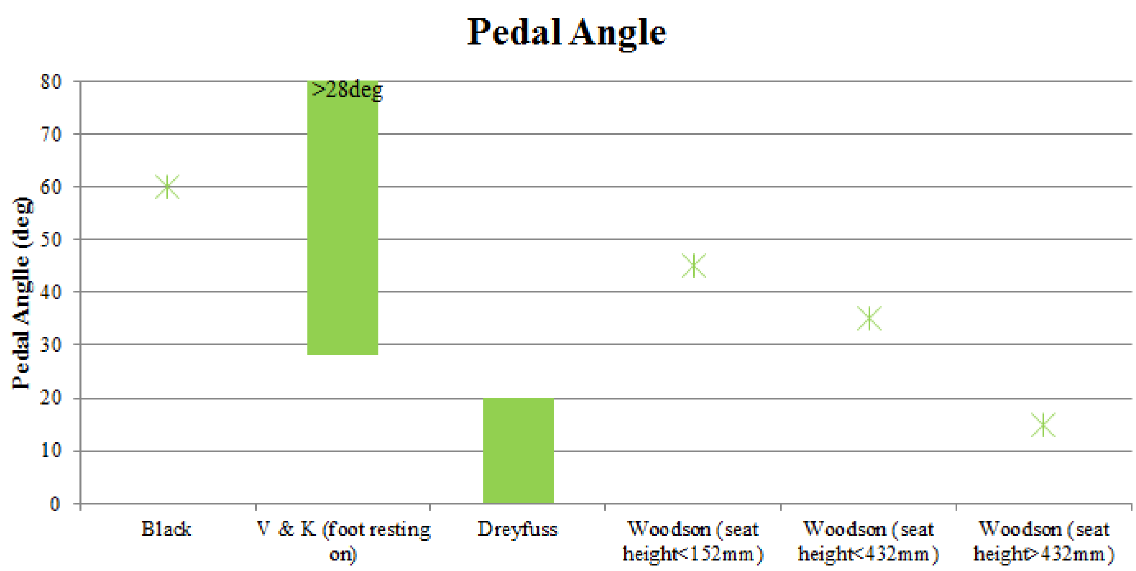


Figure 23. Summary of pedal design recommendations-pedal angle. (The asterisk indicates the preferred pedal angle.)

2.3.7 Pedal resistance.

Pedal resistance (also referred to as pedal force) refers to the resistant force the foot feels when pressing the pedal. It affects pedal operation in several ways. For example, in normal driving conditions, pedal resistance could be used as a cue for drivers to differentiate one pedal from the other and to modulate the force applied on the pedals. Because the desirable pedal resistance is closely related to the maximal foot/leg force the driver can apply, studies that measured force applied on pedals are also included.

Gough and Beard (1936) measured the maximum force that can be applied and maintained on an airplane rudder pedal. They also investigated the influence of pedal locations and the accuracy of estimating applied force. A widely cited experiment by Hugh-Jones (1947) studied the relationship between the maximum force exerted on pedals, and the knee and thigh angle. According to his measurement, the maximum force increases as the knee angle increases to 160 degrees, and then decreases rapidly. The maximum force of 3759 ±157 N (845 ±35.4 lb) can be obtained when the thigh angle is 15 degrees and the knee angle is 160 degrees. Elbel (1949) studied both the leg strength (maximum leg force) and the leg endurance (amount of time the participant can maintain a pre-determined force level with the leg muscle). The author identified low but significant correlation between leg strength and leg endurance. Dupuis (1959) studied the tractor operation characteristics and their effect on human stress. The author stated that given the brake pedal is properly located, the regular operating force applied on the pedal should be less than 343 N (77 lb), and if not in an emergency, the maximum pedal force should not be greater than 391 N (88 lb).

Aoki (1960) measured the braking force on a vehicle mock-up from 60 males, 54 high school girls (16 years of age), and 37 disabled adults of both genders. The author concluded that the pedal resistance should be less than 294 N (66 lb) with an optimum of 196 N (44 lb). If the pedal is operated by the ankle, the resistance should be less than 196 N (44 lb).

According to Black (1966), the accelerator pedal should have a resistance range of 36 to 53 N (8 to 12 lb), and the brake pedal resistance should be less than 267 N (60 lb). The author briefly described the experiments that led to the recommendations. Nineteen participants were instructed to reproduce the forces of different levels using a number of foot controls. The forces that participants thought they were applying on the pedals (the intended forces) were compared with the actual forces they were applying. Results revealed that when the intended force is below 29 N (6 lb), the accurate perception of level of force is lost, and when the intended force is over 89 N (20 lb), the foot fatigue level rises. In addition, the force of 36 N (8 lb), according to the author, was calculated to be the level of force that affords the foot resting on the accelerator pedal. As for the brake pedal, because the power brake was not prevalent at the time when Black's book was written, the recommended resistance for the brake pedal was based on the assumption that the brake was not powered. Force of 267 N (60 lb) enables the car to reach a deceleration of 1g with good disc brakes.

Trombley (1966) studied the effect of pedal resistance on the reaction time to a visual stimulus and the foot travel time to a fixed stop through constant angle and travel distance. He identified that using 36 N (8 lb) of pedal resistance can effectively reduce the reaction time and foot travel time, and can provide support when the foot is resting on the pedal.

Van Cott and Kinkade (1972) had pedal resistance recommendations for pedals for generic purposes. For males who operate the pedals by using a leg (as opposed to the ankle), the resistance should be no more than 890 N (200 lb). This recommendation was based on the works of Hugh-Jones (1947) and Elbel (1949). If a leg-operated pedal is frequently but not continuously used, the pedal resistance should be about 30% of the maximum force that the operator is able to apply. For a leg-operated pedal, where the foot is normally resting, the minimum resistance should be about 45 N (10 lb), giving a safety tolerance to 31 N (7 lb), which is the average foot resting force. For an ankle-operated pedal, the minimum pedal resistance should be 18 N (4 lb) less than that of a leg-operated pedal. The optimal range of resistance is 36 to 267 N (8 to 60 lb) for leg-operated pedals, and 29 to 40 N (6.5 to 9 lb) for ankle-operated pedals. The optimal resistance range for ankle-operated pedals came from Lehmann's paper (Lehmann, 1958). Lehmann summarized the studies done by Dupuis, Preuschen and Schulte (1955) on tractor seats and controls. The optimal resistance was identified to be 29 to 34 N (6.5 to 7.6 lb), using the speed regulation and foot comfort as criteria on the accelerator pedal.

According to Dreyfuss (1973), the accelerator pedal resistance should be 18 to 67 N (4 to 15 lb) with an optimal range of 27 to 40 N (6 to 9 lb), and the brake pedal resistance should be 18 to 267 N (4 to 60 lb) with an optimal range of 18 to 133 N (4 to 30 lb).

Mortimer (1974) pointed out that the maximum pedal resistance should be no greater than the maximum force that can be applied by 5th percentile female. The author suggested using 400 N (90 lb) as the brake pedal resistance and stated that this value would ensure that "no more than 5% of female drivers, and about 1% of male drivers are unable to apply adequate brake pedal force" (Mortimer, 1974, p. 513). Mortimer's study was carried out on an adjustable, wood seat. A total of 599 participants (276 females and 323 males) were given two scenarios by verbal commands: 'standard' motivation to simulate normal braking maneuver and 'induced' motivation to simulate emergency braking maneuver.

Woodson's recommendations were based on seat height (Woodson, 1981).

- If the seat is higher than 432 mm (17 in.), the brake pedal resistance should be less than 89 N (20 lb).
- If the seat is about 330 mm (13 in.), the value should be less than 178 N (40 lb).
- If the seat is lower than 152 mm (6 in.), the value should be less than 623 N (140 lb).

The pedal resistance for accelerator pedal should be less than 44 N (10 lb).

Brackett et al. (1989) stated that the minimum pedal resistance should allow the foot to gently rest on the pedal and suggested using 334 N (75 lb) for the brake pedal and 89 N (20 lb) for the accelerator pedal.

The pedal resistance recommendations in the MIL-STD-1472G (U.S. Department of Defense, 2012) are listed in Table 3 and a summary of the design recommendations on pedal resistance is shown in Figure 24.

Table 3. Recommended Pedal Resistance by MIL-STD-1472G (U.S. Department of Defense, 2012)

	Foot not resting on pedal	**Foot resting on pedal**	**Ankle- operated pedal**	**Leg- operated pedal**
Min	18 N (4 lb)	45 N (10 lb)	n/a	45 N (10 lb)
Max	90 N (20 lb)	90 N (20 lb)	<45 N (10 lb)	800 N (180 lb)

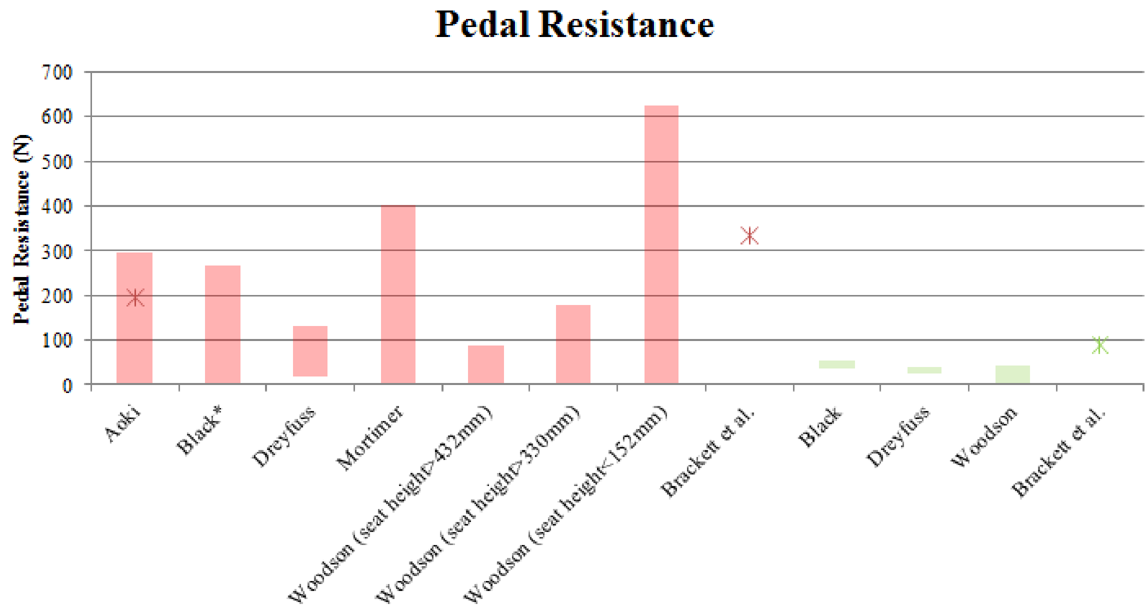


Figure 24. Summary of pedal design recommendations--pedal resistance. (The asterisk indicates the preferred pedal resistance.) Note: Black's recommendation was based on a brake system without power assistance.

2.3.8 Pedal feel.

"Pedal feel" is used to describe drivers' subjective feelings about the pedals. This term has not been defined consistently by researchers. Typically, pedal feel involves the combination of several pedal characteristics such as pedal resistance, pedal travel and acceleration/deceleration.

In 1970, Mortimer and his colleagues tried to identify the pedal characteristics that could affect driver-vehicle performance (U.S. Department of Transportation, 1970). The ratings of brake system controllability were based on deceleration/pedal force gain. The authors identified that a deceleration/pedal force gain range of 0.0027 to 0.0047 g/N (0.012 to 0.021 g/lb) was most preferred. No significant relationship was identified between the rating and the pedal travel.

Ebert and Kaatz from General Motors developed a Brake Feel Index (BFI) in order to predict customers' satisfaction levels regarding the pedal (Ebert & Kaatz, 1994). The calculation of BFI involved seven parameters, including pedal force, pedal travel and response time, and they were given different weights, although the exact calculation process was not revealed. According to their experiments, the satisfaction derived by BFI correlated well with customers' actual ratings.

To study brake pedal feel, Bill, Semsch, and Breuer (1999) conducted on-road experiments with variable pedal/vehicle characteristics and carried out a survey to obtain drivers' evaluations. They identified two factors that can greatly affect brake feel: idle travel and 'jump-in level' (the deceleration at the end of brake idle travel). Bill et al. recommended both an optimal jump-in level of 5.8% (of maximum deceleration) and an optimal idle travel of 29 mm (1.1 in.).

Abbink and Van der Helm (2004) studied pedal force perception with different footwear. The study participants applied a baseline force of 25 N (5.6 lb) on the gas pedal with different footwear (i.e., sock, bowling shoe and sneaker). A sinusoidal force stimulus of different frequencies and amplitudes was applied on the sole. The frequencies were 0.3 Hz, 0.5 Hz and 1 Hz, and the amplitudes ranged from 1 N (0.2 lb) to 14 N (3.1 lb). Three trials of 0 N (0 lb) were mixed in between. For each frequency there were six repetitions, during which the sequence of force amplitudes was randomized. After each presentation of force stimulus, the participants were asked if they felt the force stimulus with responses of 'yes' or 'no'. The researchers identified that increasing force amplitudes and decreasing frequencies facilitate the force perception, regardless of footwear type. They also identified that the participants' force perception capability was best with socks and worst with bowling shoes.

More recently, Lee and Kim studied the relationship between pedal's engineering metrics and customers' satisfaction for both the accelerator pedal and brake pedal (Lee & Kim, 2010, 2012). For the brake pedal, they proposed ideal relationships between hydraulic line pressure and response time, between deceleration and pedal force, and between deceleration and pedal travel. For the accelerator pedal, they concluded that vehicles with 0.6g launch acceleration at 20 mm (0.8 in.) pedal travel and less than 0.1g acceleration at 5 mm (0.2 in.) pedal travel show the highest customer satisfaction.

A number of other studies have also examined pedal feel. Zehnder, Kanetkar, and Osterday (1999) proposed two pedal-feel emulator designs to simulate a known pedal force/travel curve. Basch, Sanders, Hartsock, and Evans (2002) identified that the pedal's lining properties have little impact on pedal feel. De Arruda Pereira (2003) benchmarked four competitor vehicles of the Ford Fiesta to come up with the desired relationship between pedal force and pedal travel. Dairou, Priez, Sieffermann, and Danzart (2003) identified important parameters that contribute to the pedal feel and enabled prediction of pedal feel using these technical parameters. Therefore, they were able to predict the pedal feel, given the pedal technical parameters, and provide the pedal design specifications, given the expected pedal feel. Day and colleagues also developed a model to predict brake pedal feel at the design stage (Day, Ho, Hussain, & Johnstone, 2009).

Pedals are an important component of Human Vehicle Interface (HVI). Although there have been safety concerns about pedals, the existing design guidelines, standards and research studies reviewed above provide few pedal design specifications from the perspective of improving comfort and safety of older drivers who are overrepresented in pedal misapplication errors.

2.4 Aging Driver Population

Over the past 40 years, the U.S. population, licensed drivers and registered vehicles have increased steadily (Figure 25). From 1961 to 2011, the numbers of drivers and registered vehicles have increased by 244% and 331%, respectively.

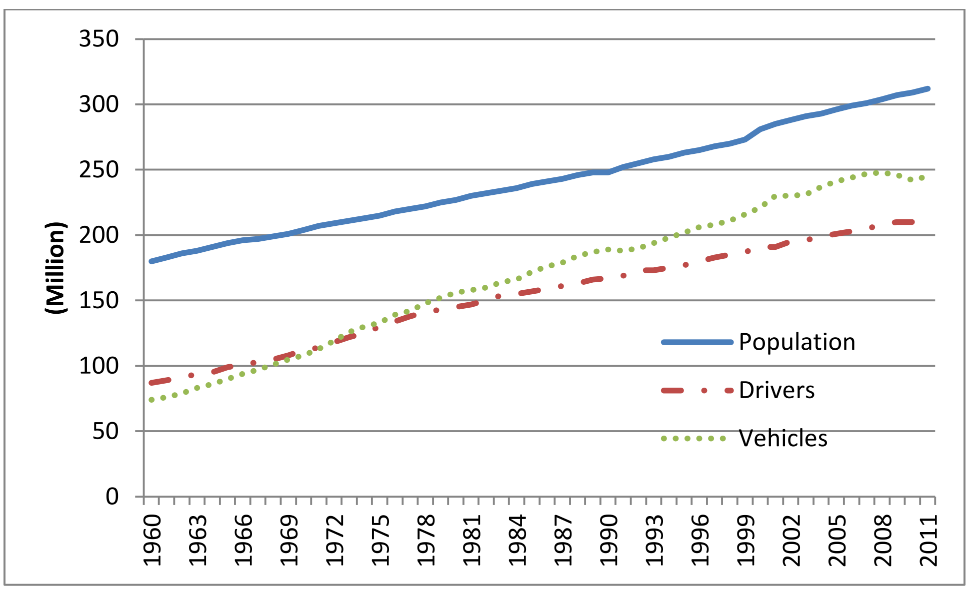


Figure 25. U.S. licensed drivers, registered vehicles, and resident population from 1961 to 2011(Federal Highway Administration, 2010).

The trend of motorization has been accompanied by a growth of the older population (Figure 26). The percentage of the older population (65 years old or above) was 9% in 1960 and was 13% in 2010 (U.S. Census Bureau, 2011). As a result of the increasing older population, from 2002 to 2011 the number of licensed older drivers (age > 65) has increased from 19.9 million to 35 million, and the percentage of older drivers among all licensed drivers increased from 10% to 16% (Figure 27) (National Highway Traffic Safety Administration, 2014).

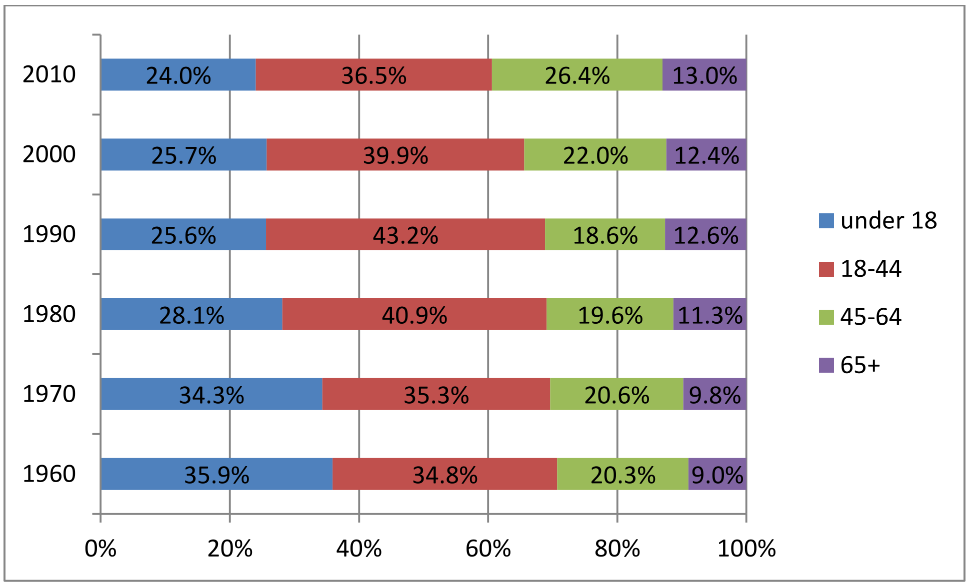


Figure 26. U.S. population structure from 1960 to 2010 (U.S. Census Bureau, 2011).

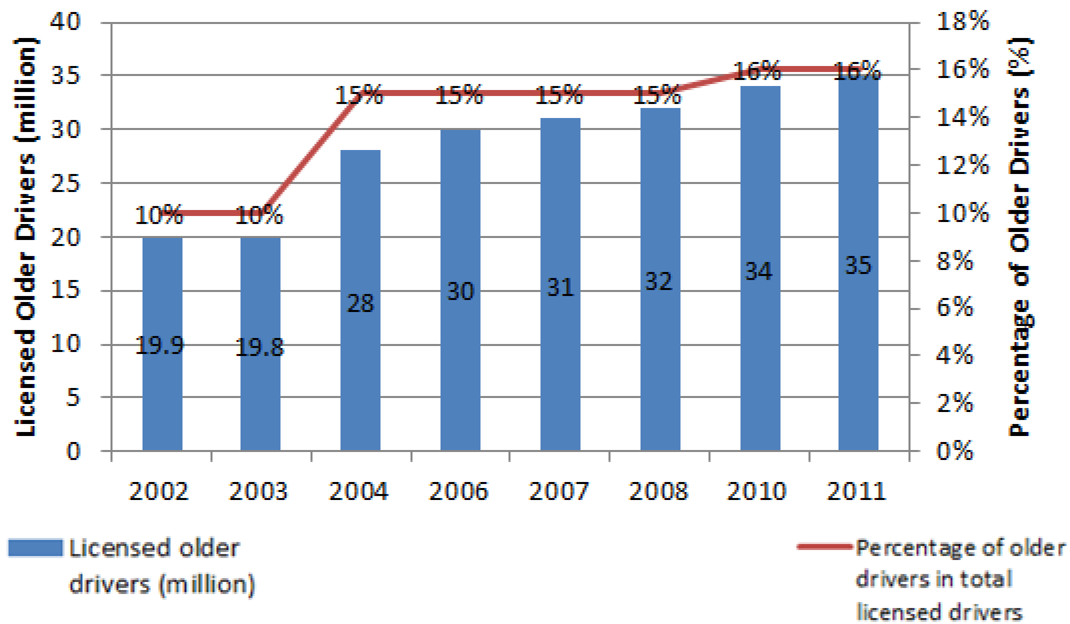


Figure 27. Number of licensed older drivers and percentage of older drivers in all driving population from 2002 to 2011 (NHTSA, 2014). Data of 2009 are missing.

The number of older drivers will continue to increase as the baby boomers reach the age of 65. Figure 28 shows the number of licensed drivers grouped by age from 1996 to 2011 (in five year intervals).

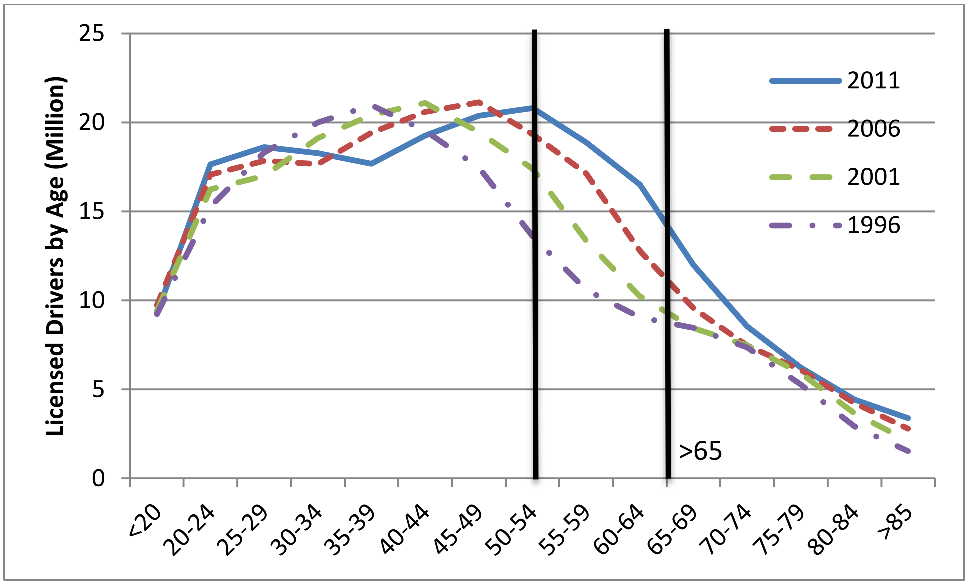


Figure 28. Number of licensed drivers grouped by age (Federal Highway Administration, 2012).

In 2011, the age group of 50 to 54 has the largest number of licensed drivers. Therefore, in the 2020's the peak of the curve will reach 65 years old. By estimation, the number of drivers over age 65 will be about 40 million in 2020 (Dellinger et al., 2002).

2.5 Travel Patterns of Older Drivers

Older drivers in the US exhibit some travel-related characteristics that are different from that of their younger counterparts. The American Association of Retired Persons (AARP) published a report on changes of older drivers' travel patterns (Lynott & Figueiredo, 2011). The report reveals the following characteristics of older drivers' travel: (a) from 2001 to 2009, older drivers' (drivers over 65 years old) share of trips and miles (among drivers of all ages) has grown by 11% and 7%, respectively; (b) older females travel significantly less than older males, but the gap between genders is shrinking; and (c) many older drivers would prefer to get out more often.

Collia, Sharp and Giesbrecht (2003) studied basic travel patterns of older American drivers and compared the patterns with those of younger drivers in the US. The following patterns are worth noting: (a) older drivers rely mostly on personal vehicles; (b) for short daily trips, older females travel less than older males, and for long distance trips, females and males travel at about the same rate; and (c) medical conditions reduce older drivers' travels.

Benekohal, Michaels, Shim and Resende (1994) conducted a survey to study the aging effect on older drivers' travel patterns. They identified that (a) 70% of older drivers drive at least five days a week, and the majority of the travel occurs in a town or a city; (b) as people age, they reduce highway driving and increase urban driving; and (c) older drivers tend to drive in non-peak hours. A study by Langford and Koppel (2006) also summarized older drivers' driving patterns. Older drivers

- reduce their exposure by driving fewer annual kilometers;
- make shorter trips and fewer trips (by linking different trips together);
- limit peak hour and night driving and restrict their long distance travel;
- take frequent breaks; and
- drive on familiar and well lit roads.

2.6 Crash Involvement and Fatalities of Older Drivers

A primary concern about the increasing number of older drivers is traffic safety. Figure 29 shows the number of drivers in reported crashes and driver fatalities grouped by age in 2009. Drivers between the ages of 65 and 74, and those drivers over the age of 74 accounted for 7.3% and 7.9% of all fatalities, respectively. As shown in Figure 28, the numbers of drivers in these two age groups (65 to 74 and over 74) were less than the number of drivers from ages 25 to 50, which means there were fewer older drivers on the road than younger drivers. Therefore, the risk older drivers are facing, reflected in Figure 29, is an underestimation. The number of drivers in crashes and fatalities was normalized by the number of licensed drivers in each age group (Figure 30). Although older drivers were still the least likely to be involved in a crash, their fatality rate was higher than middle-aged drivers, which means once the older drivers were involved in crashes, they were at a higher level of risk. This is due to the fragility of older drivers (Li, Braver, & Chen, 2003).

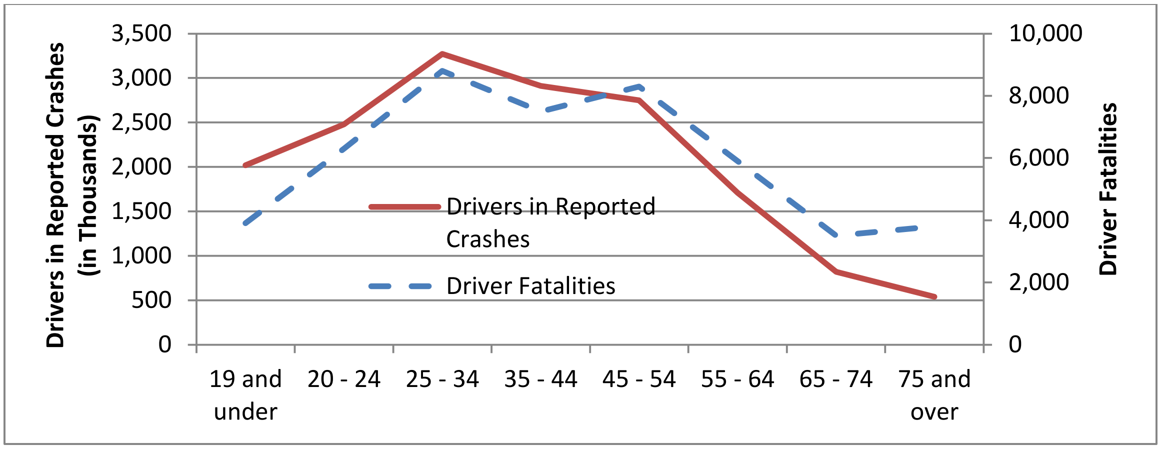


Figure 29. Drivers in reported crashes and driver fatalities by age in 2009 (U.S. Census Bureau, 2012).

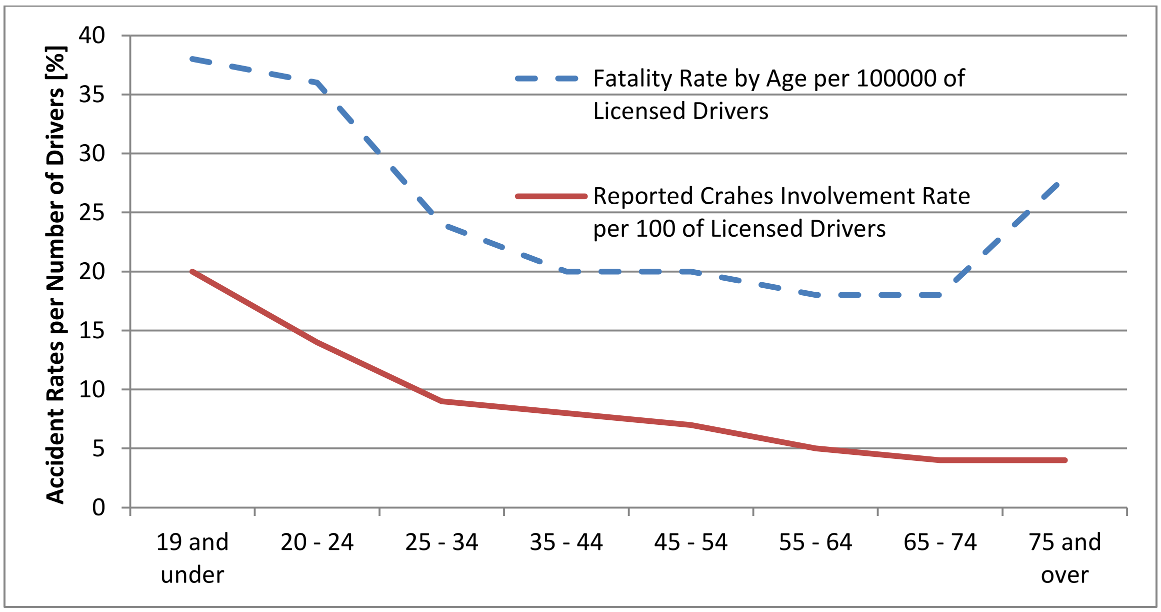


Figure 30. Accident rate per number of licensed drivers by age in 2009 (U.S. Census Bureau, 2012).

Another factor, as previously discussed, is that older drivers generally travel less than their younger counterparts. Figure 31 shows the total miles of travel grouped by age. The number of drivers over 65 was significantly less than that of any other age groups. Figure 32 shows the crash involvements and fatalities normalized by miles travelled in each driver age group. The older driver fatalities per 100 million miles traveled outnumbered that of other age groups.

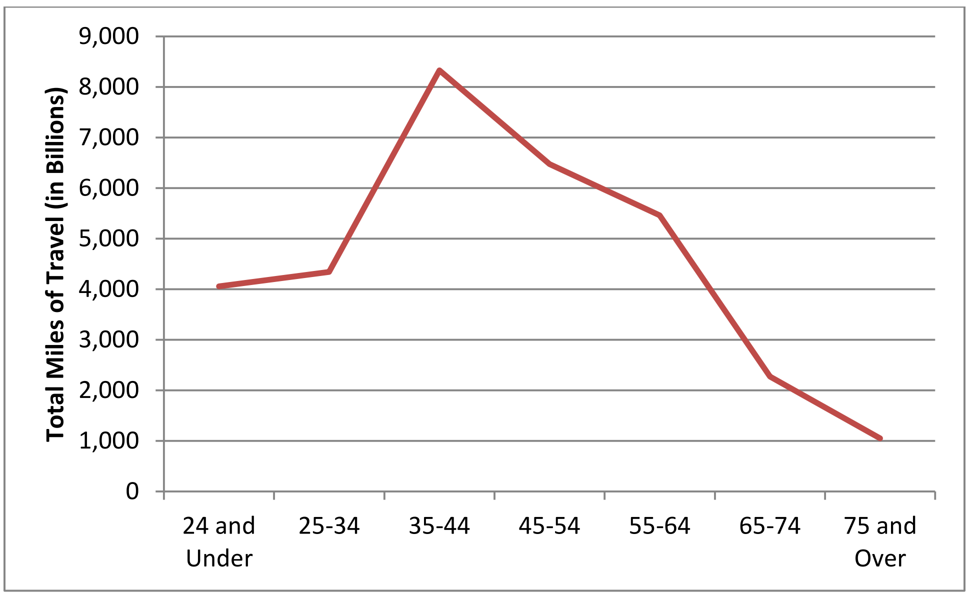


Figure 31. Total miles of travel by age in 2009 (Federal Highway Administration, 2009)

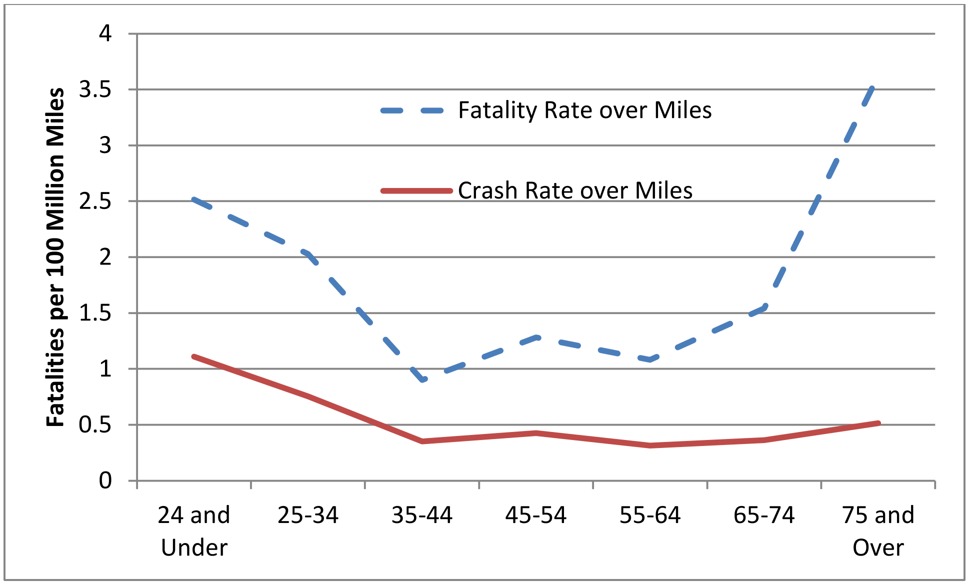


Figure 32. Fatalities and crash involvements per 100 million miles by age in 2009 (Federal Highway Administration, 2009).

2.7 Factors Associated with Crashes Involving Older Drivers

Numerous studies have identified factors associated with older driver crashes. Bayam, Liebowitz and Agresti (2005) conducted a meta-analysis on the existing literature related to older drivers and crashes in which older drivers were involved. The reviewed studies were organized by variables including driver, vehicle, occupants and other road users, environmental conditions and geographical situations, roadway and accidents. Their key findings are summarized in Table 4.

Table 4. Literature Review of Older Drivers and Crashes (Bayam et al., 2005)

Driver	The older drivers have more crashes per mile travelled than younger drivers. Age may or may not be a risk factor depending on different samples, but it is a predictor of injury and fatality. Gender difference exists in the likelihood of being involved in (fatal) crashes, being at-fault and the crash type. Older females are overrepresented in crashes in the safest conditions. Driving rates (percent of driving population) vary more between genders in older adults than in younger adults. Alcohol use is not a significant risk factor for older drivers. Fragility is the dominant factor for the higher fatality rate among older drivers. The higher crash rate among older drivers is associated with medical conditions and declining abilities that are related to driving. The medical conditions and abilities discussed are visual acuity and cognitive functions.

	Failure to read and interpret the signs quickly enough is a major cause of crash among older drivers.
Vehicles	The majority of crashes involving senior drivers occur at speeds of 63 to 95 km/h (39 to 59 mph). The benefit of using seatbelts varies with age and as age goes up, the benefit decreases. Compared to younger drivers, senior drivers are more likely to drive passenger cars.
Occupants and other road users	Older drivers pose more risk to themselves and their older passengers than other road users. Other road users also pose risks to older drivers.
Environmental conditions and	Older drivers mostly drive in safe environmental conditions (e.g., good weather and daytime).

geographical situations	
Roadway	Intersection- related crashes are common among older drivers. Older drivers, especially females, are more likely to be involved in crashes while turning left. Older drivers have difficulties entering the highway.
Crashes	Older drivers are overrepresented in side impact crashes.

Some driver characteristics and risk factors of older drivers in Australia identified by Langford and Koppel (2006) include: less likely to drive drunk; less likely to drive on a high-speed road; more likely to use a seatbelt, more likely to drive older vehicles and to drive in daylight hours; more likely to have difficulties at intersections, especially those without traffic lights; and more likely to have difficulties interacting with other vehicles.

By combining police crash records and hospitalization data in Australia, and using injury severity rating as a dependent variable, Boufous, Finch, Hayen and Williamson (2008) identified that single vehicle crashes with impact of an object would more likely cause severe injury to older drivers. They also identified intersection configuration, rurality, speed limit and driver error were good predictors of older driver crashes.

Roge et al. (2004) conducted a simulator study where drivers following a vehicle needed to identify the color of a signal in the central area of their visual field and a signal at different eccentricities of the front vehicle tail light. Nine young drivers (between 22 and 34 years old) and nine older drivers (between 46 and 59 years old) participated. The authors identified that the useful visual field would decrease with drivers' age. Stutts, Stewart and Martell (1998) stated that cognitive functions that are important to driving are compromised by Alzheimer's disease and other dementing illnesses that affect older adults. These cognitive functions include memory, attention, scanning and other skills such as information processing, rapid decision making and problem solving. Bayam et al. (2005) pointed out that older drivers' physical limitations, such as head and upper body range of motion, made it difficult to look around for traffic and that these physical limitations were associated with older drivers' crashes during lane changes and left turns.

Li et al. (2003) studied older drivers' fragility using national data systems. The authors calculated the deaths per driver (an indicator of fragility) in a crash and drivers involved in crashes per vehicle-mile of travel (VMT, an indicator of excessive crash involvement). It was identified that the fragility started to increase steadily at ages 60 to 64, accounting for 60% to 95% of the excess death rates per VMT. The authors also suggested that although both fragility and over-involvement of older drivers in crashes account for excess death rates, the fragility is more important. Zhang, Lindsay, Clarke, Robbins and Mao (2000) reported positive correlation between the risk of fatality or injury and the following conditions among older drivers: epilepsy, dementia, diabetes mellitus, heart disease and hypertension, back pain and poor memory, vision disorders and hearing loss.

2.8 Pedal Misapplication as a Risk Factor

The prevalence of crashes due to pedal application errors (PAEs), also referred to as pedal error or pedal misapplication, where drivers depress the accelerator pedal when they intend to depress the brake pedal, has received public attention. Although the literature reviewed above does not list PAE explicitly as a cause of crash for older drivers, the analysis of PAE crashes reveals that increasing age is a predictor of such events (U.S. Department of Transportation, 2012). Two statistics were reported in the frequency distributions of PAE crashes by driver age: the percent of PAE crashes by five-year age groups, and the percent of licensed drivers in the U.S. population for each age group. The ratio of the two percentages was used to indicate the degree to which each age group is involved in PAE crashes vs. the degree to which each age group is represented in the driving population (U.S. Department of Transportation, 2012). Both the news media and the North Carolina (NC) crash database indicate higher crash involvement at both ends of the distribution, which means that both the younger and the older driver are overrepresented in PAE crashes (U.S. Department of Transportation, 2012). PAE crashes investigated in the study cited above may be only a portion of what actually occurred. The reasons for underestimation of the PAE problem may be the following: (a) many PAEs did not result in a reportable accident and thus were not registered in the database; (b) not all drivers admitted to the authorities that they pressed the unintended pedal; and (c) those crashes that were registered as caused by ‘brake failures’ may actually have been caused by PAE because the drivers may not have been aware of having pressed the wrong pedal (Schmidt, 1989).

2.8.1 Characteristics of PAE crashes.

In order to identify the contributing factors of PAE, the characteristics of crashes, such as the environment when they occur, need to be understood. The U.S. Department of Transportation (2012) presented a thorough literature review of the PAE. The statistics of the PAE came from the NC crash database (2004 to 2008), National Motor Vehicle Crash Causation Survey (NMVCCS, 2005 to 2007) and news media reports (2002 to 2012). The findings relevant to this work are summarized as follows.

Gender.

Analyzing the NC crash database, The U.S. Department of Transportation (2012) identified that females are over represented in PAE crashes. According to the authors, females accounted for 63% of 2,400 PAE crashes, whereas they only accounted for 44% of all types of crashes based on a statewide crash database during 2004 to 2008. Both the NMVCCS and the news media analyses also identified that females are more likely to be involved in the pedal misapplication crashes.

Height.

Height and gender are related to each other. The NC crash database indicates that shorter drivers are more prone to pedal misapplication crashes. The other two resources did not provide sufficient information to make this conclusion.

***Crash location*.**

In the NC crash database, 57% of the pedal misapplication crashes occurred in parking lots, and 42% of them occurred on roadways. Parking lots were more likely the crash locations for older drivers. The NMVCCS only has records of on-road crashes. Sixty percent of them were at non-intersection locations, and 11% were at intersection-related locations. The news media analyses revealed that 77% of the crashes occurred where drivers were most likely carrying out parking maneuvers (U.S. Department of Transportation, 2012).

***Pre-Crash maneuver*.**

In the NC crash database, 39% percent of pedal misapplication crashes occurred when drivers were travelling straight ahead, and another 39% occurred when drivers were performing parking maneuvers. Eleven percent occurred while carrying out turning maneuvers, and 5% occurred while slowing or stopping. For drivers over 76 years old, pedal misapplication crashes occurred more while parking than any other maneuvers. According to the NMVCCS which excluded parking lot crashes, 55% of crashes occurred while going straight, 11% while negotiating curves and 7% while changing lanes. In the news media analyses, the largest proportion (61%) of the crashes occurred during parking maneuvers, and entering a parking lot has the highest rate of crashes for older drivers. (U.S. Department of Transportation, 2012).

Startle response.

Among all pedal misapplication crashes identified in the NC crash database, 19% were associated with startle response or panic. The top contributing startle types are "panic stop to avoid a collision" and "startle following loss of control of the vehicle" (U.S. Department of Transportation, 2012, p. 43). Twenty percent of the crashes in media reports and 58% of the NMVCCS reported crashes were associated with startle or panic (U.S. Department of Transportation, 2012).

Driver in-attention and distraction.

According to the NC crash database, inattention was the most frequent driver contributing factor, accounting for 44% of the pedal misapplication crashes where the driver contributing factor was coded. Driver distraction accounted for another 4% of the pedal misapplication crashes. The types of distractions were examined further. Among 2,411 pedal misapplication crashes, 166 crashes had descriptions of distractions. The most frequent distractions types were driver looking away (42), driver reaching for an object (30), and passengers arguing or yelling at the driver (19). Driver distraction was identified in 39% of the NMVCCS pedal misapplication crashes and 12% of the news media reported crashes (U.S. Department of Transportation, 2012).

Driver out-of-position.

The definitions of driver out-of-position and of driver inattention/ distraction have overlaps. Out-of-position instances include

- reaching for something,
- looking left or right,
- re-entering the vehicle, and
- sitting out of position.

Out of 2,411 pedal misapplication crashes in the NC crash database, 73 were coded as "out-of-position". The most frequent types of actions by drivers out-of-position included the following: reaching across the vehicle, or into the back seat, or down into the floorboard area (29); re-entering the vehicle to stop it from rolling (21); looking left or right (10); and looking left and reaching (5). In NMVCCS, 10% of pedal misapplication crashes were associated with being out-of-position. In news media analyses, 12 crashes were related to the driver looking or reaching to the side or rear of the vehicle, and five were related to the driver re-entering the vehicle to stop it from rolling (U.S. Department of Transportation, 2012).

Footwear.

Although the type of footwear was not recorded in the NC crash database, it was revealed in the one-on-one telephone conversations with the drivers involved in pedal misapplication crashes identified from the NC crash database. Ten drivers participated in this case study (two males and eight females ranging from ages 29 to 85). Three females reported wearing clogs, and one reported wearing low-heeled pumps. Other footwear included leather walking shoes, athletic shoes/sneakers and skateboard shoes. One driver could not recall the footwear at the time of the crash.

2.8.2 Studies of the PAE causes.

Rogers and Wierwille (1988) studied the relationship between different types of PAEs and pedal configurations at different vehicle speeds using a driving simulator. The study was conducted using four pedal configurations (to represent a sport sedan, a full-size sedan and those pedal configurations that have smaller pedal vertical separation) at two speeds (to represent highway and suburban driving conditions). The foot movement tasks consisted of the foot moving (a) from the accelerator pedal to the brake pedal, (b) from the brake pedal to the accelerator pedal, (c) from the floor to the brake pedal, and (d) from the floor to the accelerator pedal. The PAE was categorized into four groups by severity: serious (driver mistakes one pedal for the other or depresses both pedals), catch (pedal interferes with foot movements), scuff (similar to catch but the interference is minimal) and instructional errors (failure to perform instructed tasks). The authors identified that the frequency of PAEs and the different pedal configurations' effect on PAEs were associated with the severity of PAEs and vehicle velocity.

Schmidt (1989) investigated the contributing factors of PAEs. Three major questions were answered:

- How did PAEs occur?
- Why did drivers fail to notice the misapplications?
- Why did drivers persist in depressing the accelerator pedal for so long?

The answers to the two of the questions (i.e., how PAE occurred and why drivers persisted depressing the accelerator pedal for so long) are highly relevant and, thus, summarized individually as follows. According to Schmidt, the PAE occurs due to either incorrect pedal choice or incorrect pedal application execution that comes from foot aiming variability or foot aiming bias. "Variability refers to dispersion around the mean movement direction, usually expressed as a variable error, or the within-subjects (over trials) standard deviation of the performer's responses about his or her own mean" (Schmidt, 1989, p.350). The bias refers to the "constant error" or the deviation from the intended position. Causes of foot aiming variability include movement amplitude and movement time, and the causes of foot aiming bias include head and body position, as well as head and gaze direction. When discussing the effect of head and body position on the foot aiming, Schmidt explained that because the head and the foot are physically connected, the head turning-- to look over the shoulder when most drivers reverse the vehicle-- will cause the foot aiming position biased to the right. Schmidt cited two studies to explain the effect of head and gaze direction on limb aiming. Both experiments were conducted using either arm (blind positioning to a target) or fingers (rotating a knob) while rotating head or gaze direction. The results showed that the bias of limb positioning was mainly caused by change of head direction rather than gaze direction, and the biased limb positioning was to the opposite direction of the head (i.e., when the head turned left, the limb positioning was biased to the right). Schmidt related the results identified in the two studies with the PAEs and concluded that when the head was turned to the left to look at the left rearview mirror, the foot position might be biased to the right, and the foot could press the accelerator pedal instead of the brake pedal.

Three explanations were given to account for the fact that some drivers failed to correct the pedal misapplication and instead, persisted in applying the accelerator pedal for an extended amount of time.

Hypervigilance (commonly known as panic), according to Schmidt, is "the most effective way to understand this persistence" (Schmidt, 1989, p. 361). Schmidt cited the three causes of the hypervigilant state and associated them with the PAE: (1) A strong stimulus is present. In a PAE crash, the stimulus is the sudden acceleration and loud engine sound. (2) The stimulus is perceived as life threatening. The drivers involved in PAE crashes are extremely fearful that the passengers and themselves will be injured or killed. (3) There is the fear that if a solution is not identified, severe consequences will occur shortly, which is exactly the type of fear experienced by the involved drivers. A related explanation (explanation number two) is "perceptual narrowing" (Schmidt, 1989, p. 362). It is stated that under the condition of panic caused by unintended acceleration, the information-processing ability decreases, and some effective solutions are not taken because the stress narrows the driver's focus. The third explanation is "habitual responses under stress" (Schmidt, 1989, p. 362), made habitual through well-practiced responses through daily driving (hard braking). The author stated that habitual responses work well in usual cases. However, in stressful cases like unintended acceleration, the driver's habitual response of braking hard leads to mistaken application of the accelerator pedal (Schmidt, 1989).

Vernoy and Tomerlin (1989) hypothesized that PAEs occur because drivers misperceive the vehicle centerline. They had participants sit in stationary, experimental vehicles and respond to a series of verbal or visual commands by depressing either the brake or the accelerator pedal. The perceived centerline of the vehicle was measured from both outside and inside of the vehicle. A horizontal line of LED lights was placed in front of the vehicle, and the participants were asked to select the light representative of the vehicle centerline. At the end of the session, the participants sat as if they were driving and placed an adhesive dot on the dashboard to indicate the point that they perceived as the center of the vehicle. Vernoy and Tomerlin correlated the pedal errors and the perceived vehicle centerlines but failed to identify any significant relationship between them. In addition, the authors studied the foot placement on the brake pedal. The participants were instructed to place the foot flat on the vehicle floor before each pedal application. The instructions to press the pedals were given using slides. The foot placement was measured during the practice trial, and the startle braking (braking maneuver carried out after being startled) was measured by coding potential foot placement using numbers from 0 to 6 (Figure 33).

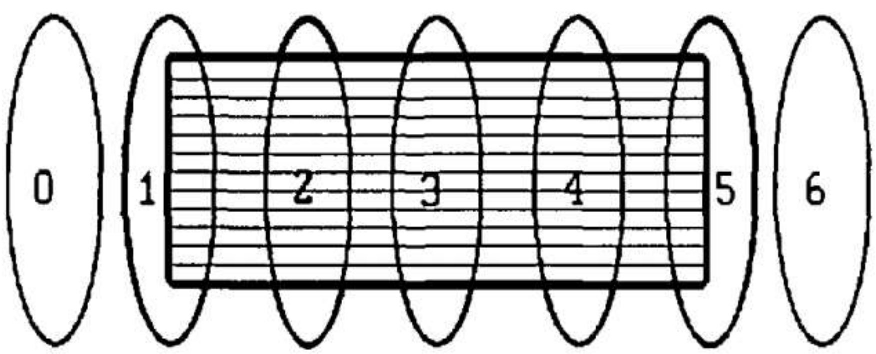


Figure 33. Foot placement coding by Vernoy and Tomerlin (1989)

In the practice trial, the average foot placement was to the right of the pedal centerline in all eight experimental vehicles. An analysis of variance (ANOVA) revealed that the foot placements in all vehicles were significantly different from each other. The foot placement during startle braking was only coded as 0 if the participant pressed and stayed on the brake pedal; was coded as 1, if the participant missed the brake pedal; or was coded as 2, if the participant pressed only on the accelerator pedal. Of the 26 errors identified in 258 trials, 12 were number 1 error, and 14 were number 2 error. No significant difference was identified between vehicles as to the pedal error frequency.

Roush, Pezoldt and Brackett (1992) examined the driver operation characteristics which may increase the likelihood of PAEs. The driver operations they studied included right foot location when shifting gears, simultaneous use of both pedals, drivers' postures when reversing, and foot movement strategy (lifting or pivoting). Twenty-six males and 26 females from ages 15 to 81 participated in the first experiment. Three vehicles were used: the participant's personal car, a 1984 Dodge Diplomat and a 1986 Audi 5000. An inactive, closed road with cones was used to simulate urban driving. In the second experiment, 120 males and 96 females were observed. The authors identified that a significant number of drivers did not place or hover their foot on the brake pedal when they shifted from park to reverse gear, and a small portion of drivers used both feet to operate pedals. In 27.6% of reversing maneuvers, drivers looked over the right shoulder to check traffic. About 39% of the participants looked over the left shoulder, and 31% looked over both shoulders. Only 2.6% used mirrors exclusively. The observation of the foot movement strategy (foot lifting or foot pivoting) was not successful. In a large number of brake applications, the researchers could not see clearly the foot movement to make a distinction between these two foot movement strategies. In cases where the observation was possible, substantial amounts of both foot lifting and foot pivoting were recorded.

Crandall et al. (1996) studied the effect of driver anthropometry, footwear, and the foot-pedal interaction on foot and ankle injury. Thirty young drivers (15 males and 15 females, ranging from 19 to 27 years old) participated in a simulator study. Driver's foot movement was recorded and digitized. The braking behavior in both emergency and non-emergency braking situations was analyzed as a function of foot length and stature. The foot behavior was characterized by pivoting (heel anchored on the floor while moving the forefoot between the two pedals), lifting (entire foot lifted while moving the foot between the two pedals) or both. It was shown that in emergency braking scenarios, drivers with feet longer than 24 cm (9.4 in.) were more likely to pivot, and those with shorter feet were more likely to lift. In non-emergency braking scenarios, drivers with feet longer than 26 cm (10.2 in.) were more likely to pivot, and those with shorter feet were more likely to lift. The stature of the driver did not significantly affect driver's foot behavior. Drivers of different statures were more likely to pivot the foot in emergency braking scenarios, and they were more likely to lift the foot in non-emergency braking scenarios. Using six of the participants, the researchers concluded that whether drivers adopt foot pivoting or foot lifting, when transferring the foot from pedal to pedal, depended more on the stature rather than the gender. They also identified that the foot moving distance of tall-statured drivers was far less than that of short-statured drivers; however, the ankle plantar flexion angles of short-statured drivers were more than that of tall-statured drivers.

A study conducted by Cantin et al. (2004) compared the foot movement characteristics of 25 older drivers (aged from 61 to 79) and 15 younger drivers (aged from 21 to 42) during pedal application at intersections. In the simulator study, participant's ankle movements were captured by tracking the reflective marker in the video recordings. The authors identified that older drivers exhibited more variable foot movement. Specifically, when moving the right foot from the accelerator pedal to the brake pedal, older drivers had more hesitations and smaller movements (beyond jitter) than younger drivers. Unfortunately, the authors could not associate the results directly with PAE.

Trachtman, Schmidt and Young (2005) investigated the pedal configuration's role in PAEs . Also using the NC crash database, they identified vehicles that were involved in unintended accelerations and PAEs, as well as peer vehicles (vehicles with similar size, cost, etc. but from different manufacturers) that were not involved. Three pedal configuration dimensions that were thought critical in PAEs (lateral distance from steering wheel centerline to the right edge of brake pedal, lateral and perpendicular separation between the accelerator and the brake pedal) were measured in the accident-involved and non-involved peer vehicles. The authors failed to find significant relationships between these dimensions and PAEs.

Freier, Seeley, Marklin and Saginus (2010) investigated the PAEs that were suspected to be caused by the insufficient gap between pedals and adjacent footwell structures (e.g., transmission tunnel and left foot wall) of fleet vehicles (e.g., pickup trucks, commercial vans, service vehicles, etc.) in electric utility industry. The researchers measured the relevant vehicle dimensions of 35 vehicles and dimensions of work boots. Then the calculated gap between the accelerator pedal and the brake pedal (the work boot's width plus 50.8 mm) was compared with the measured gap of the utility vehicles. The measured gap was identified to be inadequate in many vehicles, even when the boot was centered on the accelerator pedal, not to mention if the boot was shifted leftward. The utility workers reported that they often rested the heel in between the brake and accelerator pedal, which posed the risk of the boot toe sticking underneath the brake pedal.

CHAPTER THREE

GAPS, RESEARCH QUESTIONS AND HYPOTHESES

3.1 Introduction

Past studies have identified factors associated with older drivers and crashes in which they are involved. More specifically, analyses of pedal application error (PAE) crashes reveal that increasing age is a risk factor associated with such events (U.S. Department of Transportation, 2012). This chapter provides the research gaps identified during an extensive review of existing literature and poses research questions and hypotheses that address the absent research.

3.2 Gap One: Lack of Studies on Older Drivers' Pedal Operation Characteristics in Baseline Stopping Tasks

As detailed in Chapter Two, the study by U.S. Department of Transportation (2012) identified various driving tasks with higher risk of pedal misapplication crashes, such as parking and emergency braking. In order to understand the reasons why these driving tasks are overrepresented, older drivers' pedal usage under normal driving conditions needs to be understood first. This was accomplished by establishing a baseline of older drivers' pedal usage characteristics during 10 stopping tasks while approaching 10 stop signs located along a pre-determined, neighborhood driving route.

Research question 1.

Is the foot movement strategy (pivoting vs. lifting) dependent upon drivers' stature? Do drivers with short stature more likely use a foot lifting strategy and taller drivers more likely use a foot pivoting strategy when moving the foot from the accelerator pedal to the brake pedal?

Hypothesis 1.

This study hypothesized that when moving the foot from the accelerator pedal to the brake pedal in baseline stop sign tasks, there is a significant positive correlation between the percentage of pivoting (the number of pivots divided by 10) and the stature, which means the greater the stature, the more pivots there are in the 10 baseline stopping tasks for each participant. This is because drivers' stature, regardless of gender, may affect their sitting position in the vehicle, which determines the foot movement method. It was hypothesized that the correlation between drivers' stature and the percentage of pivoting would be large ($r > 0.5$).

Research question 2.

Is the foot movement strategy (pivoting vs. lifting) of drivers dependent upon the drivers' shoe lengths? Do drivers with short shoe length more likely use a foot lifting strategy, and drivers with long shoe length more likely use a foot pivoting strategy when moving the foot from the accelerator pedal to the brake pedal?

Hypothesis 2.

This study hypothesized that when moving the foot from the accelerator pedal to the brake pedal in baseline stop sign tasks, there would be a significant positive correlation between the percentage of pivoting (the number of pivots divided by 10) and the shoe length, which means the greater the shoe length, the more pivots there would be in the 10 baseline stopping tasks for each participant. This is because drivers' shoe length, regardless of gender, may affect their foot- anchoring position on the vehicle floor, which determines the foot movement method. It was hypothesized that the correlation between older drivers' shoe length and the percentage of pivoting would be large ($r > 0.5$).

Research question 3.

How does the foot movement method (pivoting vs. lifting) of drivers affect the lateral foot placement on the brake pedal?

Hypothesis 3.

This study hypothesized that in all baseline stop sign tasks the average lateral foot placements on the brake pedal would be significantly to the left for drivers who used the foot lifting, as compared to the foot placements on the brake pedal by drivers who used the foot pivoting. This is because when pivoting, the driver's heel limits the amplitude of the foot movement; when lifting, drivers tend to move the foot further to the left to avoid inadvertently hitting the accelerator pedal.

3.3 Gap Two: Lack of Studies on Older Drivers' Pedal Operation Characteristics in Startle-braking Tasks

The U.S. Department of Transportation (2012) has identified emergency braking as a driving task with higher risk of pedal misapplication crashes. Schmidt (1989) listed hypervigilance (panic) as a cause of the PAE. Schmidt also stated that the limb movement accuracy is dependent on the amplitude and the time of the limb movement. In addition, when receiving auditory startle stimuli, the driver's limb contractions, such as a knee flex, will occur and make limb movement less accurate (Bridger, 1995, p.313). Thus, there is a need to understand how pedals are used when drivers are startled and need to brake quickly.

Research question 4.

Do older drivers more likely use a foot lifting strategy rather than a foot pivoting strategy in a startle-braking task compared to the baseline stop sign tasks?

Hypothesis 4.

This study hypothesized that in a startle-braking task the percentage of foot lifting would be significantly higher than the percentage of foot lifting in the baseline stopping tasks because of the lower limb's contraction (i.e., knee flex) at the auditory startle stimuli.

Research question 5.

How does an older driver place his or her foot on the brake pedal in a startle-braking task? How is that foot movement and placement different from a stopping task?

Hypothesis 5.

This study hypothesized that the lateral foot placement on the brake pedal in a startle-braking task would be significantly to the right of the average lateral foot placement in baseline stopping tasks, as a result of fast foot movement at the auditory startle stimuli.

3.4 Gap Three: Lack of Studies on the Role of Fatigue in Older Drivers' Pedal Usage Characteristics

Research question 6.

Do older drivers exhibit obvious signs of fatigue indicated by slower foot transfer time after 1.5 hours of driving?

Hypothesis 6.

This study hypothesized that for older drivers the average foot transfer time of the last three of the five foot transfers in the final pedal calibration would be significantly longer than the average foot transfer time of the last three foot transfers in the initial pedal calibration due to fatigue. The last three foot transfers were used instead of all five transfers. The first two foot transfers were used as practice to get participants familiar with this task, resulting in more consistency with the participants' last three foot transfers. Fatigue was investigated because PAEs are prevalent in parking lots where drivers may feel tired after driving.

3.5 Gap Four: Lack of Studies on Older Drivers' Pedal Usage Characteristics When Reaching Out of the Vehicle

As stated previously, a driver being out-of-position is one of the causes of pedal misapplication crashes (U.S. Department of Transportation, 2012). Schmidt (1989) discussed the relationship between head orientation/gaze location and limb movement/placement accuracy. However, the studies that Schmidt cited were conducted in a condition which is different from that in driving. The differences included the following: 1) Hands rather than feet were used in the cited experiments. 2) Cited experiments were carried out in a slow, consciously controlled manner. In contrast, most of the pedal misapplications occurred unconsciously and sometimes in a short period of time. 3) Cited experiments used a dark environment to minimize visual information, whereas the pedal misapplication could happen without compromised visibility. Therefore, it was worth investigating older drivers' pedal operation while reaching out of the window in a realistic environment.

During this study each participant carried out two reaching out and swiping card tasks: one took place at the gated entrance of an outside parking lot, and the other at the gated entrance of a parking deck. The data from both reaching out tasks were used. The card reader at the entrance of the outside parking lot was replaced mid-way through the study. The new card reader has a bigger interface and is more sensitive to the card, compared to the previous card reader; therefore, some of the latter participants did not have to reach out as far to finish the card swiping task compared to former participants.

Research question 7.

Is an older driver's foot transfer time when approaching a curb-side device (i.e., a card reader, a drive-through food service, etc.) significantly longer than that in stop sign maneuvers?

Research hypothesis 7.

This study hypothesized that the average foot transfer time when approaching both curb-side devices would be significantly longer than the average foot transfer time in the baseline stop sign maneuvers because an older driver becomes more cautious when trying to stop the vehicle at an appropriate distance to the curb-side device that requires the driver to reach outside of the vehicle.

Research question 8.

How does reaching out of the vehicle affect older drivers' lateral foot placement on the brake pedal?

Hypothesis 8.

This study hypothesized that for older drivers who keep their right foot on brake pedal during reaching out of the vehicle, the right most lateral foot placement would be significantly rightward of the foot placement before reaching out the driver's side window. (The event of reaching out started from the time when the participant's hand crossed the vehicle window to move towards the card reader, and ended at the time when the hand crossed the vehicle window to move back into the vehicle.) This hypothesis was driven by the fact that driver's interaction with a curb-side device is associated with higher risk of PAE (U.S. Department of Transportation, 2012), and it is suspected that the driver being out of position is the cause of difference in lateral foot placement before and during reaching out.

Research question 9.

How does an older driver's stature affect the time it takes him or her to reach out and finish the card-swiping task?

Hypothesis 9.

This study hypothesized that there would be a significantly negative correlation ($r < -0.5$) between the stature of the driver and the time it takes an older driver to reach out and successfully finish the card-swiping task. The greater the stature of an older driver, the less time it would take the driver to reach out of the window. This is because drivers with greater stature can easily reach out of the window to complete the task.

3.6 Gap Five: Lack of Studies Comparing Older Drivers' Pedal Usage Characteristics in Forward Parking Tasks

Parking maneuvers are reported to be associated with a high rate of PAE. Based on the NC crash database, parking accounts for 25% of the PAE pre-crash maneuvers, and according to data from news media analysis, this percentage is reported as 61% (U.S. Department of Transportation, 2012). The demanding maneuvers needed to park a vehicle while maintaining accurate operation of the pedals require that the driver's attention be allocated wisely to different aspects, such as pedestrians, surrounding vehicles and infrastructures. Parking maneuvers may be more challenging when older drivers have to carry out forward parking tasks in tight spaces with compromised lighting conditions. This research gap allowed for the investigation of older drivers' pedal operation in parking spaces. For this purpose, data from two forward parking tasks were used for Hypothesis 10. One parking task took place in an outside parking lot, and the other one occurred in a parking deck. More details of the environment of these two parking spaces are described in Chapter Four.

Research question 10.

What is the difference in older drivers' foot transfer time in forward parking tasks between an open parking lot with greater space and a darker parking deck with less space?

Hypothesis 10.

This study hypothesized that older drivers' foot transfer time in an open parking lot with greater environmental space would be significantly less than that in a darker parking deck with less space. Drivers tend to be more cautious in places with compromised light conditions and tighter parking spaces; therefore, slower foot transfer allows older drivers to better observe the environment and make decisions.

CHAPTER FOUR

RESEARCH DESIGN AND METHODOLOGY

4.1 Overview

This chapter provides details of the research method used to collect and analyze the data that are used to test the research hypotheses presented in Chapter Three. This was a retrospective study where all data were collected before data analysis.

The first four sections that follow provide information regarding

1. the participants and the recruitment process,

2. the pre-determined driving route used for on-road driver evaluation,

3. the instrumented vehicle equipped with data collection devices, and

4. the experiment procedure.

4.2 Participants

All participants for this study were recruited through physician referrals to the Driving Rehabilitation Program at the Roger C. Peace Rehabilitation Hospital (RCP), which is part of the Greenville Health System (GHS) in Greenville, South Carolina. The research team members met with physicians and staff of several practices within the GHS to provide information about the study. Potential participants who had been referred to the Driving Rehabilitation Program at RCP were contacted by phone by research assistants, briefed about the study, and screened for possible study inclusion. The form used in the phone screening is included in Appendix A. In this study, older adults from one control group and three treatment groups were recruited. The three treatment groups were a Mild Cognitive Impairment (MCI) group, a Peripheral Neuropathy (PN) group and an Orthopaedic (OP) group. During data analysis, older drivers across all four groups were combined without differentiating which group they belong to.

Participant inclusion criteria included

- having the ability to read, write, and speak in English;
- possessing a valid driver license;
- being a minimum age of 60 years old;
- having a height between 60 and 74 inches (5 feet to 6 feet 2 inches);
- having a minimum of three years of driving experience;
- making a minimum of three roundtrip trips per week;
- meeting the South Carolina vision requirement for driving licensure;
- having the ability to complete the study within six weeks;
- having the ability to wear comfortable snug-fitting shoes; and
- meeting the criteria to fall within one of the four groups of the larger study, which are a control group, a Mild Cognitive Impairment (MCI) group, a Peripheral Neuropathy (PN) group and an Orthopaedic (OP) group.

Potential participants were excluded if they

- drive a pickup truck, full size van, or very large SUV (e.g., Expedition, Tahoe, or Escalade);

- drive from a wheel chair;
- use adaptive driving devices;
- have had a driving evaluation administered by a Driving Rehabilitation Specialist (DRS) within the last year;
- are actively receiving treatment from an Occupational Therapist;
- currently use orthopedic support braces for right lower extremity (casts, splits, boots);
- have absent proprioception;
- have a reported history of Parkinson's disease;
- have been driving legally for less than 1 year after having a seizure;
- have a history of stroke resulting in no driving;
- drive less than 3 years after having a stroke; or
- have any injury or problems with the right leg affecting ability to walk in the last year (with the exception of surgery for hip fracture or hip replacements in the Orthopedic Surgery Group)

In order to rule out health conditions that could compromise study completion, the following question was used to screen for exclusion: "Has your doctor told you not to drive for any reason?" Participants provided consent prior to the on-road evaluation. Twenty-six licensed drivers over the age of 60 participated and completed the study (Table 5).

Table 5. Participant Demographics and Anthropometric Measurements

Groups	N	Age			Height (cm)	
		Mean	SD	Range	Mean	SD
Female	10	69.3	4.9	18	161.3	5.1
Male	16	74.3	6.9	22	176.0	5.8

4.3 Driving Route

The pre-planned, 27-mile driving route used for this study was similar to that used by RCP Driving Rehabilitation Specialists during their on-road assessment. The standard driving route included a mix of residential, arterial, and interstate traffic conditions for exposure to a broad range of roadway types, speeds, intersection control, and maneuvers. For the purpose of this study, a parking component (including both parking lot and parking deck) and a component designed to elicit a “startle” response were added at the end of the standard driving route. Both components were conducted in pre-specified locations on the RCP campus. The parking component included driving maneuvers, such as reaching out of the driver’s side window to swipe a card at the parking lot gate access, pulling straight forward into the parking space, and reversing out of the parking space. These maneuvers were carried out in both a parking deck and an open parking lot which had different light conditions and available spaces. These components were added at the end of the on-road route because earlier research suggests 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 (U.S. Department of Transportation, 2012). The on-road evaluation lasted between 1.5 hours to 2.5 hours.

4.4 Instrumented Vehicle

The test vehicle used in the study was a 2011 Chevrolet Malibu. The vehicle was instrumented with three data collection systems: a Dewetron Data Acquisition System, a Tekscan Contact and Pressure Mapping System, and a Video-metric Tracking System. The instrumentation process was conducted by a Clemson University automotive engineer with the installation directions from a bio-engineer and an automotive engineer, also from Clemson University. The equipment and instrumentation process are included in Appendix B.

4.5 Procedure

The on-road evaluation is a standardized assessment offered by RCP. During the phone call to schedule for the on-road evaluation, participants were instructed to wear tennis shoes for the evaluation to exclude footwear as an extraneous factor. Before a participant's arrival at RCP for the on-road evaluation, the instrumented vehicle was checked for the fuel level and was driven in the neighborhood (no specified route) to make sure that the vehicle battery was fully charged. Then the vehicle was parked at the front entrance to RCP where the researcher prepared the vehicle instrumentation for data collection during the on-road evaluation. The steps for preparing the vehicle instrumentation are included in the instrumented vehicle manual in Appendix B. While the vehicle was being prepared for data collection, the Certified Driving Rehabilitation Specialist (CDRS) greeted the participant in the front lobby of the hospital and explained the on-road evaluation to the participant.

In order to capture and analyze the participant's foot movement during the drive along the entire route, the CDRS wrapped Coban self-adhesive tape on top of the participant's clothing that covered the lower part of the participant's right tibia. Then the CDRS attached reflective markers ("dots") to the participant's right tibia and right shoe to ensure a clear camera view. Each dot was made by attaching a silver 50mm×50mm patch (from Diamond Grade™ Retroreflective Film) to a round, black adhesive marker as shown in Figure 34.

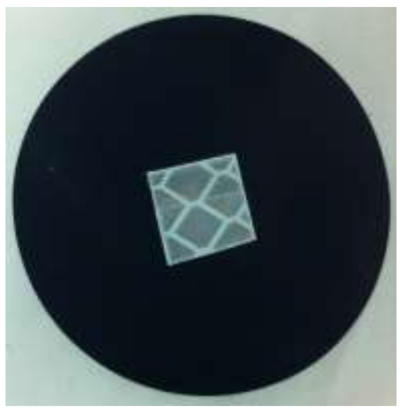


Figure 34. Reflective marker ("dot") used to capture participant's foot movement.

Dot positions are shown in Figure 35. Dot 1 and dot 2 were on the participant's right lower tibia and ankle, respectively. Dot 3 to dot 6 were on the participant's right shoe. In addition, four "structural dots" (dot 7 to 10) were used as reference.

Figure 35. Illustration of dot position with top view on the left and side view on the right.

Once the participant's preparation was complete, the CDRS escorted the participant to the instrumented vehicle, opened the front driver's door and instructed the participant to sit in the driver's seat. The CDRS then pointed out to the participant the location of the light stalk, windshield wiper stalk, key ignition and the seat adjustment. The participant was asked to adjust the driver's seat and mirrors (left, center and right mirrors) to confirm that he or she was seated comfortably with good visibility through the windshield and rearview mirrors. The CDRS then gave the vehicle key to the participant and instructed him or her to turn on the vehicle. The CDRS then sat in the front passenger seat.

Before beginning the on-road evaluation, the CDRS instructed the participants to perform an initial 'pedal calibration' where they made five consecutive foot transfers from the accelerator pedal to the brake pedal with their right foot as fast as possible. The participants were asked to reach engine revolutions-per-minute (RPM) of 2000 when pressing the accelerator pedal and then press hard on brake pedal (the brake lights were triggered). The CDRS gave instructions at the start of five transfers rather than at the start of each foot transfer. There were three purposes for the pedal calibration at the beginning of the drive: a) to provide an indicator of the participants' fatigue level because they were told to move as fast as possible, b) to confirm for the researchers that the equipment was collecting data properly, and c) to provide distinct pedal travel and force signal patterns which were used for synchronizing different data recording devices. As mentioned in the Instrumented Vehicle section above, the vehicle was instrumented with various data recording devices that started recording at different time points. In order to synchronize these recordings, the pedal calibration was used as a common event.

When participants completed the last driving task (straight parking in the staff parking lot), they were asked to reverse out of the space, drive around in the parking lot, and then maneuver into the same parking space again. After putting the car in park and before turning off the ignition, the participants were instructed to perform the pedal calibration exactly as they did at the beginning of the drive. After the pedal calibration was completed, the researcher confirmed that the data were being collected properly by using a checklist that is included in Appendix B.

The on-road evaluation was then complete. The CDRS removed the dots and the Coban self-adhesive tape and thanked the participant for his or her time. The researcher then returned to the vehicle to turn off the instrumentation, stow the equipment in the trunk, copy the data from the hard drive to the server, and then delete the data on the hard drive.

4.6 Driving Maneuvers

The current study focused on several, specific driving maneuvers along the pre-specified route.

4.6.1 Stopping at stop signs in a neighborhood environment.

The intent of the researcher was to include 10 stopping maneuvers as target driving tasks to establish a baseline for stopping performance. For this purpose, stop signs in a neighborhood with low surrounding traffic and a clear view were selected. The stopping procedure was self-paced and without instructions as to how the participant should stop. A complete route of neighborhood driving is shown in Figure 36. Table 6 shows the location of the 10 stop signs. Note that each of the 10 baseline tasks will be identified and referred to in later sections, tables and figures as A-J.

Table 6. Figure Numbers and Identification of Neighborhood Stop Signs.

Location of the Stop Sign	**ID**	**Figure**
West Seven Oaks Drive and Michaux Drive (Three-way Stop)	A	Figure 37
East Seven Oaks Drive and Leconte Woods	B	Figure 38
Leconte Woods and Chapman Road	C	Figure 39
Anthony Place and Lowood Lane	D	Figure 40
Lowood Lane and Garden Trail	E	Figure 41
Bachman Court and Garden Trail	F	Figure 42
Garden Trail and Chapman Road	G	Figure 43

Chapman Road and East Seven Oaks Drive	H	Figure 44
East Seven Oaks Drive and Leconte Woods (Three-way Stop)	I	Figure 45
East Seven Oaks Drive to Michaux Drive	J	Figure 46

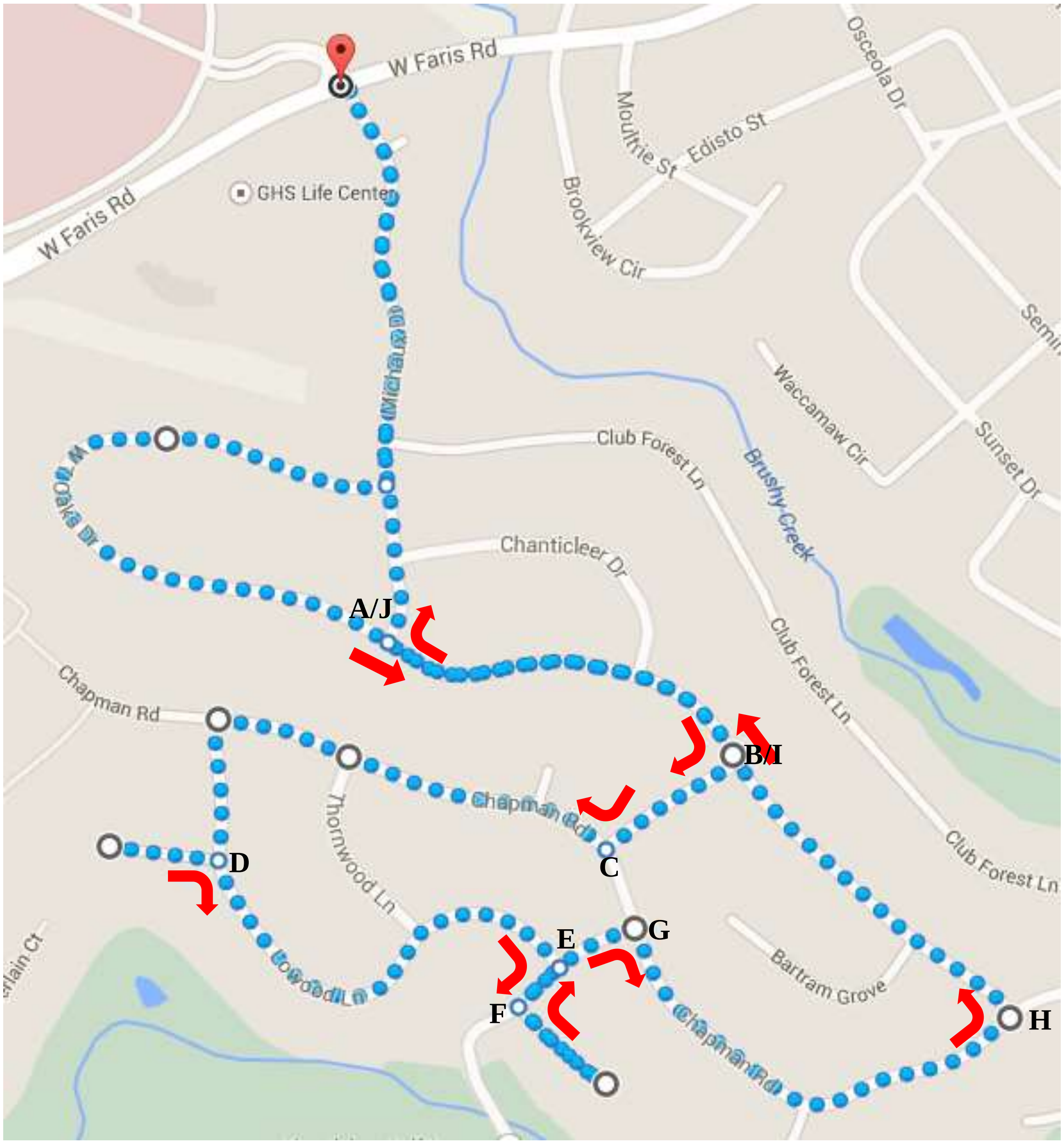


Figure 36. Route for neighborhood driving with cross signs showing the locations of stop signs and arrows show the turning directions.

Figure 37. A: Three-way stop at West Seven Oaks Drive and Michaux Drive (next step: drive straight).

Figure 38. B: Stop at East Seven Oaks Drive and Leconte Woods (next step: turn right).

Figure 39. C: Stop at Leconte Woods and Chapman Road (next step: turn right).

Figure 40. D: Stop at Anthony Place and Lowood Lane (next step: turn right).

Figure 41. E: Stop at Lowood Lane and Garden Trail (next step: turn right).

Figure 42. F: Stop at Bachman Court and Garden Trail (next step: turn right).

Figure 43. G: Stop at Garden Trail and Chapman Road (next step: turn right).

Figure 44. H: Stop at Chapman Road and East Seven Oaks Drive (next step: turn left).

Figure 45. I: Three-way stop at the East Seven Oaks Drive and Leconte Woods (next step: drive straight).

Figure 46. J: Stop at the East Seven Oaks Drive to Michaux Drive (next step: turn right).

4.6.2 Straight and forward parking maneuvers, reaching out to swipe card and 'startle brake' after completion of standard driving route.

The final portions of the on-road evaluation were conducted on the RCP campus (Figure 47) at the end of the 27-mile route. The driving tasks that were analyzed are shown in Table 7, and the task locations are shown in Figure 47. Both "reaching out and swiping card at gate access" task and "straight parking into the parking space" task were performed twice by each participant, one at the parking deck and the other at the parking lot. Both the parking deck and the parking lot are designated for GHS staff members.

Table 7. Parking Component Driving Tasks Analyzed

Driving Task
Reaching out and swiping card at gate access
Straight parking into the parking space
Startle brake

Figure 47. Aerial view of the RCP campus. (Red arrows indicate gated entrances to two staff parking areas and card readers. The red star indicates the site for the ‘startle brake’ response. The cross sign indicates the site of straight parking in the open parking lot.)

4.6.2.1 Reaching out and swiping card at a gated entrance into the parking deck.

Within the parking component of the study, participants drove through two gated entrances; one is located at the entrance of the parking lot, and the other is located at the entrance of the parking deck.

After completion of the standard 27-mile course, participants returned to the RCP campus where they were asked to drive towards the entrance of the five-floor parking deck (Figure 47). The parking deck entrance is gated (Figure 48), and the CDRS instructed the participants to stop the vehicle at the gate access. Next, the CDRS gave an employee ID card to the participant and asked the participant to swipe it in front of the card reader to open the gate. The dimensions of the card reader are shown in Figure 49.

Figure 48. Gated entrance to the parking deck with the card reader circled in red.

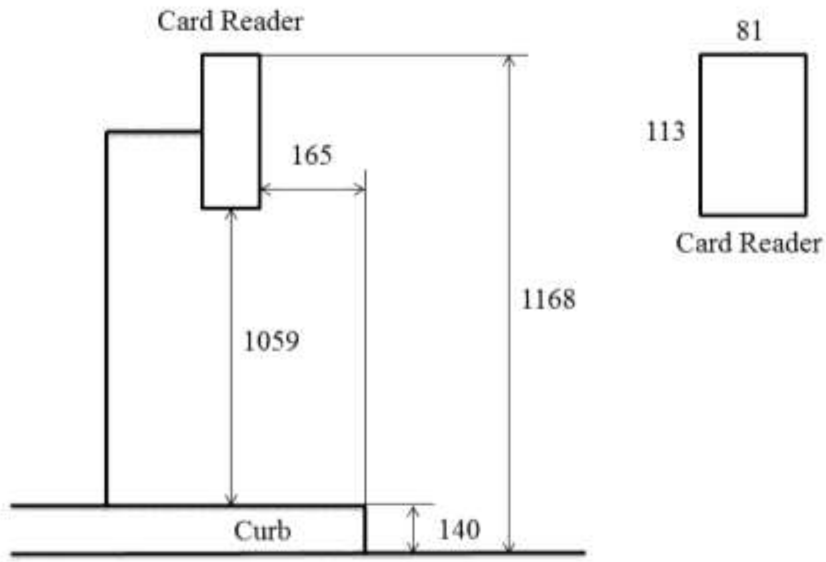


Figure 49. Dimensions (in mm) of the card reader at the entrance to the parking deck.

4.6.2.2 Straight parking into a parking space in the parking deck.

After entering the gate, the participants were guided by the CDRS to the fourth floor of the parking deck. A parking space on the fourth floor in the parking deck was reserved for participants to carry out the parking maneuvers (Figure 50). The deck parking space is 264 cm wide with compromised lighting condition compared with the parking space in the outdoor parking lot. The CDRS instructed the participants to drive up to the fourth floor, turn left and then park the vehicle in the reserved space. Then they were asked to reverse the vehicle out of the parking space, to drive around in the parking deck and to park at the same parking space again. The CDRS instructed participants to reverse out of the space and then exit the parking deck.

Figure 50. Reserved parking space on the fourth floor of the parking deck.

4.6.2.3 Startle brake.

After exiting the parking deck, the participants performed the ‘startle brake’ maneuver on the road parallel to the parking deck. (The place where the ‘startle response’ was carried out is indicated by the star in Figure 47.) The ‘startle brake’ was an emergency brake scenario that was carried out when participants were unexpectedly ‘startled’ by a vocal stimuli created by the CDRS. The CDRS first evaluated the environment to make sure it was safe to perform a hard brake maneuver. If it was deemed unsafe, the CDRS instructed the participant to loop around the campus and to come back on the same road until it was safe to carry out the maneuver. The participants were aware that a ‘startle brake’ response was a component of the evaluation, but they were not told when or where it would occur. To initiate the startle braking response, the CDRS shouted to the participants, “Stop the car!”

4.6.2.4 Reaching out and swiping card at a gated entrance into the parking lot.

After the ‘startle brake’ maneuver, the participants drove on to the entrance of the parking lot with gated access (indicated by the other red arrow in Figure 47). As before, participants were given the employee ID card to swipe for access into the parking lot. See Figure 51. The card reader at the entrance of the parking lot was replaced after seven sets of useful data had been collected. (Eleven on-road assessments had been accomplished before the card reader was replaced, and seven sets of data out of eleven were used for the data analysis.) The previous card reader was the same as that used at the entrance into the parking deck, the dimensions of which is shown in Figure 52. The new card reader has a bigger interface and is more sensitive to the card; thus, participants did not have to reach out as far to finish the card swiping as they did with the previous card reader. The dimensions of the card reader are shown in Figure 53.

Figure 51. Gated entrance into the parking lot.

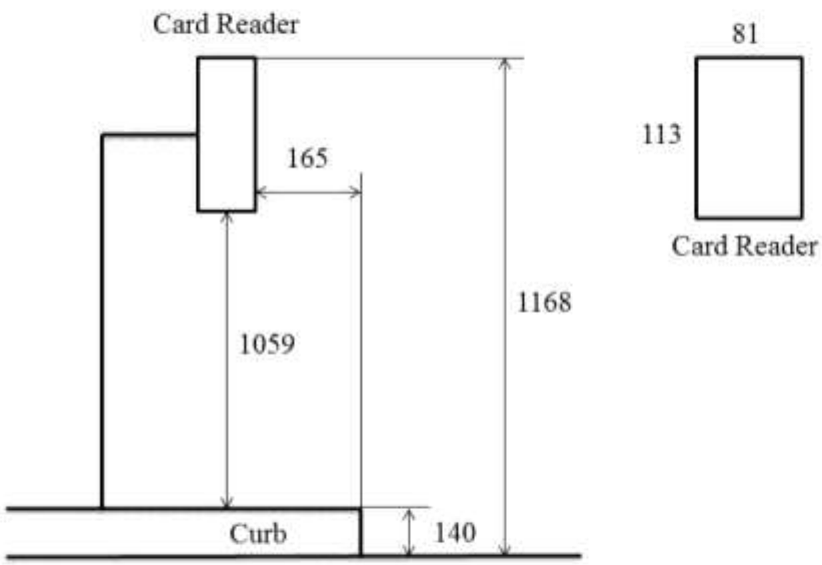


Figure 52. Dimensions (in mm) of the old card reader at the entrance to the staff parking lot.

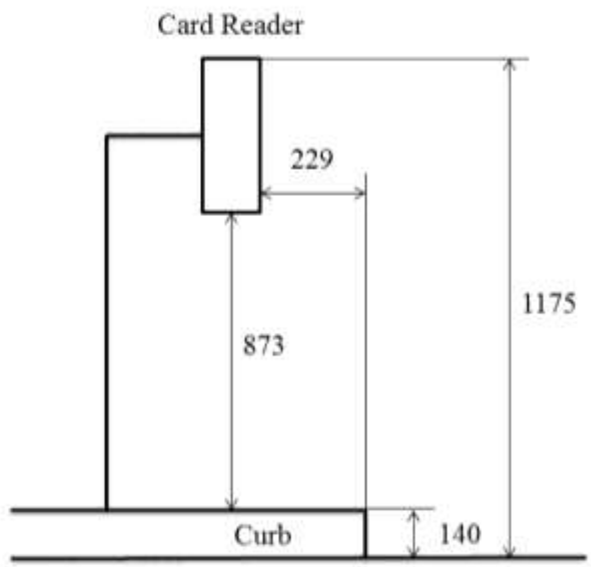


Figure 53. Dimensions (in mm) of the new card reader at the entrance to the staff-parking lot.

4.6.2.5 Straight parking into a parking space in the parking lot.

Once the participants entered the gated parking lot, they were asked to drive straight into a reserved parking space with a width of 277 cm (Figure 47). It should be noted that there was another reserved parking space on the right where a passenger vehicle used by the CDRS was parked during data collection. However, the parking space on the left was not reserved, so there was no control over whether or not this parking space was occupied when the participant performed the straight parking task. As explained previously, participants were instructed to reverse out of the parking lot space, drive around the parking lot, and pull into the same space again as the final driving task prior to final pedal calibration.

Figure 54. Reserved parking space at the outdoor parking lot.

4.7 Data Processing

The data collected by the instrumentation installed in the test vehicle can be categorized as Dewetron data, Tekscan data, and video recording. (Please see the instrumentation manual in Appendix B for more details.) The same set of data was collected for the entire process of the on-road evaluation. In order to examine each driver's performance during the driving tasks specified in section 4.6 above, a task analysis was conducted for each driving event to identify each participant's individual action ("sub-task"), such as moving the right foot from the accelerator pedal to the brake pedal. A channel evaluation of the data collected by the instrumented vehicle was also performed in order to find out if all the participant's actions were captured. The channel evaluation was important because the task analysis was conducted independently, without taking into account the ability to capture all the sub-tasks. For example, "driver looking at the passenger side mirror" was listed as a sub-task in the task analysis. However, the results of channel evaluation revealed that the sub-task of "driver looking at the passenger side mirror" was not captured because the accurate driver gaze location was not available. Based on the results of task analysis and channel evaluation, a revised list of sub-tasks was used. Their segmentation (the criteria of starting and ending of each sub-task) follows.

4.7.1 Task analyses.

In order to gain insight into the older drivers' pedal operation in different driving tasks, a driving task needed to be broken into multiple steps. For example, the task of reaching out of the vehicle can be segmented into steps such as (a) moving the foot from the accelerator pedal to the brake pedal, (b) pressing the brake pedal and stopping the vehicle in front of the curb-side device, (c) unbuckling the seatbelt, (d) shifting to the parking gear and (e) reaching out of the vehicle. Table 8 to Table 11 shows how a major driving task (such as 'reversing at the parking lot') was broken down to several sub-tasks (e.g., 'foot transfer from the accelerator pedal to the brake pedal', 'look left to check traffic', etc.). Note that the sub- tasks in each table could be duplicated by the driver or that the sequence of the sub-tasks could be different than listed. Also note that not all sub-tasks listed in the task analyses were used to code the major driving events. The reason for this is detailed in the section of channel evaluation (4.7.2 below), and the selected sub-tasks to be coded and their segmentation criteria are listed in section 4.7.3 that follows.

Table 8. Task Analysis of Driving Task “Stop”

Foot on accelerator pedal
Foot transfers to brake pedal
Press brake pedal
Check traffic
Stop to wait for preceding vehicle
Foot transfers back to accelerator pedal
Foot transfers to brake pedal
Press on brake pedal
Foot transfers to accelerator pedal
Press on accelerator pedal to proceed

Table 9. Task Analysis of Driving Task “Startle Braking”

Foot on the accelerator pedal
(CDRS’s command to stop)
Transfer foot to brake pedal
Press the brake pedal
Car comes to full stop

Table 10. Task Analysis of Driving Task "Straight Parking"

Foot on the accelerator pedal
(CDRS's instructions)
Transfer foot to brake pedal
Press the brake pedal
Car comes to full stop
Foot on accelerator pedal
Foot transfer to the brake pedal
Press the brake pedal
Look left for pedestrians and cars
Look right for pedestrians and cars
Foot transfers back to accelerator pedal
Press on accelerator pedal
Foot transfers to brake pedal
Press on brake pedal
Turn steering wheel toward desired direction
Car comes to full stop in the parking space

Table 11. Task Analysis of Driving Task "Entering the Gate"

Foot on accelerator pedal
Foot transfers to brake pedal
Press on brake pedal
Roll down the driver side window
Turn the steering wheel to desired direction

Car comes to full stop
Change to parking gear
Get badge from the CDRS
Reach out side window to swipe the card
Left arm returns back to the car
Unbuckle the seatbelt
Reach out side window to swipe the card
Left arm returns back to the car
Open the driver side door
Reach out to swipe the card
Left arm returns to the car
Step out of the car to swipe the card
Return to the car and sit on the driver's seat
Give the badge back to the CDRS
Close the driver side door
Fasten the seatbelt
Press on the brake pedal
Change to drive gear
Foot transfers to accelerator pedal
Press the accelerator pedal
Turn the steering wheel to desired direction
Proceed past the gate

4.7.2 Channel evaluation.

Because the task analyses were conducted without taking into account the quality of data that the instrumented vehicle was able to collect, it was unknown whether the sub-tasks listed above could be captured and then analyzed. For example, the sub-task “driver looking at the passenger side mirror” could not be captured because the data acquisition equipment did not provide accurate driver gaze location. Therefore, the instrumented vehicle channels were evaluated as to their capabilities of successfully capturing the sub-tasks listed above (See Table 12). Table 12 also lists possible solutions for those sub-tasks that were not captured. Note that the channel evaluation was to obtain the equipment’s best data- capturing ability. It was conducted before the real data (data used for analysis) were accessed and analyzed; thus, it did not indicate any missing data that were identified in the data analysis phase.

Table 12. Instrumented Vehicle Channel Evaluation

Sub-tasks	Channels needed	Type of Signal	Usability	Best Resolution	Possible Solution
Gear selection	Camera recordings	2D color image	Good	Able to see the hand gripping the gear lever and selecting the gear	n/a
Foot transfers between pedals (from accelerator to brake and from brake to accelerator)	Brake pedal travel	Percentage	Good	+/- 5%. The pedal travel signals have slight and manageable noise.	n/a
	Accelerator pedal travel	Percentage	Good	+/- 10%. The pedal travel signals have slight and manageable drift and noise.	n/a
	Camera	2D color	Good	Able to see	n/a

	recordings	image		foot transferring between pedals	
Turn steering wheel to desired direction	Camera recordings	2D color image	Limited; cannot gauge the steering wheel position	Not able to gauge the steering wheel angle	Yaw rate
Press/hold brake	Brake pedal travel	Percentage	Good	+/- 5%. The pedal travel signals have slight and manageable noise.	n/a
Press accelerator	Accelerator travel	Percentage	Good	+/- 10%. The pedal travel signals have slight and manageable drift and noise.	n/a
Car comes to full stop	Velocity	Numeric	Good	+/- 5%.	n/a
Check driver side mirror	Camera recordings	2D color image	Limited; accurate driver gaze position not available	Able to determine the start and end of the tasks “driver looking left” and “driver looking right”.	Change this metric to ‘look left’
Turn head over left/right shoulder	Camera recordings	2D color image	Limited; accurate driver gaze position not available	Able to determine the start and end of the tasks “driver looking left” and “driver looking right”.	Change this metric to ‘look right’
Check center	Camera recordings	2D color image	Limited; accurate	Able to determine	Change this metric

mirror			driver gaze position not available	the start and end of the tasks “driver looking left” and “driver looking right”.	to ‘look right’
Check passenger side mirror	Camera recordings	2D color image	Limited; accurate driver gaze position not available	Able to determine the start and end of the tasks “driver looking left” and “driver looking right”.	Change this metric to ‘look right’
Reach arm to hold passenger seat	Camera recordings	2D color image	Good	Not able to see driver’s hand when hand is behind the passenger seat but able to see the arm	n/a
Turn body to neutral position	Camera recordings	2D color image	Good	Able to tell whether body is back to neutral	n/a
Watch left through window	Camera recordings	2D color image	Limited; accurate driver gaze position not available	Able to tell if the driver is looking left, straight ahead or right	n/a
Watch right through window	Camera recordings	2D color image	Limited; accurate driver gaze position not available	Able to determine the start and end of the tasks “driver looking left” and “driver looking right”.	n/a

Stop to wait for preceding car	Velocity	Numeric	Good	+/- 5%.	n/a
	Camera recordings	2D color image	Able to see the preceding car; cannot tell the distance in between	n/a	n/a
Roll down the driver side window	Camera recordings	2D color image	Limited due to visibility of driver's left hand	n/a	n/a
Get badge from the CDRS	Camera recordings	2D color image	Good	n/a	n/a
Left arm reaches out to swipe the card	Camera recordings	2D color image	Good	Able to tell when driver's left hand crosses the window	n/a
Left arm returns back to the car	Camera recordings	2D color image	Good	Able to tell when driver's left hand crosses the window	n/a
Unbuckle the seatbelt	Camera recordings	2D color image	Good	n/a	n/a
Open the driver side door	Camera recordings	2D color image	Good	Able to tell if the door is open or not	n/a
Step out of the car to swipe the card	Camera recordings	2D color image	Good	Able to see driver stepping out of the car	n/a
Return to the car and sit on the driver's seat	Camera recordings	2D color image	Good	Able to see driver stepping back into the car	n/a
Give the badge back to the CDRS	Camera recordings	2D color image	Good	n/a	n/a
Close the	Camera	2D color	Good	n/a	n/a

driver side door	recordings	image			
Fasten the seatbelt	Camera recordings	2D color image	Good	n/a	n/a
Proceed into the gate	Camera recordings	2D color image	Good	Able to see the gate beam and the foot transfer	n/a

As seen in Table 12, some sub-driving tasks, as listed in the task analyses, were not captured, or the channel quality did not allow for in-depth analysis. For example, the sub-tasks ‘driver checking the driver side mirror’ could not be distinguished from ‘driver looking to the left’ because the driver’s gaze location was not captured with an eye-tracking device. Therefore, the sub-tasks needed to be revised before being coded in the data analysis process, based on the column of “Possible Solution” in Table 12.

4.7.3 Selected sub-tasks and their segmentation.

The selected sub-tasks from the task analyses are listed in Table 12. To record the starting and ending time points of each sub-driving event, the segmentation criteria needed to be created. Note that some tasks were treated as instant events, which means when coding the participant’s tasks, they were marked as “Yes” if the participant did so, and “No” if otherwise. This is because these sub-tasks were minor compared to other sub-tasks. For example, gear selection was marked as an instant task because it was only used as a trigger of the start and end of a driving event. In Table 13, instead of proving the task’s start and end criteria, only the criterion of the occurrence is provided for instant events.

Table 13. Segmentation Criteria for Sub-tasks

Sub-tasks	Start	End

Gear selection	The moment when hand touches the gear shift	
Look to the left	The initiation of a substantial left turning of head	The moment when head returns to the neutral position
Look to the right	The initiation of a substantial right turning of head	Head returns to the neutral position
Foot moves from brake pedal to accelerator pedal	The moment when brake pedal travel is 10% of its full travel	The moment when the accelerator travel is 2% of its full travel
Foot moves from accelerator pedal to brake pedal	The moment when accelerator pedal travel is 2% of its full travel	The moment when the brake travel is 10% of its full travel
Foot stays on brake pedal	The moment when brake pedal travel is 10% of its full travel	The moment when brake pedal travel is 10% of its full travel
Foot stays on accelerator pedal	The moment when the accelerator travel is 2% of its full travel	The moment when the accelerator travel is 2% of its full travel
Foot hovers over brake pedal	The moment when brake pedal travel is 10% of its full travel	The moment when brake pedal travel is 10% of its full travel
Foot hovers over accelerator pedal	The moment when the accelerator travel is 2% of its full travel	The moment when the accelerator travel is 2% of its full travel
Reaches out to swipe the card	The moment when the card crosses the side window when the driver reaches out to swipe the card	The moment when the card crosses the side window when the driver's hand returns back in the window

4.7.4 Tekscan data processing.

The Tekscan instrument records the pressure in each sensel (a sensing unit of the sensor). Based on the pressure data, Tekscan can export the force applied on the sensor, the location of the center of force (COF) and the contact area on brake pedal. Table 14 illustrates sensels on a Tekscan sensor 9811E that are used to detect force applied on the brake pedal. Table 14 provides the sensor technical parameters.

Table 14. Tekscan Sensor 9811E Parameters

Item	Size (mm)
Column width	6.3
Row width	7.9
Column spacing	12.7
Row spacing	12.7
Sensel length	12.7
Sensel width	12.7

The lateral foot placement on the brake pedal is expressed as a percentage (Figure 55). It was derived from the exported location of the COF.

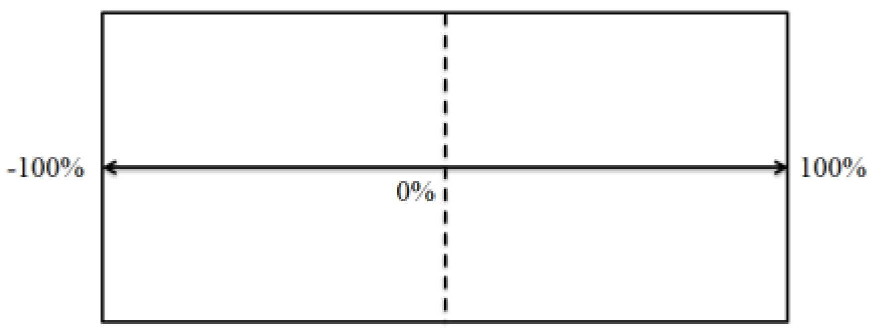


Figure 55. COF location representation on the brake pedal.

4.8 Data Source for Each Hypothesis

The data used to test each hypothesis came from different sources (e.g., in-clinic measurement or on-road assessment) and types of equipment (e.g., Dewetron or Tekscan). Table 15 shows how the data used for each hypothesis were collected (e.g., by in-clinic measurement or Tekscan, etc.). The hypotheses in Table 15 are represented by short phrases rather than full statements. The crosses in each cell indicate the data sources for the hypotheses. For example, Hypothesis 1 is about the correlation between stature and the participant's tendency of using foot pivoting in the baseline tasks. Stature was measured in the in-clinic session of the study, and participant's foot movement strategy was captured by video camera; therefore, two cells were checked.

Table 15. Sources of Data Used for Each Hypothesis

			Four Types of Data Sources		
Five research gaps		10 research hypotheses abbreviated	In-clinic measurement	Dewetron/Camera	Tekscan
1	Baseline stopping tasks	Stature ~ pivot vs. lift	x	x	
		Shoe length ~ pivot vs. lift	x	x	
		Placement on pedal ~ pivot vs. lift		x	x
2	Startle-braking task	Strategy same as baseline?		x	
		Placement same as baseline?			x
3	Fatigued foot transfer tasks	Transfer times at calibration initial vs. final		x	
4	Gate reaching tasks	Transfer time greater than baseline?		x	
		Reaching and placement		x	x
		Stature's impact on reaching time	x	x	
5	Parking deck vs. lot	Transfer time lot vs. deck		x	

CHAPTER FIVE

RESULTS

5.1 Introduction

This chapter presents the results of statistical analyses for the 10 hypotheses proposed in Chapter Three and brief interpretations of the statistics. Missing data, in terms of their effects on the hypotheses and the baseline stopping tasks, are reported in section 5.2. In addition, reasons for missing data and number of participants affected by missing data are presented. Sections 5.3 through 5.7 describe the analysis techniques to determine the results for 10 baseline stopping tasks, the startle-braking task, pedal calibration tasks, reaching out tasks, and forward parking tasks, respectively. These five sections correspond to the five research gaps.

5.2 Missing Data

The missing data were caused by a) Tekscan sensor failing to capture the data; b) camera black-out in the middle of the drive; c) human error; d) an environmental issue; and e) other. The main human errors were that the CDRS did not instruct participants to perform 1) the startle-braking task or 2) the pedal calibration tasks. The environmental issue was that the gate at the parking deck or parking lot was open, and the participant did not have to reach out and swipe the card. Table 16 shows the reasons for missing data and the number of participants affected by the missing data for each hypothesis. For example, Hypothesis 4 was to compare the foot movement strategy in 10 baseline tasks and the startle-braking task. Two participants did not perform the startle-braking task because the CDRS did not instruct them to do so. Therefore, the number “2” was placed in the cell to indicate the number of participants not performing the task. The last column shows the total number of participants affected by the missing data. Therefore, the sample size for each hypothesis will be 26 minus the total number of participants affected by the missing data.

Table 16. Reasons for Missing Data and Number of Participants Affected by Missing Data

				Reasons for missing data (n=number of participants affected by missing data)								
Five research gaps		10 research hypotheses abbreviated	No missing data	Dewetron/Camera	Human error (missing shoe measurement)	Human error (CDRS instruction)	Vehicle in parking and foot off the pedal	Participant did not reach out	Tekscan sensor	Tekscan laptop	Gate open	Total
1	Baseline stopping tasks	Stature ~ pivot vs. lift	x									0
		Shoe length ~ pivot vs. lift			1							1
		Placement on pedal ~ pivot vs. lift							1			1
2	Startle-braking task	Strategy same as baseline?				2						2
		Placement same as baseline?				2				1		3

3	Fatigued foot transfer tasks	Transfer times at calibration initial vs. final		1		6						7
4	Gate reaching tasks	Transfer time greater than baseline?		1							6	7
		Reaching and placement		1			4			1	6	12
		Stature's impact on reaching time		1				1			6	8
5	Parking deck vs. lot	Transfer time lot vs. deck		1		4						5

5.2.1 Hypotheses affected by missing data.

Each hypothesis that was affected by missing data and the reasons for missing data are as follows:

- Hypothesis 2: One participant was missing the shoe length measurement because the shoe profile drawing done by the CDRS could not be found.

- Hypothesis 3: One participant was missing the mean lateral foot placement due to Tekscan computer failure that occurred halfway through the drive.

- Hypothesis 4: Two participants were missing the foot movement method because the CDRS did not instruct the participants to perform the startle-braking task.

- Hypothesis 5: Three participants were missing the lateral foot placement data in the startle-braking task because the Tekscan laptop failed during the drive, or the CDRS did not instruct the participants to perform the startle-braking tasks.

- Hypothesis 6: Seven participants did not have mean foot transfer time data due to computer shut-off before the pedal calibration tasks, or the CDRS did not instruct the participants to perform the pedal calibration tasks.

- Hypothesis 7: Seven participants were missing the mean foot transfer time when approaching the gated accesses (the gate at the parking deck and the gate at the parking lot). This was due to a) the camera blacking out and the participant' s interaction with the card reader not being recorded; b) at least one gate (either at the parking deck or the parking lot) being open at the participant's arrival so that the participant did not have to brake to enter the gate.

- Hypothesis 8: Twelve participants were missing the mean lateral foot placement before reaching out and the right-most lateral foot placement during reaching out. This was caused by a) camera black out and the participant' s interaction with the card reader not being recorded; b) at least one gate (either at the parking deck or the parking lot) being open, hence, the participant did not have to stop and swipe the card; c) the participant's foot was not on the brake pedal; and/or d) the Tekscan laptop failed during the drive.

- Hypothesis 9: Eight participants were missing the reaching-out time. This was caused by a) the camera blacking out and the participant' s interaction with the card reader not being recorded; b) the participant stepping out of the vehicle; c) at least one gate (either at the parking deck or the parking lot) being open and the participant not havingto stop and swipe the card.

- Hypothesis 10: Five participants were missing the foot transfer time, either at the parking lot or the parking deck or both, which was caused by the camera black-out, or the CDRS did not instruct the participant to carry out the tasks.

5.2.2 Baseline stopping tasks.

If data were complete for the 10 baseline stopping tasks, each participant should have 10 lateral foot placement data points, each corresponding to one stopping task. In other words, for each stopping task, there should be 26 data points corresponding to the 26 participants. The lateral foot placement on the brake pedal was captured at the moment when the brake pedal travel was 10% of its full travel, which was the "trigger" of the event, "foot on brake pedal". Some lateral foot placement data are missing due to the Tekscan sensor's failure to capture the force at the moment when the brake pedal was 10% pressed. Figure 56 illustrates the color coding used in Table 17 which shows the lateral foot placement data in baseline tasks for all participants. Across 26 participants, 10 participants (38.5%) had at least one missing data point. The percent of missing data points ranged from 10% to 100% (mean: 55%, standard deviation: 30%). One participant had no lateral foot placement data at all, due to a Tekscan computer shut-off. However, the other data of this participant, such as foot transfer time and stature, were still available. Therefore, this participant was included whenever possible, considering the relatively small sample size. All 10 tasks had at least one missing data point. The percent of missing data points ranged from 40% to 70% (mean: 55%, standard deviation: 10%).

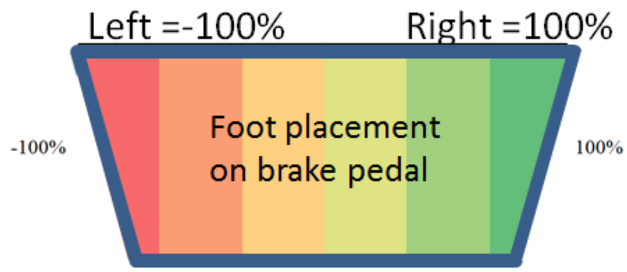
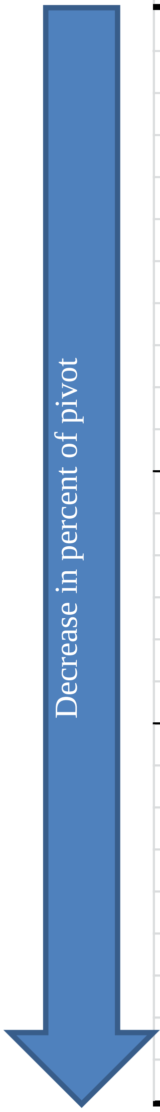


Figure 56. Color coding used to show lateral foot placement on the brake pedal.

Table 17. Lateral Foot Placement for the 10 Baseline Tasks.



Participant	Percent of pivot	Foot placement in 10 baseline stopping tasks* (NA=Not Available)									
		A Task 1	B Task 2	C Task 3	D Task 4	E Task 5	F Task 6	G Task 7	H Task 8	I Task 9	J Task 10
1	100%	NA	22%	NA	NA	-89%	-89%	-89%	NA	NA	0%
2	100%	NA	NA	NA	NA	NA	NA	NA	NA	44%	NA
3	100%	59%	89%	89%	89%	89%	89%	89%	89%	-72%	89%
4	100%	NA	NA	NA	67%	67%	NA	67%	67%	67%	67%
5	100%	78%	87%	88%	88%	87%	86%	87%	86%	87%	88%
6	100%	-52%	82%	79%	72%	80%	81%	71%	83%	82%	86%
7	100%	59%	50%	55%	89%	42%	89%	71%	32%	57%	21%
8	90%	88%	89%	89%	88%	89%	88%	89%	88%	89%	89%
9	90%	NA	89%	81%	89%	67%	44%	89%	NA	NA	NA
10	90%	89%	NA	89%	89%	89%	89%	89%	89%	89%	89%
11	90%	81%	81%	89%	89%	89%	89%	89%	88%	87%	89%
12	80%	88%	86%	89%	87%	83%	72%	83%	28%	83%	85%
13	70%	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%
14	60%	44%	NA	44%	44%	NA	NA	44%	44%	NA	NA
15	60%	89%	62%	58%	55%	65%	-20%	48%	71%	26%	45%
16	30%	NA	NA	NA	89%	89%	NA	NA	NA	NA	NA
17	30%	87%	88%	88%	88%	88%	89%	87%	88%	89%	89%
18	10%	89%	59%	63%	53%	56%	89%	88%	87%	55%	88%
19	0%	67%	89%	78%	NA	NA	NA	NA	NA	NA	NA
20	0%	44%	31%	52%	36%	79%	29%	74%	73%	75%	63%
21	0%	89%	88%	89%	88%	82%	88%	89%	89%	89%	89%
22	0%	24%	37%	19%	32%	32%	22%	47%	34%	38%	42%
23	0%	64%	-67%	68%	75%	NA	NA	77%	68%	49%	76%
24	0%	89%	89%	50%	87%	88%	80%	88%	81%	88%	77%
25	0%	51%	89%	88%	86%	87%	87%	88%	88%	85%	67%
26	0%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note. *The foot placement captured when brake pedal was 10% pressed

The missing data had a big impact on the data analysis because of the small sample size.

The researcher identified that by replacing the lateral foot placement at a single frame

(0.03 second/frame) with the mean lateral foot placement sampled from a slightly longer period of time, the data missing issue would be mitigated. This is because the data were available in the frames following the frame that corresponded to the time point when the brake pedal was 10% pressed. To make sure that the validity of the result would not be significantly affected, a very short period of time (0.5 second) was chosen as the "window", and the mean lateral foot placement in 0.5 second after the brake pedal was pressed 10% was used, instead of the lateral foot placement at the moment when the brake pedal was 10% pressed. No greater "window" (a time period over 0.5 second) was chosen, considering the fact that a greater "window" is associated with a greater likelihood that a driver's foot would move on the pedal. If the driver's foot moved on the brake pedal, the mean lateral foot placement would no longer be a good substitute of the instant lateral foot placement.

Table 18 shows the lateral foot placement in 10 baseline tasks after data replacement, using the mean lateral foot placement to restore data availability. By using the mean lateral foot placement, the number of participants with at least one missing data point reduced from 10 to six, out of 26 (23.1%). The percent of missing data points ranged from 10% to 100% (mean: 50%, standard deviation: 35%). Task wise, the percent of missing data points ranged from 20% to 50% (mean: 30%, standard deviation: 11%).

Table 18. Lateral Foot Placement in 10 Baseline Tasks after Data Replacement. (NA indicates that the Tekscan failed to capture the data.)

Participant	Percent of pivot	Foot placement in 10 baseline stopping tasks** (NA=Not Available)									
		A Task 1	B Task 2	C Task 3	D Task 4	E Task 5	F Task 6	G Task 7	H Task 8	I Task 9	J Task 10
1	100%	44%	-33%	-89%	-89%	-89%	-89%	-31%	-89%	-89%	-50%
2	100%	44%	44%	NA	NA	44%	44%	NA	NA	44%	NA
3	100%	88%	86%	87%	89%	85%	86%	86%	88%	80%	87%
4	100%	88%	NA	67%	77%	71%	67%	67%	67%	67%	67%
5	100%	84%	87%	84%	86%	86%	86%	87%	88%	87%	88%
6	100%	83%	83%	83%	76%	84%	70%	74%	83%	82%	84%
7	100%	83%	87%	84%	89%	45%	88%	75%	67%	79%	29%
8	90%	81%	87%	72%	80%	87%	84%	89%	88%	87%	89%
9	90%	83%	84%	83%	89%	86%	44%	64%	NA	89%	89%
10	90%	89%	89%	89%	89%	89%	89%	89%	89%	89%	89%
11	90%	80%	79%	89%	81%	85%	89%	85%	88%	87%	86%
12	80%	88%	88%	89%	87%	87%	87%	86%	85%	87%	85%
13	70%	88%	88%	85%	89%	87%	87%	84%	86%	89%	87%
14	60%	70%	46%	44%	67%	44%	81%	62%	71%	44%	44%
15	60%	87%	74%	74%	69%	84%	81%	83%	80%	67%	60%
16	30%	NA	89%	89%	92%	89%	NA	NA	NA	NA	NA
17	30%	73%	88%	85%	87%	88%	89%	87%	88%	88%	89%
18	10%	82%	68%	57%	61%	60%	88%	81%	87%	82%	78%
19	0%	67%	86%	78%	NA	NA	NA	NA	NA	NA	NA
20	0%	47%	27%	58%	41%	83%	41%	71%	67%	71%	67%
21	0%	88%	87%	91%	88%	85%	89%	86%	87%	88%	90%
22	0%	32%	37%	26%	36%	52%	16%	43%	42%	47%	47%
23	0%	58%	77%	76%	83%	72%	61%	82%	77%	62%	75%
24	0%	87%	82%	60%	86%	86%	85%	88%	83%	83%	79%
25	0%	79%	85%	86%	88%	84%	86%	88%	88%	79%	80%
26	0%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note. **The mean foot placement in 0.5 seconds after the brake pedal was 10% pressed

To obtain an overview of the relationship between percent of pivot and lateral foot placement on the brake pedal and to check whether data replacement caused bias to the relationship, the two variables were plotted twice, once with original data (Figure 57) and a second time with data after replacement (Figure 58). A comparison between Figure 57 and Figure 58 shows that data replacement did not significantly impact the relationship between percent of pivot and lateral foot placement. In addition, it did not reveal a clear linear relationship between the two variables, thus showing that the percent of pivot was not necessarily related to the lateral foot placement. However, it shows that participants tended to use the right portion of the brake pedal in the baseline tasks.

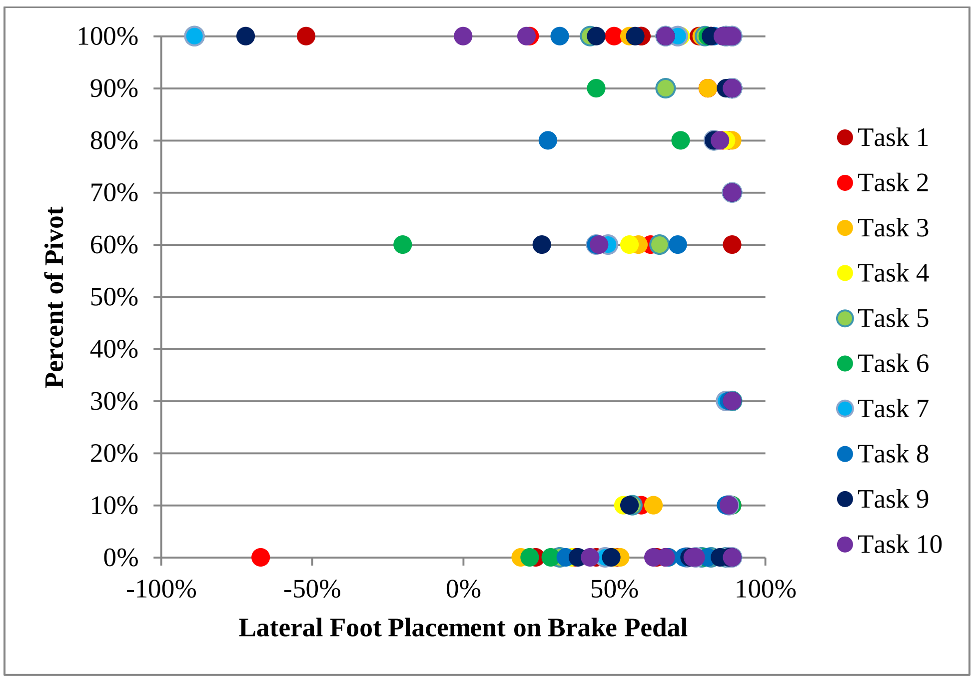


Figure 57. Relationship between percent of pivot and lateral foot placement (with original data).

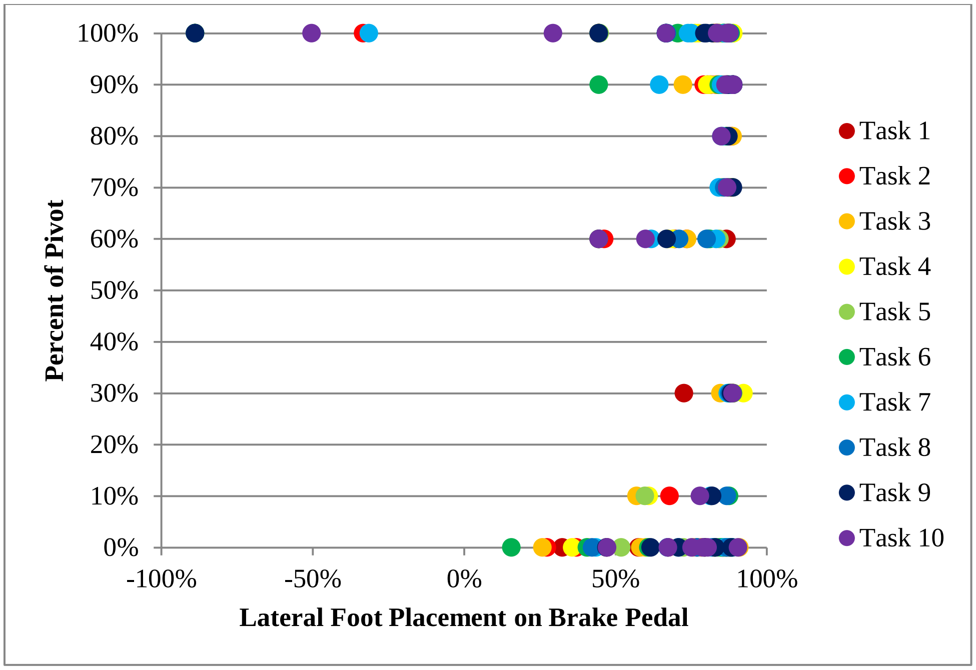
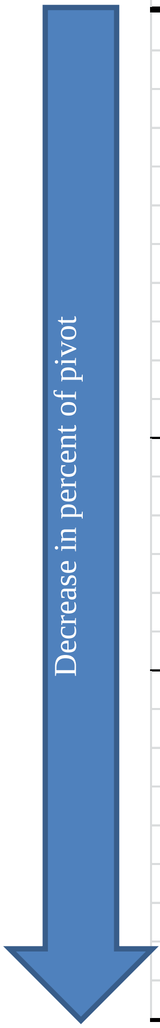


Figure 58. Relationship between percent of pivot and lateral foot placement (after data replacement).

5.3 Results of the Baseline Stopping Tasks

Gap One identified a need to understand older drivers' pedal operation characteristics in the baseline stopping tasks, where the drivers performed 10 stops at stop signs located in a residential area. (See Chapter Four section 4.6.1.) No PAEs were identified when drivers carried out the baseline stopping tasks. Table 19 is an overview of the foot movement strategy used in the 10 baseline tasks.

Table 19. Foot Movement Strategy in 10 Baseline Stopping Tasks



		Foot movement strategy in 10 baseline stopping tasks									
Participant	Percent of pivot	A Task 1	B Task 2	C Task 3	D Task 4	E Task 5	F Task 6	G Task 7	H Task 8	I Task 9	J Task 10
1	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
2	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
3	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
4	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
5	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
6	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
7	100%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
8	90%	Pivot	Pivot	Pivot	Pivot	Pivot	Lift	Pivot	Pivot	Pivot	Pivot
9	90%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Lift
10	90%	Lift	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot
11	90%	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Pivot	Lift	Pivot	Pivot
12	80%	Pivot	Pivot	Pivot	Pivot	Pivot	Lift	Pivot	Pivot	Lift	Pivot
13	70%	Pivot	Pivot	Lift	Lift	Pivot	Pivot	Pivot	Pivot	Lift	Pivot
14	60%	Pivot	Pivot	Pivot	Lift	Pivot	Lift	Lift	Lift	Pivot	Pivot
15	60%	Pivot	Lift	Pivot	Lift	Pivot	Pivot	Pivot	Lift	Lift	Pivot
16	30%	Pivot	Lift	Lift	Lift	Pivot	Lift	Lift	Lift	Lift	Pivot
17	30%	Lift	Pivot	Lift	Lift	Lift	Pivot	Lift	Lift	Lift	Pivot
18	10%	Pivot	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
19	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
20	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
21	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
22	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
23	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
24	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
25	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift
26	0%	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift	Lift

Note. Two sets of foot placement data were captured. Version1: foot placement when brake pedal was 10% pressed; version 2: mean foot placement in 0.5 seconds after the brake pedal was 10% pressed. Yellow indicates recovered foot placement data in version 2, and red indicates missing foot placement data in version 2.

Hypothesis 1 stated that when moving the foot from the accelerator pedal to the brake pedal in the baseline stop sign tasks, there would be a significant positive correlation (r >

0.5) between the percentage of pivoting (the number of pivots divided by 10) and the stature, which means the greater the stature, the more pivots there are in the 10 baseline stopping tasks for each participant.

The relationship between the percentage of pivoting (*M* = 54%, *SD* = 44%) and the stature (*M* = 170.4 cm, *SD* = 9.1 cm) was investigated using Pearson product-moment correlation coefficient. There was a strong, positive correlation between the two variables ($r(25) = .51$, $p<.01$), with a high percentage of pivoting associated with greater stature (Figure 59). Regarding effect size, Cohen (1988) suggested the following guidelines (Table 20).

Table 20. Cohen's Effect Size Reference Table

***r* Value**	**Correlation Effect**
***r*=.10 to .29 or *r*=-.10 to -.29**	Small
***r*=.30 to .49 or *r*=-.30 to -.49**	Medium
***r*=.50 to 1.0 or *r*=-.50 to -1.0**	Large

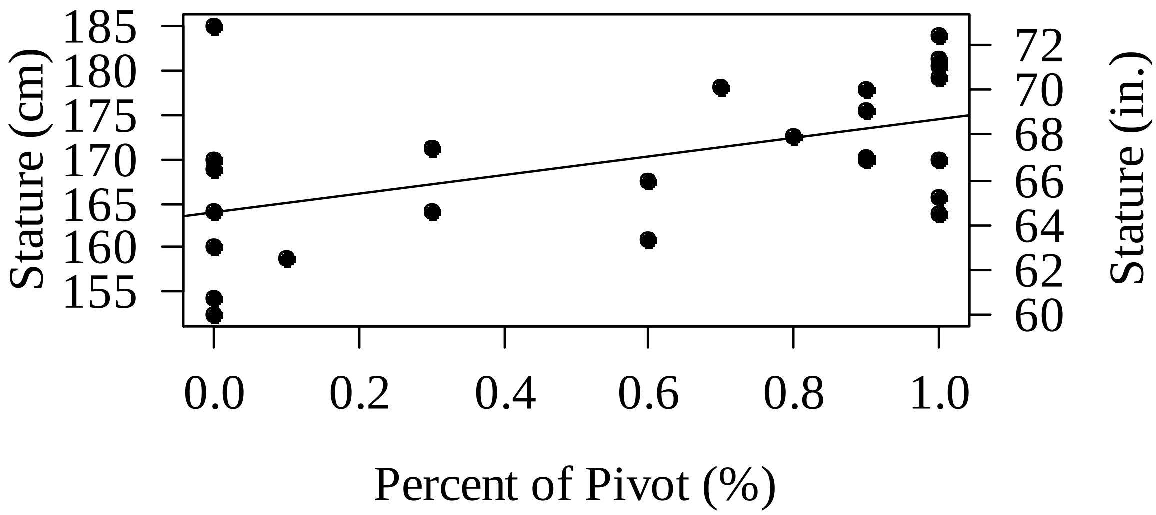


Figure 59. Scatter plot showing the correlation between drivers' statures and the percent of pivot in 10 baseline stopping tasks.

The result shows that the taller the driver, the more likely the driver will use foot pivoting instead of foot lifting when transferring the foot from the accelerator pedal to the brake pedal in a stopping maneuver.

Hypothesis 2 stated that when moving the foot from the accelerator pedal to the brake pedal in baseline stop sign tasks, there would be a significant positive correlation ($r > 0.5$) between the percentage of pivoting (the number of pivots divided by 10) and the shoe length, which means the greater the shoe length, the more pivots in the 10 baseline stopping tasks for each participant. The relationship between percentage of pivoting and the shoe length was investigated using Pearson product-moment correlation coefficient. There was a strong, positive correlation between the two variables ($r(25) = .50$, $p < .01$), with a high percentage of pivoting (M = 54%, SD = 44%) associated with greater shoe length (M = 29.9 cm, SD = 2.5 cm; Figure 60). The result shows that the longer the driver's shoe, the more likely the driver will use foot pivoting instead of foot lifting when transferring the foot from the accelerator pedal to the brake pedal in a stopping maneuver.

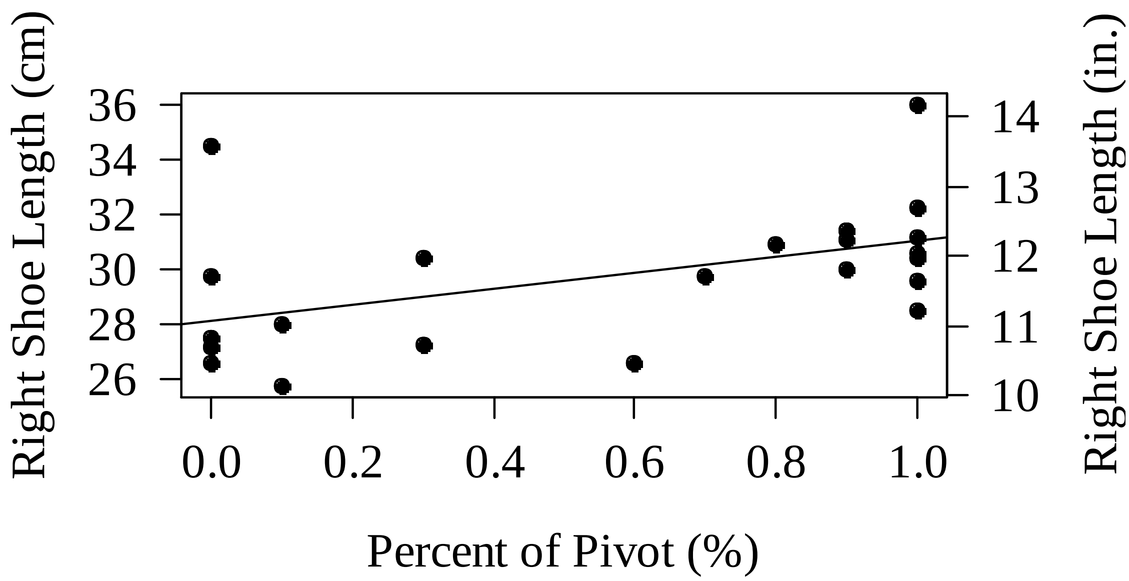


Figure 60. Scatter plot showing the correlation between drivers' shoe lengths and the percent of pivot in 10 baseline stopping tasks.

Two correlation tests were conducted (one between stature and percent of pivot, and the other between shoe length and percent of pivot) for the following reasons: a) Individuals may have disproportional stature and shoe length, and b) it is unknown whether stature or shoe length is more likely to affect percent of pivot. Among the participants in this study, the shoe length (*M* = 29.9 cm, *SD* = 2.5 cm) and the stature (*M* = 170.4 cm, *SD* = 9.1 cm) are significantly correlated ($r(23) = .87$, $p < .01$).

Hypothesis 3 stated that in all baseline stop sign tasks the average lateral foot placements on the brake pedal would be significantly to the left for drivers who used the foot lifting movement, as compared to the foot placements on the brake pedal by drivers who used the foot pivoting movement. In other words, the more pivots in the 10 baseline stopping tasks, the greater the average lateral foot placement on the brake pedal. As illustrated in Chapter Four section 5.2.2, the lateral foot placement was recorded as percentage values. The sign of the value ("+" or "- ") indicates the placement of the foot, where a positive value means the foot placement was on the right portion of the brake pedal, and a negative value means the foot placement was on the left portion of the brake pedal (Figure 61). Therefore, the greater the value is, the more rightward the lateral foot placement.

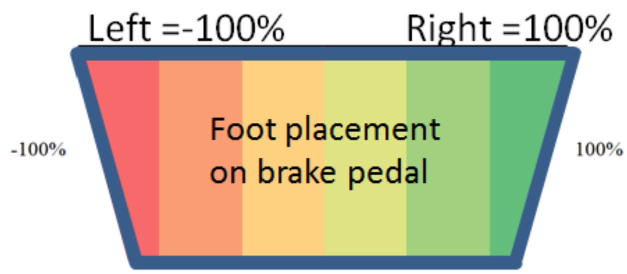


Figure 61. Color coding used to show lateral foot placement on brake pedal.

The discussion in Section 5.2.2 specified how much missing data were restored by using the mean lateral foot placement of 0.5 after the 10% brake pedal travel was reached. The mean lateral foot placement across 10 baseline tasks was used for Hypothesis 3. As stated earlier, one participant was missing the mean lateral foot placement, due to Tekscan computer failure. The relationship between the percentage of pivoting (M = 54%, SD = 44%) and the rightwardness of the lateral foot placement (M = 72%, SD = 31%) on the brake pedal was investigated using Pearson product-moment correlation coefficient. No significant positive correlation between the two variables was identified ($r(23) = -.12$, p =

.72), which means the foot movement method did not significantly affect the lateral foot placement on the brake pedal. See Figure 62.

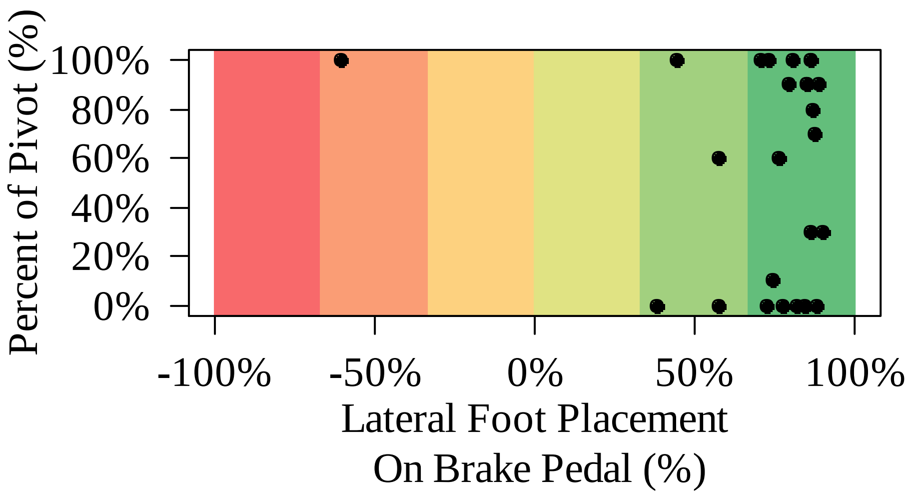


Figure 62. Scatter plot showing the correlation between the lateral foot placement on brake pedal and the percent of pivot in stop sign tasks.

5.4 Results for Startle-braking Task

Gap Two identified a need to understand older drivers' pedal operation characteristics in a startle-braking task. The pedal operation characteristics of a startle-braking task were compared with the pedal operation characteristics in the baseline stopping tasks. No PAEs were identified in the startle-braking task.

Hypothesis 4 stated that in a startle-braking task, the percentage of foot lifting would be significantly higher than the percentage of foot lifting in the baseline stopping tasks. As pointed out previously, two participants were missing the foot movement method data due to absence of the startle-braking task for those two participants. Because the percent of pivot data in baseline tasks (ratio data) is of different type than the foot transfer strategy in startle-braking (categorical/binary data), a one-sample *z*-test was used. A difference between the average percent of pivot in baseline stopping tasks across all participants (54%) and the percent of pivot in startle-braking task (21%), $z = -3.23$, $p < 0.01$, is significant. It is shown that the percent of pivot in startle-braking was significantly lower than that in baseline tasks, indicating that participants tended to use foot lifting in startle-braking.

Hypothesis 5 stated that the lateral foot placement on the brake pedal in a startle-braking task would be significantly to the right of the average lateral foot placement in the baseline stopping tasks. Similar to the data used for Hypothesis 4, two participants were missing the foot movement method data due to absence of the startle-braking task for those two participants. In addition, one participant is missing the foot placement data due to Tekscan computer failure.

A paired sample *t* test was used to compare the lateral foot placement between startle braking and baseline tasks, and results showed that the lateral foot placement in startle braking (M = 61%, SD = 20%) was not significantly to the right of the average lateral foot placement in the baseline tasks (M = 69%, SD = 31%; $t(22) = 1.49$, $p = .92$). In other words, although the foot movement time was much shorter in startle braking than in the baseline driving tasks, driver’s lateral foot placement was not necessarily to the right, compared with the average lateral foot placement in the baseline tasks. Figure 63 shows the average lateral foot placements in baseline tasks and in startle-braking task.

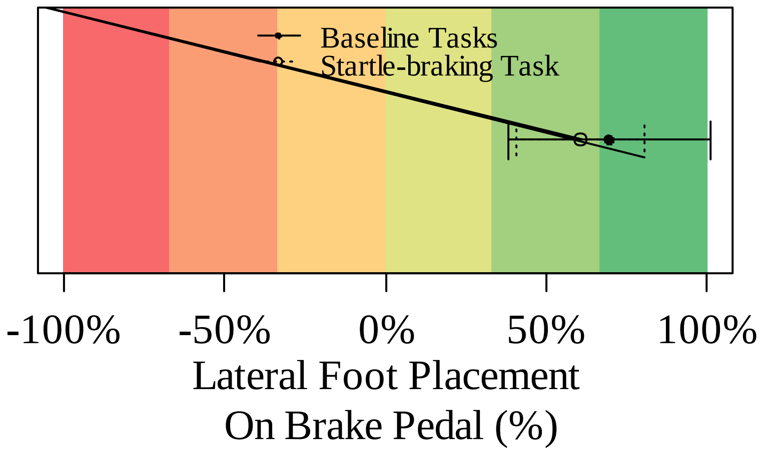


Figure 63. Average lateral foot placement on brake pedal in startle-braking task and baseline tasks.

5.5 Results for Pedal Calibration Tasks

Gap Three identified the need to understand the role of fatigue in older drivers' pedal usage. This was accomplished by having each participant perform two pedal calibration tasks: 1.) moving the foot from the accelerator pedal to the brake pedal as fast as possible for five times at the start of the 1.5 hour on-road assessment, and 2.) moving the foot from the accelerator pedal to the brake pedal as fast as possible for five times at the end of the 1.5 hour on-road assessment.

Hypothesis 6 stated that for older drivers the average foot transfer time of the last three of the five foot transfers in the final pedal calibration would be significantly longer than the average foot transfer time of the last three foot transfers in the initial pedal calibration. As stated previously, seven participants did not have mean foot transfer time data due to computer shut-off before the pedal calibration tasks or absence of the pedal calibration tasks. Result of a dependent sample *t*-test showed that the average foot transfer time of the last three of the five foot transfers in the final pedal calibration (*M* = 0.38 seconds, *SD* = 0.31 seconds) was not longer than the average foot transfer time of the last three foot transfers in the initial pedal calibration (*M* = 0.49 seconds, *SD* = 0.45 seconds; $t(18) = 1.26$, $p = .89$). In other words, it did not appear that the drivers were fatigued after 1.5 hours of driving, based on the comparison of foot transfer time between initial and final pedal calibration.

5.6 Results for Reaching-Out Tasks

Gap Four identified the need to understand older drivers' pedal operation when reaching out of the vehicle driver's window. The task involved the participants reaching out of the driver's window to swipe a card when entering a gated access. No PAEs were identified when drivers carried out the reaching out tasks.

Participants adopted different strategies (e.g., some participants opened the door to swipe the card and some reached through the window opening to swipe the card) in the reaching-out and swiping task. Table 21 summarizes participant's behavior in the reaching-out task. Six factors were manually coded by the researcher.

- Repositioning the vehicle: Participants needed to stop the vehicle at an appropriate distance to the card reader in order to swipe the card. Participants' preferred distance may not have been achieved at the first stopping attempt, and they needed to reposition the vehicle. This factor indicates participants' ability to manage the lateral position of the vehicle. Only cases where the participants needed to reverse the vehicle were counted positive for this factor.

- Using the parking gear: Engaging the parking gear prior to reaching out and swiping the card is a good practice and can prevent PAEs.
- Unbuckling the seat belt: Some participants chose to unbuckle the seatbelt prior to reaching out and swiping the card in order to gain more room for upper body movement and to compensate for the distance between the card reader and the vehicle. Therefore, it indirectly indicates participants' ability to manage the lateral position of the vehicle.
- Opening the door: Some participants chose to open the door to gain even more room for body movement and to compensate for the distance between the card reader and the vehicle.
- Positioning the left elbow: Each participant's left elbow position during the card swiping task was categorized as a) elbow on the door (the elbow was resting on the door) and b) elbow out of window (the elbow was positioned out of the window), which correspond to two levels of effort (in increasing order) required to successfully complete the card-swiping task. The left elbow position was coded only when participants did not open the door to swipe the card.
- Positioning of the head: Each participant's head position during card swiping was categorized as a) head in the car, b) head partially out of window, and c) head out of window, which correspond to three levels of effort (in increasing order) required to successfully complete the card-swiping task. The head position was coded only when participants did not open the door to swipe the card.

Note that the camera view used to categorize the participant’s head and arm position was captured by the camera installed on the topright corner of the windshield. More detailed sub-categorization (such as how much the arm reaches out of the vehicle during card-swiping) was not possible due to equipment limitations.

Table 21. Participants' Behaviors in the Reaching-Out Tasks

Participant	Location	Whether repositioned vehicle?	Whether used parking gear?	Whether unbuckled?	Whether opened door?	Left elbow position 1=on the door 2=out of window	Head position 1=in the car 2=partially out 3=out of window
1	Deck	No	No	No	No	2	1
	Lot	No	No	Yes	No	2	2
2	Deck*	NA	NA	NA	NA	NA	NA
	Lot	No	No	No	No	2	1
3	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
4	Deck	No	No	No	No	2	3
	Lot	No	No	No	No	2	1
5	Deck**	No	Yes	Yes	Yes	NA	NA
	Lot	No	No	No	No	2	1
6	Deck	No	No	No	No	1	1
	Lot	No	No	No	No	2	1
7	Deck**	No	Yes	Yes	Yes	NA	NA
	Lot	No	No	No	No	2	1
8	Deck	Yes	No	Yes	No	2	3
	Lot	No	No	No	No	2	1
9	Deck*	NA	NA	NA	NA	NA	NA
	Lot	No	No	No	No	2	1
10	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
11	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
12	Deck***	NA	NA	NA	NA	NA	NA
	Lot***	NA	NA	NA	NA	NA	NA
13	Deck	No	No	No	No	2	2
	Lot	No	No	No	No	2	1
14	Deck	No	No	Yes	No	2	3
	Lot	No	Yes	Yes	No	2	3
15	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
16	Deck**	No	Yes	Yes	Yes	NA	NA
	Lot	No	No	No	No	1	1
17	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
18	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
19	Deck**	No	Yes	Yes	Yes	NA	NA
	Lot	No	No	No	No	2	2
20	Deck*	NA	NA	NA	NA	NA	NA
	Lot	No	No	Yes	No	2	3
21	Deck*	NA	NA	NA	NA	NA	NA
	Lot	No	No	No	No	1	1
22	Deck*	NA	NA	NA	NA	NA	NA
	Lot*	NA	NA	NA	NA	NA	NA
23	Deck*	NA	NA	NA	NA	NA	NA
	Lot*	NA	NA	NA	NA	NA	NA
24	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1
25	Deck**	Yes	Yes	Yes	Yes	NA	NA
	Lot	No	No	No	No	2	1
26	Deck	No	No	No	No	2	1
	Lot	No	No	No	No	2	1

Note. * indicates that the participants did not swipe the card where all six factors are not available. ** indicates that the participants opened the door to swipe the card where the left elbow position and head position are not available. *** indicates that the camera failed at the site where all six factors are not available.

For the card-swiping task at the entrance of the parking deck, 14 participants had elbow or head position data. Thirteen out of 14 participants (92.9%) positioned their left elbow out of the window, and one participant (7.1%) rested the left elbow on the door while swiping card. For head position, 10 out of 14 participants (71.4%) did not position their head out of the window;three participants (21.4%) positioned their head partially out of the window; and one participant (7.1%) positioned his/her head out of the window. For the card-swiping task at the entrance of parking lot, 23 participants had elbow or head position data. Twenty-one out of 23 participants (91.3%) positioned their elbow out of the window, and two participants (8.7%) rested their elbow on the door while swiping the card. For head position, 19 out of 23 participants (82.6%) did not position their head out of the window; two participants (8.7%) positioned their head partially out of the window; and two participants (8.7%) positioned their head out of the window.

Hypothesis 7 stated that the foot transfer time when approaching a curb-side device (i.e., a card reader, a drive-through food service, etc.) would be significantly longer than the average foot transfer time in the baseline stop sign maneuvers. It was mentioned earlier that seven participants were missing the mean foot transfer time due to a) the camera blacking out and participant' s interaction with the card reader not being recorded; b) at least one gate (either at the parking deck or the parking lot) being open at the participant's arrival so that the participant did not have to brake to enter the gate. A dependent sample *t*-test revealed that the average foot transfer time when approaching a curb-side device (*M* = 1.17 seconds, *SD* = 0.55 seconds) was not significantly longer than the average foot transfer time in the baseline tasks (*M* = 1.89 seconds, *SD* = 1.17 seconds; $t(18) = 2.34$, $p = .98$). In other words, approaching a curb-side device did not slow down the driver's foot movement from the accelerator pedal to the brake pedal. Because the *p* value was large, the opposite relationship was tested as well using a *t*-test; it was identified that the average foot transfer time in the baseline tasks (*M* = 1.89 seconds, *SD* = 1.17 seconds) was significantly longer than the average foot transfer time when approaching a curb-side device (*M* = 1.17 seconds, *SD* = 0.55 seconds; $t(18) = 2.34$, $p < .05$). The result indicates that when approaching a gate, the foot movement from the accelerator pedal to the brake pedal becomes faster compared to that in the baseline tasks.

To understand why the average foot transfer time when the drivers approached the card readers turned out to be faster than the average foot transfer time in the baseline tasks, drivers' foot movement after transferring from the accelerator pedal to the brake pedal was observed. It was identified that in the first reaching-out task (when entering the gated access to the parking deck), 13 out of 20 participants (65.0%) had foot hovering (releasing and pressing the brake pedal) after transferring the foot from the accelerator pedal to the brake pedal. In the second reaching-out task (when entering the gated access to the parking lot), 8 out of 23 participants (34.8%) also had foot hovering.

Hypothesis 8 stated that for older drivers who kept their right foot on the brake pedal while reaching out of the vehicle at the gated entrance to the parking deck, the right-most lateral foot placement would be significantly rightward of the foot placement before reaching out the driver's side window. As explained previously, 12 participants were missing both the mean lateral foot placement before reaching out and the right-most lateral foot placement during reaching out. This was due to a) the camera blacking out and the participant' s interaction with the card reader not being recorded; b) at least one gate (either at the parking deck or the parking lot) being open, so the participant did not have to stop and swipe the card; c) the participant's foot not being on the brake pedal; and/or d) the Tekscan laptop failing during the drive.

A dependent sample *t*-test revealed that the right-most lateral foot placement (M = 88%, SD = 3%) was significantly rightward of the foot placement before reaching out (M = 84%, SD = 6%; $t(13) = -3.09$, $p < .01$, Cohen's $d = .82$). Therefore, when the driver was reaching out of the left window, the foot did edge to the right. Note that among eight lifters (who used foot lifting for all baseline tasks), only one participant had complete data for this hypothesis. The large number of missing data among lifters may reduce the impact of this finding. Figure 64 shows the right-most lateral foot placement and the foot placement before reaching out.

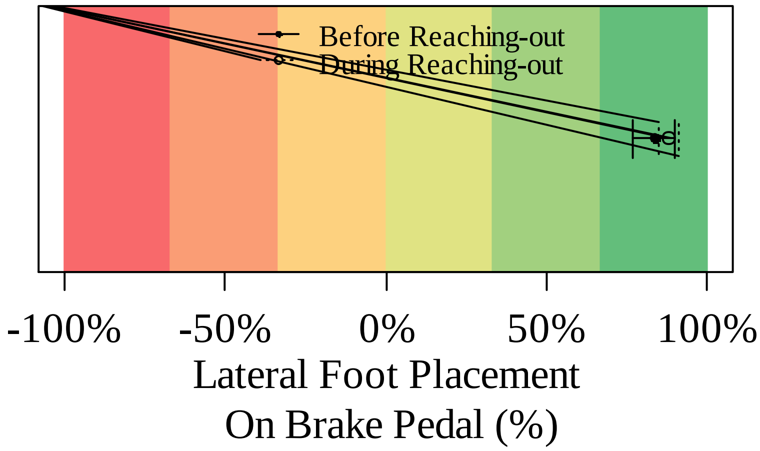


Figure 64. Lateral foot placement on brake pedal in reaching-out task.

As discussed in Chapter Four section 4.6.2.4, the card reader for the parking lot was replaced after seven participants had completed the study. The card reader for the parking deck was not replaced. Because new card reader is more sensitive, the participant did not have to hold the card as close as before to open the gate, which may affect the result of this hypothesis. To investigate the effect of the new card reader on this hypothesis further, the data were split into two subsets, one with participants using the old card reader and the other with those using the new card reader. Additionally, only data at the parking lot were used because the card reader at the parking deck was not replaced during the study, and the data were not affected. All seven participants who used old card reader at parking lot had complete data set. Among the 19 participants who used new card reader at parking lot, four missed lateral foot placement data due to Tekscan laptop failure (one participant affected), camera blacking out (one participant affected) or gate being open (two participants affected). For the cases where the old card reader was used, the right-most lateral foot placement (M = 87%, SD = 7%) was significantly rightward of the foot placement before reaching out (*M* = 77%, *SD* = 15%; $t(6) = -3.00$, $p < .05$, Cohen's $d = .86$). Figure 65 shows the right-most lateral foot placement and the foot placement before reaching out using data collected from the old card reader.

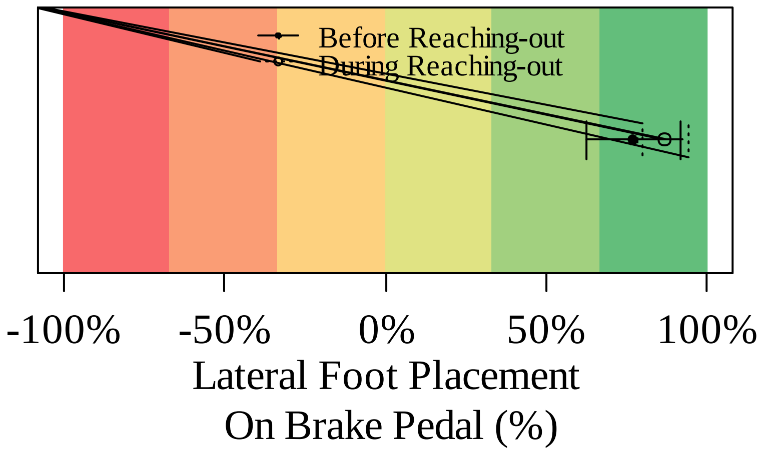


Figure 65. Lateral foot placement on the brake pedal in reaching-out task using old card reader.

For the cases where the new card reader was used, the normality assumption of *t*-test was violated ($p < .05$ in Shapiro-Wilk test). A one-sided Wilcoxon Signed-Rank Test indicated that the right-most lateral foot placement (*M* = 86%, *SD* = 10%) was not significantly rightward of the foot placement before reaching out (*M* = 85%, *SD* = 10%; $z = -1.03$, $p = .16$).

It was also identified that many drivers tended not to use the parking brake when interacting with the curb-side devices: 14 out of 19 participants (73.7%) did not use the parking brake at the entrance to the parking deck, and 22 out of 23 participants (95.7%) did not use the parking brake at the parking lot entrance. Findings of Hypothesis 8 revealed that the right-most lateral foot placement on the brake pedal during the reaching-out was significantly to the right of the lateral foot placement before reaching out. Similarly, the force applied on the brake pedal during reaching-out (M = 13.9 N, SD = 7.8 N) was significantly greater than the force applied on brake pedal before reaching out (M = 11.8 N, SD = 6.7 N; $t(13)=-2.00$, $p < .05$, Cohen's d = .29). It indicated that when reaching out and swiping the card, the driver would press harder on the brake pedal. Like Hypothesis 8, this result might be affected by the replacement of the card reader. Therefore, the data were split into two subsets: one with participants using the old card reader and the other with participants using the new card reader. Likewise, only the data collected from the reaching-out task at the parking lot would be used for this investigation because the card reader at the entrance of the parking deck was not replaced. For the cases where the old card reader was used, the normality assumption of t-test was violated ($p<.05$ in Shapiro-Wilk test). A one-sided Wilcoxon Signed-Rank Test indicated that the force applied on brake pedal before reaching out (M = 20.7 N, SD = 25.8 N) was not significantly less than the force applied on brake pedal during reaching out (M = 22.9 N, SD = 21.3 N; $z=-.57$, p = .31). For the cases where the new card reader was used, the force applied on brake pedal before reaching out (M = 13.0 N, SD = 7.3 N) was not significantly less than the force applied on brake pedal during reaching out (M = 14.5 N, SD = 8.4 N; $t(14) = -1.12$, p = .14).

Hypothesis 9 stated that there would be a significantly negative correlation between the driver's stature and the time it took him or her to reach out and successfully finish the card-swiping task. As stated before, eight participants were missing the reaching-out time, due to a) the camera blacking out so that the participant' s interaction with the card reader was not recorded; b) the participant stepping out of the vehicle; c) at least one gate (either at the parking deck or the parking lot) being open and the participant did not have to stop and swipe the card. A Pearson's correlation test revealed that there was no significantly negative correlation between the stature (M = 170.4 cm, SD = 9.1 cm) and the average reaching-out time (M = 3.65 seconds, SD = 2.64 seconds) at both gated entrances ($r(16) = .22$, $p = .37$). It did not necessarily take a taller driver less time to reach out and interact with a curb-side device.

Like Hypothesis 8, the result of the Hypothesis 9 was likely affected by the replacement of the card reader. Therefore, the data were again split into two subsets: one with participants using the old card reader and the other with those using the new card reader. Likewise, only the data collected from the reaching-out task at the parking lot would be used for this investigation because the card reader at the entrance of the parking deck was not replaced. All seven participants who used the old card reader at the parking lot had a complete data set. Among the 19 participants who used the new card reader at the parking lot, three were missing the reaching-out time due to the camera blacking out (one participant affected) or the gate being open (two participants affected). The result of Pearson's correlation test was not significant for data of the old card reader (stature: M = 171.1 cm, SD = 8.8 cm; reaching-out time: M = 3.1 seconds, SD = 1.6 seconds; $r(5) = -.51$, $p = .23$). The data of the new card reader violated normality assumption ($p < .05$ in Shapiro-Wilk test). Therefore, the Spearman's Rank Order Test was used, and the stature (M = 170.3 cm, SD = 10.2 cm) was not significantly correlated with the reaching- out time (*M* = 2.1 seconds, *SD* = .83 seconds; r_s = .05, *p* = .86. The results show that in both cases it did not take a taller driver less time to reach out and complete the card-swiping task.

5.7 Results for Forward Parking Tasks

Gap Five identified a need to understand forward parking tasks where older drivers pull vehicles into the reserved parking spaces in both a parking deck and an open parking lot. No PAEs were identified when drivers carried out the forward parking tasks.

Hypothesis 10 stated that older drivers' foot transfer time in an open parking lot with greater environmental space is significantly less than that in a darker parking deck with less space. As pointed out previously, five participants were missing the foot transfer time either at the parking lot or the parking deck or both, which was due to camera black-out. A dependent sample *t*-test revealed that the foot transfer time in an open parking lot (*M* = 1.82 seconds, *SD* = 1.26 seconds) is not significantly less than that in a darker parking deck (*M* = 2.21 seconds, *SD* = 1.54 seconds; *t*(20) = -.83, *p* = .21). A driver's foot transfer time does not differ between a bright, open parking lot and a darker parking lot with less space.

It was also identified that when parking in the parking deck, 5 out of 23 participants (21.7%) used foot hovering above the brake pedal, and when parking in the parking lot, 6 out of 24 participants (25.0%) used foot hovering.

In this chapter, the results of data analyses for the 10 research hypotheses were presented and are summarized in Table 21. In the next chapter, the results will be discussed further in terms of their implications to the understanding of pedal operation characteristics of older drivers.

Table 22. Summary of Results

			Results			
Five research gaps		10 research hypotheses abbreviated	Whether Significant	*Statistics*	Means (if applicable)	Effect Size
1	Baseline stopping tasks	Stature ~ pivot vs. lift	Yes	*r*=.51*	N/A	N/A
		Shoe length ~ pivot vs. lift	Yes	*r*=.50*	N/A	N/A
		Placement on pedal ~ pivot vs. lift	No	*r*=-.12	N/A	N/A
2	Startle-braking task	Strategy same as baseline?	Yes	*Z*=-3.23*	Average percent of pivot in baseline stopping tasks =53.8%; Average percent of pivot in startle-braking task=20.8%	N/A
		Placement same as baseline?	No	*t*=1.49	Average lateral foot placement in startle braking=60.5%; Average lateral foot placement in the baseline tasks=69.4%	N/A
3	Fatigued foot transfer tasks	Transfer times at calibration initial vs. final	No	*t*=1.26	Average foot transfer time of the last three of the five foot transfers in the final pedal calibration=0.38 seconds; Average foot transfer time of the last three foot transfers in the initial pedal calibration=0.49 seconds	N/A

4	Gate reaching-out tasks	Transfer time greater than baseline?	No	*t*=2.34	Average foot transfer time when approaching a curb-side device=1.17 seconds; Average foot transfer time in the baseline tasks=1.89 seconds	N/A
		Reaching and placement	Yes	*t*=-3.09*	Average right-most lateral foot placement=87.8%; Average foot placement before reaching out=83.6%	Cohen's d=.82
		Stature's impact on reaching time	No	*r*=.22	N/A	N/A
5	Parking deck vs. lot	Transfer time lot vs. deck	No	*t*=-.83	Average foot transfer time in an open parking lot=1.82 seconds; Average foot transfer time in a darker parking deck=2.21 seconds	N/A

Note. **p*<.01.

CHAPTER SIX

DISCUSSION

6.1 Introduction

The objective of this research study was to understand pedal operation characteristics of older drivers in various driving tasks that are associated with higher risk of PAEs, such as parking, performing an emergency stop, and reaching out of the driver's window. To further existing knowledge within this topic, 10 research hypotheses were formulated. In the previous chapter, results of the statistical tests for the 10 hypotheses are presented. To gain more insights into the findings, this chapter will further interpret and discuss the results. Section 6.2 is dedicated to the research gaps and hypotheses. Section 6.3 is on the implications of the study and Section 6.4 is about the limitations of the study and future work. Section 6.8 is the conclusion section.

6.2 Discussion of Study Results

6.2.1 Baseline Stopping Tasks

Older drivers' behavior in 10 stopping tasks was used as the baseline performance, and their behavior in other driving tasks was compared to the baseline performance. It was hypothesized that when moving the foot from the accelerator pedal to the brake pedal in the baseline stop sign tasks, there would be a significant positive correlation ($r > 0.5$) between the percentage of foot pivoting (the number of pivots divided by 10) and both the stature and the shoe length of the older drivers, respectively. Findings for both hypotheses proved to be significant, which suggested that the taller the driver is and the longer the driver's shoe is, the more likely the driver will use foot pivoting instead of foot lifting when transferring the foot from the accelerator pedal to the brake pedal in a stopping task. Both results align with Crandall's study (1996) which was carried out in a driving simulator with younger drivers. The study identified that the longer the shoe and the taller the stature, the more likely the driver will use foot pivoting. Hence, it can be deduced that the foot movement method selection (lifting and pivoting) is less of a habitual behavior, but rather anthropometrically dependent. Compared with foot lifting where drivers lift their foot off the floor, foot pivoting only requires drivers to rotate the foot around the heel, while resting the heel on the floor. In order to pivot the foot, the driver has to rest the heel close to the pedals. In other words, the longitudinal distance between the pedal and the heel-floor contact point needs to be short, so that when pivoting from one pedal to the other and when pressing down the pedal, the driver will have a shoe-pedal contact area that is large enough that the foot will not slip off the pedal. However, as observed by CDRSs, short-statured drivers' "carfit" in the driver's seat is often worse than that of tall-statured drivers (U.S. Department of Transportation, 2012). Hence, it is suspected that short-statured drivers find it hard to anchor the heel on the floor close enough to the pedals for foot pivoting, while remaining properly seated. This may explain why shorter drivers tend to use foot lifting and why taller drivers tend to use foot pivoting. With respect to the shoe length, it can been identified from Figure 60 that participants with shoe length over 29 cm (11.4 inches; roughly equivalent to Men's shoe size of 12 or Women's shoe size of 13) were more likely to use foot lifting as the foot transfer strategy. It is also worth recording the participant's sitting position and correlate it with driver's foot transfer strategy in future studies. Two important sitting position parameters to record are driver's heel anchor position on the vehicle floor and knee angle when gently resting foot on the brake pedal. In the current study, pressure sensor was installed on the vehicle floor. However, to conceal the sensor from the participants, vehicle floor mat was placed on top of the sensor and the captured pressure data were "washed-out".

Hypothesis 3 stated that in all baseline stop sign tasks the average lateral foot placements on the brake pedal would be significantly to the left for older drivers who used the foot lifting movement, as compared to the foot placements on the brake pedal by older drivers who used the foot pivoting movement. However, the hypothesis was not proven to be significant, suggesting that the lateral foot placement (M = 72%, SD = 31%) is not necessarily affected by the percent of foot pivoting (M = 54%, SD = 44%). The hypothesis was formulated based on the fact that by anchoring the heel on the vehicle floor, the range of lateral foot placement is limited by the shoe length; the driver will not be able to reach further to the left on the brake pedal if foot pivoting is used, whereas when using foot lifting, the driver will purposefully move the foot further to the left to avoid pressing on the accelerator pedal. The results did not support such reasoning, and drivers did not press the left portion of the brake pedal. There is a risk associated with the fact that drivers' foot placement on the pedal is not to the left when using foot lifting compared with foot pivoting. When using foot pivoting, the heel anchored on the vehicle floor may serve as a reference for drivers and may help them to distinguish the accelerator pedal and the brake pedal. When using foot lifting, it is likely that when drivers lift the foot off the accelerator, they lose track of their “foot aiming position” on the pedal area. It is possible that the foot “lands” on the accelerator pedal for a second time while intending to press the brake pedal, which causes a pedal error. No PAEs were identified when drivers carried out the baseline stopping tasks.

6.2.2 Startle-braking Task

Older drivers’ foot lifting and lateral foot placement on the brake pedal in a startle-braking task were analyzed. Hypothesis 4 stated that in a startle-braking task, the percentage of foot lifting would be significantly higher than the percentage of foot lifting in the baseline stopping tasks. The average percent of pivot in baseline stopping tasks across all participants (54%) was significantly higher than the percent of pivot in startle-braking task (21%), $z = -3.23$, $p < 0.01$. Findings revealed that in startle-braking, drivers are more likely to use a foot lifting movement. This means the foot movement method in startle braking may not be anthropometrically dependent, which is different from what was observed in the baseline stopping tasks. As discussed in Chapter Three, limb contractions occur as a result of startle stimuli (Bridger, 1995). In a startle-braking scenario, tension of the quadriceps brought on by startle stimuli may explain the fact that more foot lifting was observed in the startle-braking task compared to the baseline stopping tasks.

Hypothesis 5 stated that the lateral foot placement on the brake pedal in a startle-braking task would be significantly to the right of the average lateral foot placement in the baseline stopping tasks. The hypothesis was formulated based on the overrepresentation of startle braking in all types of driving scenarios in terms of PAE risks (U.S. Department of Transportation, 2012). It is suspected that when startled, drivers tend to make a fast foot movement and spend little time to aim the foot properly on the brake pedal. Because the time allowed for leftward foot movement was short, the lateral foot placement can be further to the right than the foot placement in the baseline stopping tasks. In extreme cases, the driver may even completely miss the brake pedal and press on the accelerator pedal. The result showed that the lateral foot placement in startle braking (M = 61%, SD = 20%) was no more rightward than that in the baseline stopping tasks (M = 69%, SD = 31%), indicating that the lateral foot placement is independent of whether there is a startle stimuli. The result fails to explain the overrepresentation of PAEs caused by startle response (Department of Transportation, 2012). No PAEs were identified in the startle-braking task included in the study.

Although the literature revealed that PAEs could more likely occur when the drivers were startled (Department of Transportation, 2012), there was no account of whether the drivers took their foot off the accelerator pedal. Therefore, it is possible that the drivers were in such a panic that they were “frozen” and could not make any reactions to the situation. It is also possible that the drivers simply pressed the accelerator pedal harder, mistakenly thinking it was the brake pedal. These two explanations are supported by the two concepts brought up by Schmidt (1989): “perceptual narrowing” and “habitual responses under stress”. As stated in Section 2.8.2, the driver’s information-processing ability decreases under the condition of panic, so effective solutions (such as “moving the foot”) are not taken because the stress narrows the driver’s focus. In addition, the action of braking for these very experienced drivers is an automatic process making it a well-practiced response. In the stressful case of unintended acceleration, the driver’s automatic response leads to “braking harder” on the accelerator pedal (Schmidt, 1989).

6.2.3 Pedal Calibration Tasks

Maximum foot transfer speed between the accelerator pedal and the brake pedal for calibration tasks was measured to understand the role of fatigue in older drivers’ pedal usage. Hypothesis 6 stated that the average foot transfer time of the last three of the five foot transfers in the final pedal calibration would be significantly longer than the average foot transfer time of the last three foot transfers in the initial pedal calibration, due to fatigue. It is recognized that PAEs are more likely to occur in parking lots compared to other locations (U.S. Department of Transportation, 2012). In addition, it is suspected that PAEs are associated with driver fatigue, given that prior to parking in a lot, drivers may have just completed driving for awhile. To find out if drivers exhibited clear signs of fatigue, the maximum foot transfer speed between the accelerator pedal and the brake pedal was measured after 1.5 hours of driving. The result showed that the average foot transfer time of the last three of the five foot transfers in the final pedal calibration (M = 0.38 seconds, SD = 0.31 seconds) was not significantly longer than the average foot transfer time of the last three foot transfers in the initial pedal calibration (M = 0.49 seconds, SD = 0.45 seconds). There are two potential explanations for the result: a) The route used was much shorter than the daily miles driven by the older drivers and therefore did not sufficiently fatigue the participants. b) Participants failed to consistently achieve maximum foot transfer speed in the pedal calibration tasks. According to the U.S. Department of Transportation (2011), the most recent data from 2009 show 24.0 daily miles of travel for persons over the age of 65, which is comparable to the 27.0 mile route used in the study. In addition, the study posed more physical burdens by having the participants repetitively carry out driving tasks such as reversing and forward parking into designated spaces. Therefore, the drive route used in the current study represents no less than the daily physical burden encountered by the average older driver. Given that, it is possible that the participants failed to make foot transfers at their maximum speed when carrying out the pedal calibration tasks. The comparison of mean foot transfer time at the initial and final pedal calibration revealed that the mean foot transfer time at the final calibration (M = 0.38 seconds, SD = 0.31 seconds) was less than that at the initial pedal calibration (M = 0.49 seconds, SD = 0.45 seconds). This could be the evidence that the participants did not achieve their maximum foot movement speed at the initial pedal calibration. It is possible that the participants did not fully understand the instructions given by the CDRS to move their foot as fast as possible between the pedals.

6.2.4 Reaching-Out Tasks

During this study each participant carried out two reaching-out-and-swiping card tasks; one took place at the gated entrance of an outside parking lot, and the other at the gated entrance of a parking deck. Hypothesis 7 stated that the foot transfer time when approaching a curb-side device (i.e., a card reader, a drive-through food service, etc.) would be significantly longer than the average foot transfer time in the baseline stop sign maneuvers. The rationale behind the hypothesis was that when drivers are about to carry out a card-swiping task, they tend to slow down the foot movement in order to manage the distance between the vehicle and the card reader, thereby increasing cognitive load for the driver and increasing the foot transfer time. However, the result indicated that the average foot transfer time when the participants drove towards the card reader (*M* = 1.17 seconds, *SD* = 0.55 seconds) was not significantly longer than the average foot transfer time in baseline stopping tasks (*M* = 1.89 seconds, *SD* = 1.17 seconds). Futhermore, the average foot transfer time when the participants drove towards the card reader (*M* = 1.17 seconds, *SD* = 0.55 seconds) was significantly less than the average foot transfer time in baseline stopping tasks (*M* = 1.89 seconds, *SD* = 1.17 seconds). The possible reason is that when approaching the card readers, the participants used the brake pedal to control the speed (repetitively tapping the brake pedal) and slowly cruised towards the card readers. In the first reaching- out task (when entering the gated access to the parking deck), 13 out of 20 participants (65.0%) had foot hovering (releasing and pressing the brake pedal) after transferring the foot from the accelerator pedal to the brake pedal. In the second reaching-out task (when entering the gated access to the parking lot), 8 out of 23 participants (34.8%) also had foot hovering. The fact that many participants chose to use the brake pedal to mange the speed may explain why the average foot transfer time when driving towards the card reader was not greater than the average foot transfer in the baseline stopping tasks.

Hypothesis 8 stated that for older drivers who kept their right foot on the brake pedal while reaching out of the vehicle at the gated entrance to the parking deck, the right-most lateral foot placement would be significantly rightward of the foot placement before reaching out the driver's side window. The hypothesis was proven to be true and the right-most lateral foot placement (*M* = 88%, *SD* = 3%) was significantly rightward of the foot placement before reaching out (*M* = 84%, *SD* = 6%) with a Cohen's *d* of .82 (large effect), indicating that the foot edged rightward when a driver reached out of the left window. The reason the lateral foot placement during the reaching-out tasks was investigated is that a portion of PAEs has occurred while drivers were reaching for something (U.S. Department of Transportation, 2012). It could be that drivers were reaching out to swipe a card at a gated access, ordering food using drive-through service or interacting with a drive-through bank service. It is suspected that in these types of scenarios, drivers' foot aiming positions change as a result of looking left, looking right or sitting out-of-position. As mentioned in section 2.8.2, Schmidt (1989) stated that head turning may cause the foot-aiming position to bias to the opposite direction. For example, if a driver turns his or her head to the left when reaching out, the foot- aiming position may be biased to the right and may cause the foot to accidentally press on the accelerator pedal. However, Schmidt's conclusion was inferred from experiments where only hand movements were involved rather than foot movements.

As pointed out in Section 5.6, the card reader at the entrance of the parking lot was replaced so that drivers did not have to reach out as far to swipe the card. To study the effect of different card reader, the data were subset into "data collected using the old card reader" and "data collected using the new card reader". It was identified that the right-most lateral foot placement (*M* = 87%, *SD* = 7%) during reaching out of the window was significantly to the right of the lateral foot placement before reaching out (*M* = 77%, *SD*

= 15%) only with the data collected using the old card reader (where drivers had to reach out further to swipe the card). This finding provided further evidence that reaching out (an upper body movement) can bias the lateral foot placement on the brake pedal.

Reaching out of the window is a complex action involving movements of the head, arm and upper body. No controlled experiment has been done yet to quantify the relationship between upper body movements (e.g., how much the head turns to the left, how much the arm reaches out, how much the upper torso tilts to the left) and the amount of foot-aiming bias (e.g., how much the foot-aiming position moves to the right). In the current study, the upper body movement was recorded by video cameras and can be manually categorized as “turn left”, “turn right” and “neutral”. However, the movement can hardly be quantified.

Another interesting and relevant finding in the study was that many drivers tended not to use the parking brake when interacting with the curb-side devices: 14 out of 19 participants (73.7%) did not use the parking brake at the entrance to the parking deck and 22 out of 23 participants (95.7%) did not use the parking brake at the parking lot entrance. When drivers are driving alone instead of being accompanied by the CDRS, it is highly likely that the percentage of the drivers using the parking brake when interacting with curb-side devices will be even lower.

Hypothesis 9 stated that there would be a significantly negative correlation between the driver’s stature and the time it took him or her to reach out and successfully finish the card-swiping task. The result did not show a significant result; therefore, the time to complete the reaching-out task (*M* = 3.65 seconds, *SD* = 2.64 seconds) is not necessarily associated with driver's stature (*M* = 170.4 cm, *SD* = 9.1 cm). As in hypothesis 8, hypothesis 9 was also tested with the data collected using the old card reader and data collected with the new card reader, respectively. Neither of them was significant. A potential explanation is that the short-statured drivers may have maneuvered more closely to the card reader than the tall-statured drivers, which compensated for short drivers' lack of reachability. In the current study, the driving task of reaching-out-and-swiping a card was carried out naturally without the participants being told how far from the card reader they should stop the car. In other words, the distance between the vehicle and the card-reader was not controlled.

6.2.5 Forward Parking Tasks.

Forward parking tasks where older drivers maneuvered the vehicle into reserved parking spaces in both a parking deck and an open parking lot were analyzed.

Hypothesis 10 stated that older drivers' foot transfer time in an open parking lot with greater environmental space would be significantly less than that in a darker parking deck with less space. The statistical test revealed that there was no significant difference in the foot transfer time between parking lot (*M* = 1.82 seconds, *SD* = 1.26 seconds) and parking deck (*M* = 2.21 seconds, *SD* = 1.54 seconds), even though they are associated with different spaciousness and lighting conditions. The potential reason for the result is that instead of slowing down the foot transfer from the accelerator pedal to the brake pedal, some participants preferred to use the brake pedal to manage the speed. This is similar to the reason why Hypothesis 7 was not proven to be significant. When parking in the parking deck, 5 out of 23 participants (21.7%) used foot hovering above the brake pedal, and when parking in the parking lot, 6 out of 24 participants (25.0%) used foot hovering. Therefore, it is likely that using the brake to manage speed reduced the chance that drivers would make slow foot transfers in a dark and tight parking deck.

6.3 Implications and Lessons Learned

6.3.1 Types of Pedal Application Error

PAE can be in various forms. As stated in the Section 2.8.2, Rogers and Wierwille (1988) classified the PAEs into four categories based on severity: serious (driver mistakes one pedal for the other or presses both pedals at the same time), catch (pedal interferes with foot movements), scuff (similar to catch but the interference is minimal) and instructional errors (failure to perform instructed tasks). Serious errors, as classified by the authors, were categorized as: a) mistaking accelerator pedal for brake pedal; b) mistaking brake pedal for accelerator pedal; c) overlapping both pedals while pressing accelerator pedal; and d) overlapping both pedals while pressing brake pedal. The authors identified that serious errors occurred 15 times throughout the entire 72-hour study and each type of serious error occurred at least once, although they did not provide the number of occurances. The authors also investigated the PAEs under four different pedal configurations and two vehicle speeds (above 20 mph and below 20 mph) and identified that pedal configurations made a difference on the total number of PAEs. The pedal configuration differences in error rate also varied according to the severity of errors. They identified that pedal configurations made a difference on catch errors when the vehicle speed was below 20 mph and on scuff errors when the vehicle speed was both above and below 20 mph.

Schmidt et al. (1997) queried the NCSC database and identified 219 crashes that were caused by PAE. Two types of PAE (i.e., foot slipping off and mistakenly pressing the accelerator pedal) were correlated with the driving scenarios (Table 23). When drivers were avoiding obstacles or when the vehicles were stopped, almost all PAEs were in the form of the foot slipping off. When the vehicles hit or were hit by other objects, or when the vehicles were turning, the majority of the PAEs were in the form of pressing the accelerator pedal mistakenly. The reasons behind the correlation, according to the authors, were not clear. It is suspected that the reason all PAEs were in the form of pressing the accelerator pedal mistakenly when the vehicles hit or were hit by other objects was that the drivers were panicked by the crashes that they failed to take their foot off the accelerator pedal. It is also suspected that when the vehicles were turning, drivers' kinesthetic cues that they usually rely on to locate the pedals did not help to provide accurate pedal positioning so that drivers pressed the accelerator pedal mistakenly.

Table 23. Types of PAE and Driving Scenarios (Schimidt et al., 1997)

Driving Scenario	**Foot slipping off**	**Pressing the accelerator pedal mistakenly**
Avoiding an obstacle	8	0

Vehicle was stopped	25	1
Slowing down	42	13
Vehicle hit or was hit by another object	0	12
Turning	6	27

Department of Transportation (2012) also investigated the types of PAEs by querying the narrative descriptions of the crashes in two databases, i.e., NHTSA's National Motor Vehicle Crash Causation Survey (NMVCCS) and the North Carolina Crash State Crash Database (NCSC) . Of the 110 crashes that were related to PAE identified from the NMVCCS database, 31 were caused by the driver applying the wrong pedal and 2 were caused by the drivers' foot slipping off the brake pedal and pressing the accelerator pedal. Of the 2930 crashes that were related to PAE identified from the NCSC database, 2411 were caused by the driver applying the wrong pedal and 58 were caused by the drivers' foot slipping off the brake pedal and pressing the accelerator pedal. In fact, the results may be an underestimation of the percent of cases where the foot slipped onto the accelerator pedal because some of the narrative descriptions of crashes may not be detailed enough to include such information as to whether the foot slipped off the brake pedal.

6.3.2 Vehicle Make and Type

It is of interest to find out whether specific vehicle makes are tied with a higher percentage of PAEs. A further question to consider is whether these vehicles have different pedal configurations. Department of Transportation (1989) identified 10 vehicles with above-average complaint rate of sudden acceleration for further investigation. However, the study did not disclose the market share of the identified vehicles. Therefore, it could be that there were more of those vehicles in the market than others so they received more complaints. This study also measured the pedal layouts of 17 vehicles, some of which were overrepresented in sudden acceleration incidents and the others were used as controls (the report did not reveal the brand and number of the selected vehicles). The report stated that the pedal layout in the vehicles from the control group made it difficult for drivers to apply substantial force on both pedals simultaneously. It is suspected that the vehicles in the control group had greater lateral pedal separations so that it was difficult to press both pedals at the same time.

As reviewed in Section 2.8.2, Trachtman et al. (2005) investigated the effect of pedal configuration on PAE rate and did not find evidence that pedal configuration played a significant role in the PAE. Again this study did not normalize the number of vehicle models they identified for investigation to these models' overall representation among all vehicles registered in the US to remove the effect of market share.

Department of Transportation (2012) investigated the NCSC database and identified the vehicle makes in 2397 PAE cases. The identified vehicle makes largely reflected the composition of vehicle fleet registered in the US. In other words, there is no evidence that the PAE occurred with specific vehicle makes.

In addition to vehicle make, vehicle type may also be relevant to the PAE. The vast majority of the existing PAE investigations focused on passenger vehicles. However, Department of Transportation (2012) revealed a few PAE cases involving trucks. Trucks likely have different pedal layout compared to passenger vehicles. In general, the pedals in trucks can be higher above from the vehicle floor (hanging pedals). This makes foot pivoting difficult for drivers with small feet because they will have little foot-pedal contact when anchoring their heels on the floor.

6.3.3 Foot Placement on Pedals

Although foot placement on pedals, especially on the brake pedal, plays an important role in pedal design and PAE investigation, there are only a few studies which measured the foot placement during pedal operation. As reviewed earlier in Section 2.8.2, Vernoy and Tomerlin (1989) recorded the foot placement on brake pedal by placing ovals (representing the foot position) over a rectangle (representing the brake pedal); (see Figure 33). Brackett and Koppa (1988) examined the accuracy of drivers' recall of brake pedal location in a driving simulator. Participants had to move their foot from the accelerator to a position where they thought the brake pedal should be.. They recorded the foot movement using a video camera and measured the foot placement location by marking the floorboard in 5.08 cm grid squares. Crandall et al. (1996) studied the foot location by tracking the reflective material attached on the posterior calcaneal. The distances from the brake pedal center to the posterior calcaneal of six participants (three males and three females) were recorded. The authors stated that taller drivers moved their foot less than shorter drivers did and, according to the authors, it may be because shorter drivers had longer legs or longer feet. It appeared that this statement could not be supported by their measurement. Sam et al. (2009) developed an ergonomics data measurement system to study pedal operation characteristics. They used pressure sensor to measure the force applied on seat, vehicle floor, pedals and shoe insole. However, the article only discussed the development and validation process of the measurement system.

6.3.4 Pedal Layout Measurement

As stated above, the current study is a component of a larger study. In another component of the study, the pedal layouts of 117 subject vehicles and the experiment vehicle (the 2011 Malibu) were captured using laser measurement equipment. The subject vehicles were mostly sedans. Trucks were excluded from the measurement. As shown in Figure 66, the locations of six representative points of the pedals (top left, middle left, bottom left, top right, middle right, and bottom right) were captured.

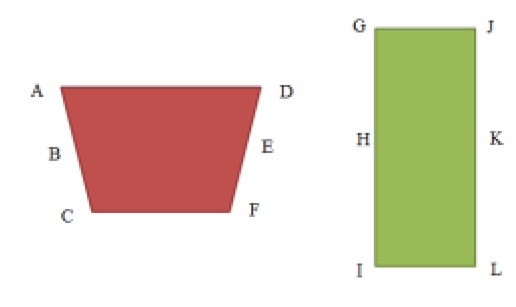


Figure 66. Pedal layout measurement.

With the location of the representative points, the “average” pedal layout of the 117 subject vehicles and the pedal layout of the 2011 Malibu were plotted. It can be seen in

Figure 67 that the brake pedal in the 2011 Malibu is higher than the average brake pedal of the 117 subject vehicles. This may be the reason that a number of participants with a small foot used predominantly foot lifting when transferring between pedals in the 2011 Malibu. The accelerator pedal in the 2011 Malibu is longer than the average accelerator pedal. The lateral separation between the brake and accelerator pedal in the 2011 Malibu (72 mm) is about the same as that in the average pedal layout (73 mm). According to the recommended lateral pedal separations as reviewed in Section 2.3.3(Figure 17), the lateral pedal separation of either the 2011 Malibu or the average subject vehicles was towards the lower end of the recommended values. In the next section, the lateral pedal separation will be discussed in more detail.

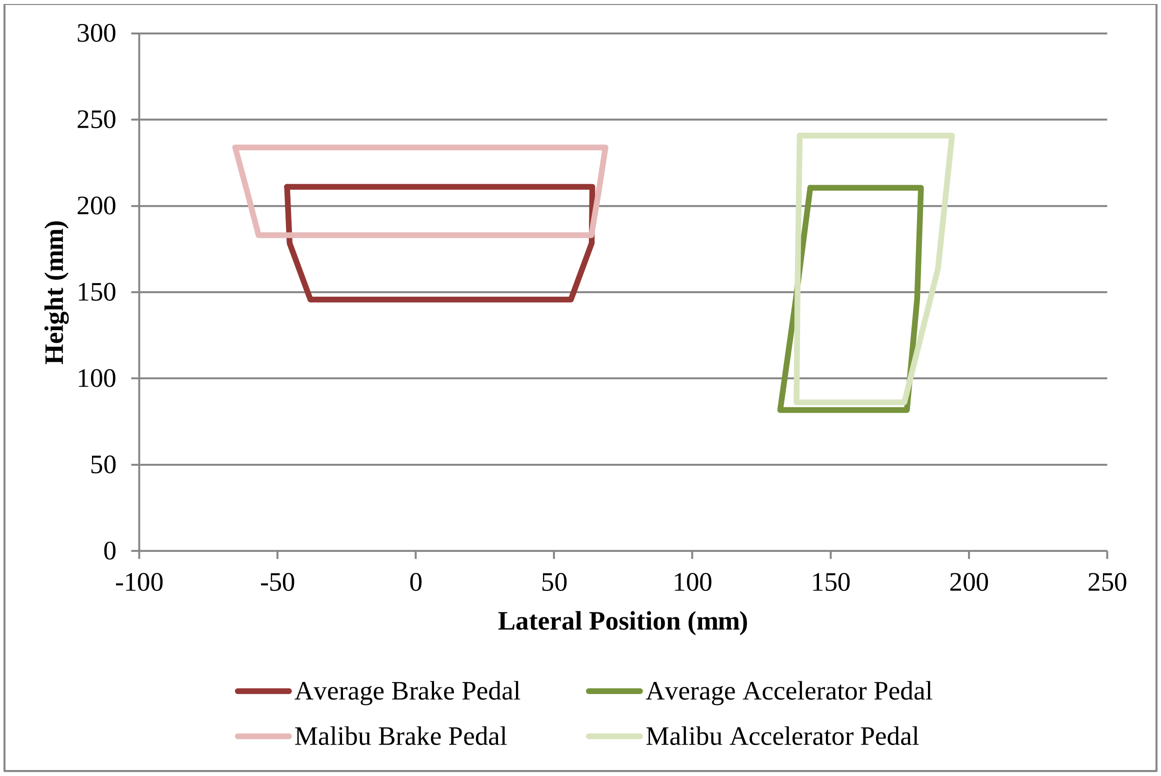


Figure 67. Pedal layout of "average" subject vehicles and the experiment vehicle.

6.3.5 Proposed Pedal Design

From Figure 62 it can be seen that most participants tended to use the right portion of the brake pedal. There are two potential contributing factors: a) foot inverted when moving from the accelerator pedal to the brake pedal (Figure 68); b) brake pedal is higher than the accelerator pedal (the perpendicular separation as discussed in Section 2.3.3). As seen in Figure 68, when the foot moves towards the brake pedal, the first contact is a “line-contact” between the sole and the right edge of the brake pedal. Then the sole rotates slightly counter-clockwise (from the rearview) to get greater contact area. Ideally, the drivers should move their foot further to the left to press the center of the brake pedal because it will provide a greater and firm contact between the sole and pedal. In reality, the contact was mostly between the left portion of the sole and the right portion of the brake pedal. The drivers tended not to move their foot further to the left because it would take them more effort to do so and they were capable of applying the brake even with partial contact (compared with the contact when the foot presses the center of the brake pedal).

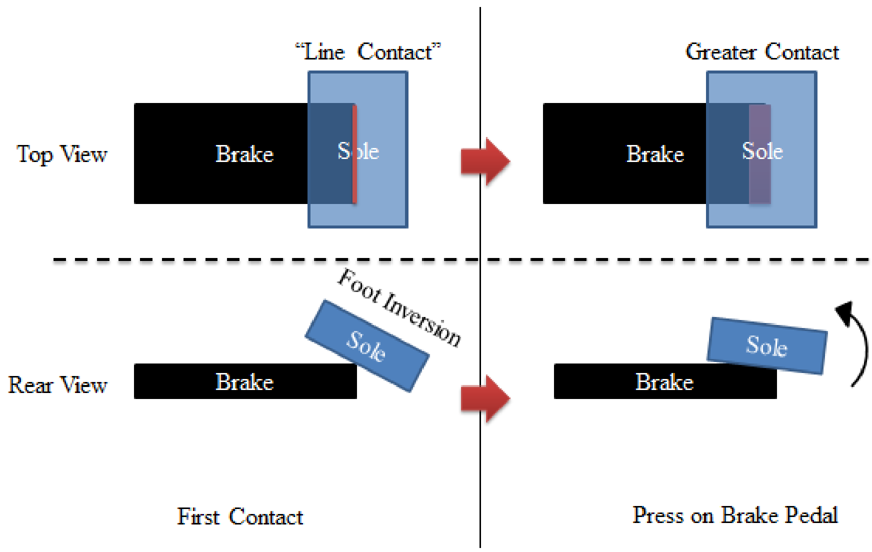


Figure 68. Rear view of foot inversion when pressing the brake pedal.

There are mainly two types of risk associated with partial contact between the sole and the brake pedal: a) the foot may slip off the brake pedal (For pedal layout where the brake pedal is close to the accelerator pedal, the foot may slip onto the accelerator pedal); b) the foot may end up pressing on both pedals when pressing down the brake pedal. There are two situations where the above risks can be greater: a) In an emergency situation where drivers make a quick foot movement to the brake pedal, the foot placement on the brake pedal can be more inaccurate than that in a typical foot movement; b) In cases where the drivers' foot is resting on the floor and they need to use the brake (e.g., when disengaging the cruise control), the foot placement could be inaccurate.

Therefore, the goal of pedal design optimization is bifold: a) to reduce the risk of the foot slipping onto the accelerator pedal or pressing on both pedals at the same time; b) to increase the accuracy of foot placement on the brake pedal in various driving scenarios (e.g., emergency braking, braking to disengage cruise control). Other design considerations are: a) the pedal layout should allow drivers to use foot pivoting most of time because foot pivoting is a more natural way of foot transfer strategy compared with foot lifting; b) the pedal layout should accommodate drivers with different shoe sizes; c) the pedal layout should not produce unacceptable fatigue level, especially when drivers need to transfer between the two pedals frequently (e.g., urban driving).

In order to reduce the risk of the drivers' foot slipping onto the accelerator pedal and the risk of pressing two pedals at the same time, the lateral separation between the two pedals should be increased. Increasing the lateral pedal separation may also reduce the confusion of the brake and accelerator pedals and increase the foot placement accuracy.

When discussing foot movement and pedal operation, Brackett et al. (1989) pointed out that when trying to reproduce a learned movement using only kinesthetic memory, there will be a tendency to overshoot short distance and undershoot greater distance. In other words, when moving the foot from the accelerator pedal to the brake pedal, assuming that the target foot placement is the center of brake pedal, the foot placement is more likely to be on the right portion of the brake pedal than on the left portion. Therefore, moving the brake pedal leftward has the benefit that even if the foot “undershoots” (fails to reach far enough to the target position) ,when transferring from the accelerator pedal to the brake pedal, the foot is less likely to land on the accelerator pedal or overlap both pedals.

Caldwell (1956) and Caldwell and Herbert (1956) identified that the arm movement accuracy tended to increase as the extremes of arm flexion and extension were approached. Based on these results, Lloyd and Caldwell (1965) suggested that limb movement against resistance produced by the muscles themselves yielded greater positioning accuracy than movement with aiding force. When applied to foot movement during pedal operation, it implies that if more effort is needed in foot transfer between pedals, the foot placement is likely to be more accurate. Therefore, increasing the lateral pedal separation apprears to be desirable. On the other hand, the constraint on the maximum lateral pedal separation is that the pedals should allow drivers with small a foot to use foot pivoting most of the times. Based on the abovementioned, a new pedal design will be proposed. The design steps are as follows.

Step 1: Determine the foot internal-external rotation angle when pivoting between the two pedals (Figure 69).

In the current study, the foot internal-external rotation angle was measured by tracking the reflective markers (as discussed in Section 4.5). The foot rotation angle during foot transfer ranged from 26 degrees (internal rotation; angle β as shown in Figure 69) to 70 degrees (external rotation; angle α as shown in Figure 69) across all participants. Admittedly, not all drivers can achieve this rotation angle range. Ideally, a database of foot rotation angle range which also includes the percentile of the population who can achieve certain angle ranges would be available for reference. For example, 90th percentile of people over the age of 60 has an ankle angle range between 10 degrees of internal rotation and 40 degrees of external rotation. Without such information, an estimation needs to be made. The ankle angle range achieved by the participants in the current study (from 26 degrees of internal rotation to 70 degrees of external rotation) may not be achieved by an most drivers. In order to accommodate a larger population, 80th percentile of the above range will be used in the following calculations as the range of foot rotation angle when pivoting between two pedals, i.e., from 12 degrees (internal rotation; angle β as shown in Figure 69) to 49 degrees (external rotation; angle α as shown in Figure 69).

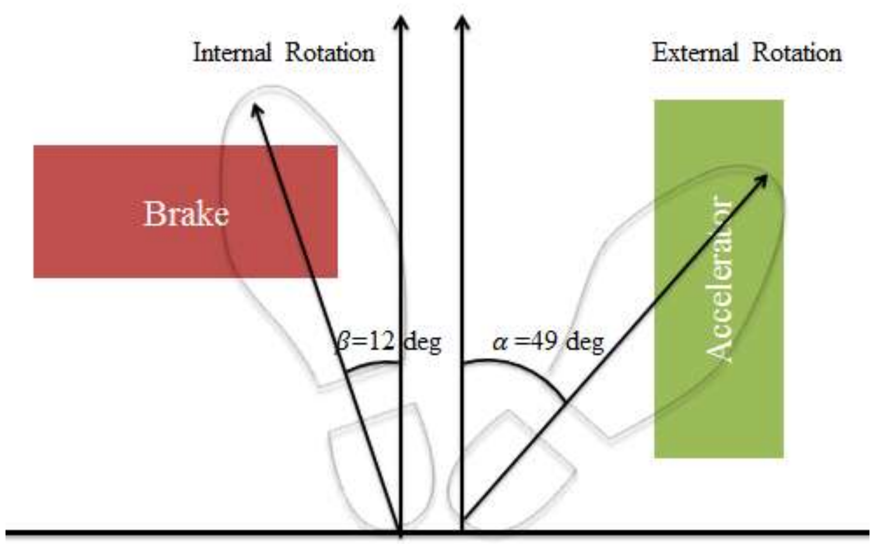


Figure 69. Proposed lateral pedal separation design (Step 1).

Step 2: Determine the foot-pedal contact position.

In general, people use the Ball-of-Foot (BoF) to press the pedal. Although according to the SAE's definition, the BoF is 203 mm from the heel (SAE International J1100, 2009), in reality the length between the BoF and the heel is variable depending on the foot length. It is assumed that the length between the BoF and the heel is 70% of the full shoe length. The shoe lengths in the current study ranged from 258 mm to 360 mm. In order to accommodate drivers with small shoes, the shortest shoe length in the current study will be used in the calculation. Therefore, for drivers with small shoes, the length between BoF and the heel is 181 mm. The lateral distance from the BoF to the heel in internal rotation and in external rotation (shown as distance a and b in Figure 70) can be calculated (a=181 mm×sin 49=137 mm; b=181 mm×sin 12=38 mm).

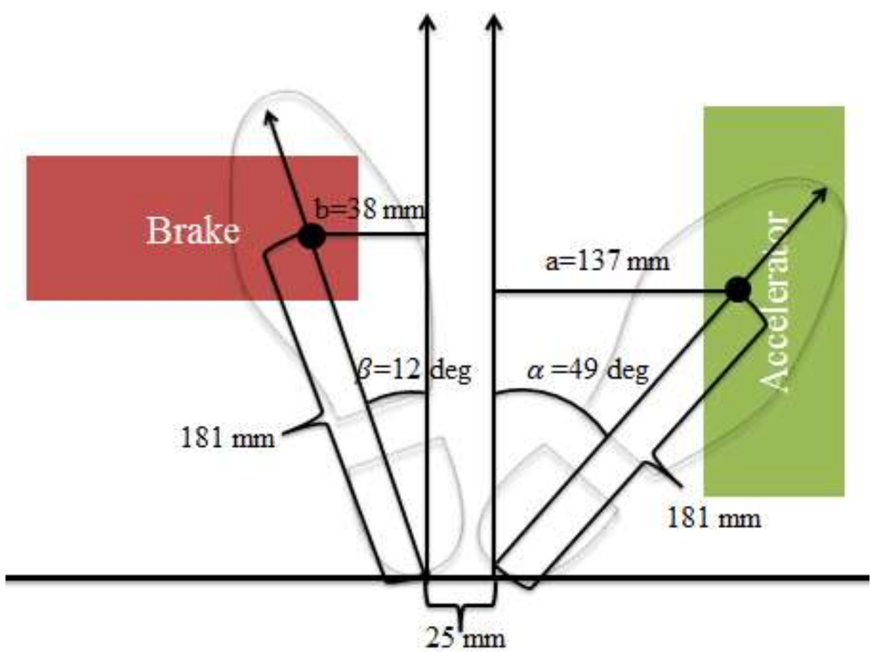


Figure 70. Proposed lateral pedal separation design (Step 2).

Step 3: Determine lateral pedal separation.

When thefoot pivots from the accelerator pedal to the brake pedal, the heel rolls to the left on the floor and forms a “line’contact” with the floor (Figure 71). The length of the “line” is dependent on the diameter of the heel portion of the sole. Black (1966) suggested using 25 mm as an estimation.

In addition, the BoF position should not be where the pedal edge is (see the blue circle in Figure 71). In other words, to provide drivers with a greater contact area between sole and pedal, the BoF-pedal contact point is moved inward form the pedal edge by 25 mm. Therefore, the final lateral pedal separation can be calculated which is 150 mm.

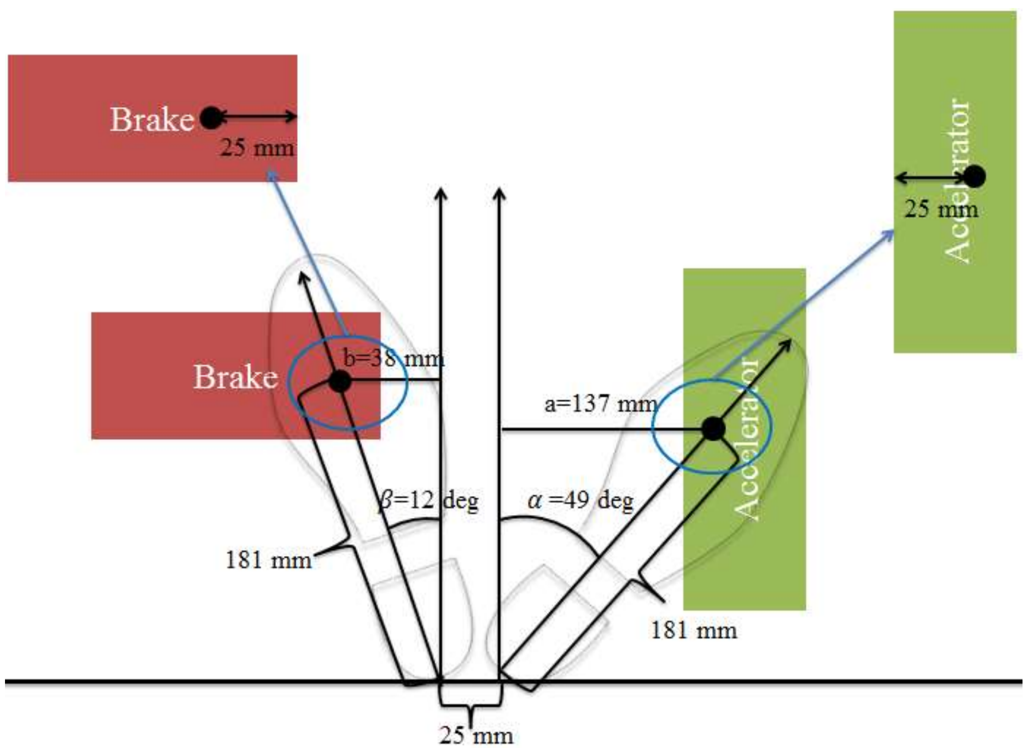


Figure 71. Proposed lateral pedal separation design (Step 3).

To increase the lateral separation, it is suggested that the perpendicular separation between the pedals be reduced. As mentioned above, the pedal operation is a “blind positioning process" and the drivers rely on the kinesthetic cues to locate pedals. The perpendicular separation may have served this purpose and helped drivers to distinguish the brake and the accelerator pedal because drivers need to raise their foot (dorsiflexion) to apply brake. However, during the combination of upward movement (raising foot) and leftward movement (transferring foot to brake pedal), the foot may get caught by the brake pedal (Figure 72). If the lateral separation is increased, a large perpendicular separation is no longer needed as a kinesthetic cue of pedal position. This is because increased lateral separation makes the foot rotation angle when accelerating much more different from the foot rotation angle when braking. The greater angular difference of the foot when operating different pedals provides good kinesthetic cues of pedal location.

In addition, a smaller perpendicular separation also reduces the effort of foot transfer. Increased lateral separation makes drivers use the full range or nearly the full range of foot internal-external rotation. The increased effort caused by greater lateral separation may be balanced by using coplanar pedal layout (brake and accelerator pedal on the same plane) as suggested by Snyder (1976), Morrison, Swope and Halcomb (1986) and Brackett et al. (1989).

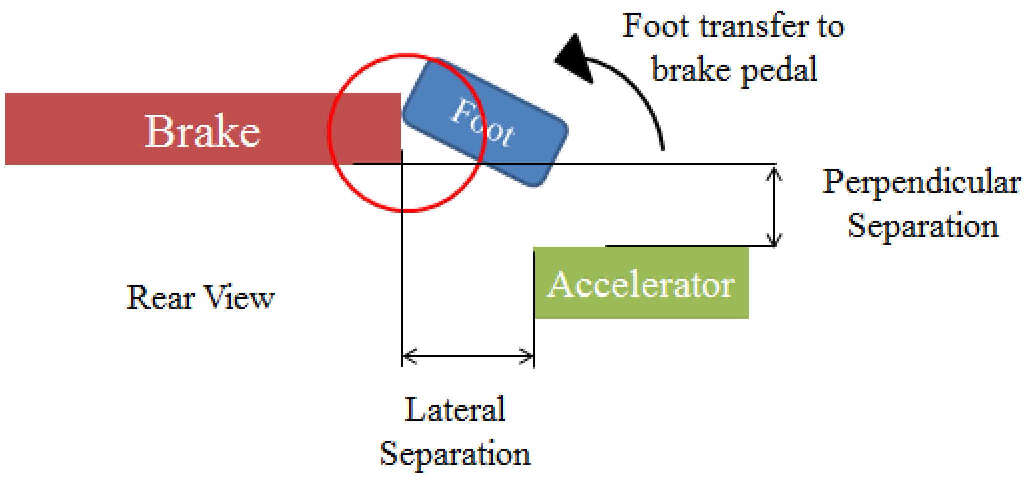


Figure 72. Foot gets caught by the brake pedal when transferring from the accelerator pedal to the brake pedal.

As to the brake pedal shape, a wide brake pedal that is symmetric around the center of the seat is recommended to accommodate the foot placement that is more variable (Schmidt, 1989) and potentially further to the left, which is possible when performing emergency braking, trying to disengage the cruise control or when the drivers are misaligned with the vehicle center (Vernoy and Tomerlin, 1989).

Although manual transmission is not in the scope of the current study, it is of interest to understand the pedal design in vehicles with manual transimission. In such vehicles, the brake pedal could be narrower compared to vehicles with automatic transmission. This is more evident in racing vehicles. There are three potential reasons. First, it is obvious that the footwell space is limited and in order to accommodate the clutch pedal on the left, the brake pedal needs to be narrower. Second, the brake pedal deisgn no longer needs to accommodate drivers who use their left foot to brake. Therefore, the brake pedal does not have to be symmetric around the center of the seat. Last, drivers of manual vehicles are less likely to get misaligned with the center of the driving position so that the variance of their foot placement on the brake pedal appears to be less compared to those driving vehicles with automatic transmission. This is because drivers with manual transmission have to frequently use the clutch pedal (especially during low speed driving), by which they re-adjust their seating posture to be symmetric to the center of the seat which helps them to maintain the ability to distinguish the two pedals. This also contributes to the fact the PAEs occurred less in vehicles with manual transmission.

6.3.6 Design of Brake Pedal Pad and Shoe Sole

Another solution to avoid the foot slipping off the brake pedal is to increase the friction between the shoe sole and brake pedal pad. Few studies focused on the friction between the shoe sole and automotive pedal pads. According to Al-Osaimy and Ali (2012), at dry sliding, the friction coefficient between rubber-soled shoes and rubber brake pedal pads is higher when sliding in transverse direction than longitudinal direction (Figure 73). However, when pedal pads are wet, the friction coefficient is lower when sliding in transverse direction. The optimal tread width depends on the condition of the sliding surface (e.g., wet, with sand particles). In the presence of sand particles on the sliding surface, shorter tread width produced higher friction coefficient. When pedal pads are wet, 2 mm of tread width produced highest friction coefficient. The optimal hardness of pedal pads also depends on the condition of the sliding surface. Increasing the hardness of pedal pads will decrease the friction coefficient when the pedal pads are wet, but will increase the friction coefficient when the pedal pads are lubricated by oil.

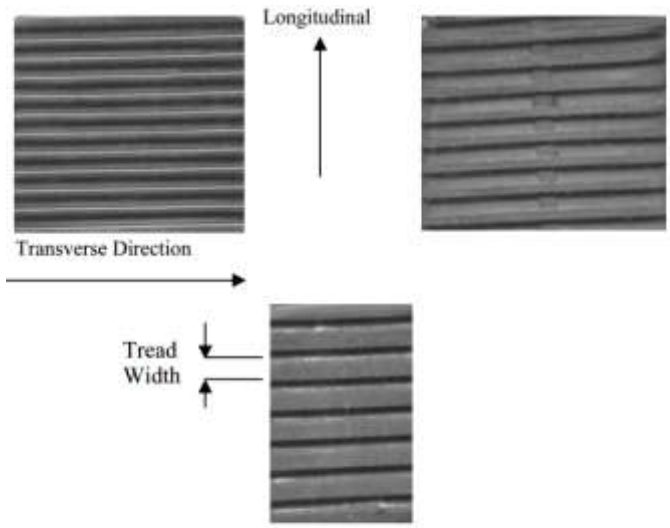


Figure 73. Sliding direction and brake pedal tread width (Al-Osaimy and Ali, 2012).

Li and Chen (2004) studied the effect of footwear materials, floor materials, contamination conditions and tread groove width on the friction coefficient. Among four tested footwear materials (neolite, leather, blown rubber and ethylene vinyl acetate), neolite had the highest friction coefficient, followed by blown rubber. Among three floor materials (terrazzo, steel and vinyl), vinyl had the highest friction coefficient and steel had the lowest friction coefficient. Among four contamination conditions (wet, water–detergent mixture, oilbrushed, and oil-poured conditions), wet conditions showed the highest friction coefficient. Among five tread groove designs (flat, groove width of 0.3 cm, 0.6 cm, 0.9 cm and 1.2 cm which are perpendicular to moving direction), tread width of 1.2 cm showed the highest friction coefficient.

Li and Chen (2005) studied the effect of tread groove orientation on the friction between shoe and floor and found that tread grooves perpendicular to the friction measurement direction produced higher friction coefficient. Li et al. (2006) studied the effect of tread groove design on the friction between shoe and floor. The study identified that the tread orientation and width will significantly affect the friction coefficient. Wider grooved footwear pads and tread grooves perpendicular to the friction measurement direction produced a higher friction coefficient. Li, Wu and Lin (2006) studied the effect of tread groove depth on the friction between shoe and floor and identified that deeper tread grooves produced a higher friction coefficient. Liu et al. (2010) studied the effect of floor conditions, shoe sole conditions, contamination conditions and surface inclined angles on the friction coefficient. Among other findings, the study identified that floors with molded grooves perpendicular to friction measurement direction showed the highest friction coefficient in all combination of conditions except for one (wet floor, flat sole and surface inclined angle of 10 degrees).

6.3.7 Cruise Control

The use of cruise control could be a factor leading to the PAE. Schmidt (1993) identified several cases of vehicle unintended acceleration that occurred when the drivers were trying to disengage the cruise control. Schmidt suspected that these cases were due to PAE. He stated that during the use of the cruise control, the drivers were freed from their habitual driving postures and they no longer had to place their foot over the accelerator pedal or the brake pedal. It was possible that the drivers were misaligned in the vehicles. Therefore, when the drivers reclaimed the control of the vehicle by pressing on the brake to disengage the cruise control system, drivers likely pressed on the accelerator pedal.

As stated by Brackett and Kappa (1988), moving the foot to the brake pedal is a “blind positioning movement”. Instead of using the visual system, the drivers have to rely on their kinesthetic sense to locate the brake pedal. The study by Brackett and Kappa examined drivers’ ability to reproduce the location of the brake pedal by having them move their foot from an accelerator pedal to an imaginary brake pedal location as rapidly as possible and then comparing their foot placement with the location of a brake pedal. The results indicated that drivers had difficulties reproducing the location of the brake pedal. Although the cases of using cruise control were not examined in this study and drivers were moving their foot from the accelerator pedal instead of from places where drivers tend to place their foot when using the cruise control, the results shed light on the causes of PAEs related to cruise control usage.

The risk of pedal error related to reclaiming control of the vehicle after cruise control usage lead to an open question, i.e., when and how the drivers should reclaim control of the vehicle after the activation of automation system such as cruise control. Most of the existing research on the operator’s (driver’s or pilot’s) performance to take over control after usage of automation concerns with their declining skills induced by long-time automation usage. As stated by Stanton and Marsden (1996), the driving skills could be decreasing as a result of lack of practice caused by automation. Larsson (2012) suggests that giving control back to the driver (after using automation) intermittently is a good thing so that drivers do not over-rely on the automation system. Interestingly, the suggestion to counteract drivers’ over-reliance on the automation by having drivers intermittently taking over control will increase the risk of pedal error by frequently requiring drivers to ‘blindly’ locate the brake pedal to disengage the cruise control.

Little research focuses on the specific issue of drivers being prone to errors when reclaiming control of the vehicle, especially in an emergency situation as seen in the cases of applying brake pedal to disengage the cruise control. However, similar issues have been discussed from a higher level (in the broader domain of human-automation interaction instead of the interaction between the driver and the autonomous vehicle). Bainbridge (1983) pointed out that reclaiming control of an automation system may require the operator to be more skilled than operating a non-automatic system because reclaiming control involves extra tasks of attentively monitoring and counteracting the effect of reclaiming-control action. The article further stated that under time pressure, the operator can only take actions relying on limited information. These theories apply to the driving task. When disengaging the cruise control and resuming active driving, the driver needs to monitor and maybe counteract the effect of braking, tapping on the brake to look for the optimal brake pedal travel. If this action (foot reaching to the brake) is done under time pressure (e.g., the driver needs to disengage the cruise control and stop quickly to avoid an obstruction), the driver needs to rely on the limited spatial memory of the brake pedal location.

One of the solutions proposed by Bainbridge (1983) to counteract the above mentioned issue is to provide a display of automatic control performance to the operator. In the case of driving, we can provide drivers with a camera view of the pedal area when the cruise control is engaged. The camera view can be in the form of a head-up display or on the infotaiment system, and it will be turned on once the cruise control is activated. The camera view of the pedal area serve two purposes: a) the drivers will use the real-time camera view of the pedal and foot to locate the brake pedal instead of relying on the spatial memory of the brake pedal location; b) in case of pedal error (drivers mistakenly press on the accelerator pedal attempting to disengage the cruise control), the drivers will be able to identify the error immediately and make corrections.

In fact, the recommendation to increase the lateral pedal separation (see Section 6.3.5) also helps drivers to obtain a more distinct spatial memory of the two pedals. By placing the brake and the accelerator pedal further apart from each other, drivers' feels of applying the two pedals will be more distinct. Once drivers get used to the new pedal layout, their foot aiming is less likely to be so biased that they press the unintended pedal. As mentioned above, the perpendicular separation between pedals needs to be smaller to reduce the effort it takes to transfer between pedals.

In addition, to accommodate the use of the cruise control, drivers need to adapt their car-following habit when using cruise control: the drivers should allow a greater distance to the vehicle in front. Different from active driving, using the cruise control takes the driver out of the control loop (Stanton et al., 1997). A greater distance to the front vehicle allows the driver extra time to "come back into the loop" and react to the situations. Lin et al. (2009) reviewed the recommendations of time-gap (time-to-collision) settings for an Adaptive Cruise Control (ACC) system as shown in Table 24. Of course, these time-gaps were designed to allow the ACC system enough time to take effect. If the drivers are added to the control loop, extra time should be added to these values. It is recommended that drivers should maintain at least 4 seconds of time-gap when using the cruise control although in-depth studies are needed to find out how long drivers need to respond properly to situations where they have to reclaim control of the vehicles.

Table 24. Recommended Time-gaps as reviewed by Lin et al. (2009)

Recommended time-gaps	**Sources**
1.50 to 2.49 seconds (motorway) 1.66 to 3.21 seconds (rural road)	Tornros et al. (2002)
2 seconds or more	Zheng and McDonald (2005)
1.1 seconds (young drivers) 1.5 seconds (middle-aged drivers) 2.1 seconds (older drivers)	Fancher et al. (1998)
1.1 to 1.8 seconds	Reichart et al. (1996)

Last, even when using the cruise control, the drivers should still be attentive to the road and traffic ahead. It is also suggested that the driver place their left foot on the foot rest most of the time. As discussed in the Section 6.3.5, drivers with manual transmission have to occasionally use the clutch pedal with their left foot so that their seating posture is more symmetric around the seat center, which possibly reduces the PAEs rate. In vehicles with automatic transmission, placing the foot on the foot rest is a good practice for maintaining proper seating posture.

6.3.8 Implications to (Intelligent) Infrastructure

Based on the finding that reaching out of the window may cause the driver's foot to move rightward and that the driver tended not to use the parking brake while stopping and reaching out, it is suggested that curb-side devices (e.g., card readers, drive-through ATMs, etc.) be re-designed to reduce the effort required for the driver to complete the interaction. As the results of the current study indicated, using a more sensitive card-reader at a gated access, reduced participants' effort of reaching out and swiping their card. This way the foot placement on the brake pedal will not be affected as much as when the drivers have to reach out hard to activate the card reader.

However, even if the curb-side device is redesigned, the drivers still need to reach out of the vehicle and the risk still exists that the reaching-out task will bias drivers' foot aiming position. To eliminate the need of reaching-out and reduce the chance of human error, it is recommended that an Automatic Vehicle Identification (AVI) system be installed at gated accesses, especially those used mostly by older drivers. The AVI system enables vehicle recognition without drivers having to interact with a curb-side device in order to be identified.

Advanced Driver Assistance Systems (ADAS) can further help to reduce human errors and protect pedestrians, occupants and infrastructures. Autonomous Emergency Braking (AEB) systems can automatically apply brake when they detect obstructions or pedestrians, mitigating the damage caused by crashes. However, depending on the vehicle velocity and distance to obstructions at the scene, the AEB system may not completely avoid crashes. In addition, the sudden brake may cause injuries inside the vehicle. While a fully autonomous vehicle is further down the road, some ADAS enable certain driving scenarios to be automated. For example, Automatic Parking Assistance (APA) makes vehicle parking a driverless process. It handles tasks such as parking space searching and pulling into or out of the parking spaces for the driver. Considering the fact that 57% of crashes caused by pedal errors occurred in parking lots as stated in Section 2.8.1, the implementation of APA can be expected to significantly reduce the risk of PAE in parking lots.

We are now entering an era where all devices (e.g., consumer products, vehicles) and infrastructures (e.g., household, garages) are connected by the so-called Internet of Things (IoT). The connection formed by vehicles is an important element of the IoT and it forms a real-time sharing of information such as location and status between vehicles and infrastructures. This communication helps people make better decisions (e.g., decide where to park), corrects or overrides risky maneuvers (e.g., steer the vehicle when the vhicle departs from the current lane, apply brake during PAE) and eventually takes over the driving tasks completely (autonomous driving).

6.3.9 Clinical and General Implications

The results of the study shed light on the occupational therapists' practice (e.g., driver assessement) and the driving habits of the general public and revealed the following.

- Compared with foot lifting, foot pivoting is a more natural foot transfer strategy. When purchasing a vehicle, it is recommended that the driver examine the pedal configuration (by alternating to press the accelerator and the brake pedal using foot pivoting) and make sure the pedals will allow him or her to pivot comfortably. In general, the higher the pedals are from the floor or the greater the perpendicular separation, the less likely the driver will use foot pivoting.

- Foot lifting allows for fast deployment of the brake pedal. This is the foot movement strategy drivers tended to use in an emergency situation or when they were startled and wanted to stop the vehicle quickly. However, some older drivers with weaker lower extremity functions are not able to use foot lifting. It is also possible that the steering wheel may hinder the driver from using foot lifting. Therefore, it is important to make sure that the drivers are able to use foot lifting in their own vehicles and stop the vehicle quickly in an emergency situation. It is recommended that the CDRS include the examination of drivers' ability to use foot lifting during an in-clinic evaluation using the driver's own vehicle.
- The participants in the current study were different from the CDRS's typical patients seen in the driving rehabilitation program in several ways: a) The older drivers who participated in this study were overall more healthy, compared to cognitively or physically impaired drivers who require in-clinic and on-road driving rehabilitation. b) The participants in this study were more aware of their driving habits (e.g., what foot transfer strategy they use while driving) than CDRS's typical patients. c) Driving rehabilitation patients are more easily fatigued than the drivers who participated in this study. This may explain the

reason why participants did not exhibit obvious signs of fatigue after the on-road evaluation (Hypothesis 6).

6.4 Limitations and Future Work

6.4.1 Limitations

Recruiting participants was difficult in the current study. As stated in Section 4.2, the study aimed to recruit 15 participants through doctors' referrals in each of the four categories: a control group, a Mild Cognitive Impairment (MCI) group, a Peripheral Neuropathy (PN) group and an Orthopaedic (OP) group. However, the number of participants in the three treatment groups was significantly less than the participants in the control group. There were only six participants in the PN group, two participants in the OP group and no participants in the MCI group. The sample size of each treatment group would make comparison between groups very difficult; therefore, a decision was made to recruit more participants for the control group and combine across the four groups. The main reasons for the difficulty in recruitment were the following: a) Participants were informed that they may lose their driver's license if they failed the driving evaluation. b) Participants would have to make three visits to the hospital site in order to complete the study. The three visits were screening, in-clinic evaluation, and on-road assessment, respectively. The whole process took about four hours. c) The criteria used to qualify participants for the treatment group were very strict. Due to the small sample size, the representativeness of the participants may be compromised. It is possible that participants who chose not to participate may be associated with a higher risk of making PAEs.

Overall, the equipment was properly installed, tested and well-maintained, although there were extraneous restrictions which may have effected the data quality. For example, Tekscan sensors were installed on the pedals to measure the force distribution. In order to make the study unobtrusive and conceal the sensors from the participants, the sensors were covered with rubber material on top of the pedals. However, the covering material distorted the sensed force distribution. Hence, the accuracy of the collected data may have been compromised.

Different from an in-door driving simulator study, an on-road driving study is faced with a more variable environment. Some examples are as follows: a) It was not known that the old card reader at the entrance of the staff parking lot was replaced after a few participants had completed the study. The old and new card readers are different sizes and exhibit different sensitivities. Therefore, the effort it took participants to activate the card reader successfully was different. b) The entrances to the parking lot and the staff parking deck were sometimes not gated, and the participants entered without having to reach out and swipe the card, which reduced the sample size. c) There were a few instances when the reserved parking space was occupied so that the forward parking task could not be conducted.

The purpose of including a startle-braking task in the current study was to elicit participants' reaction to startle stimuli and to study their pedal operation characteristics in such a situation. It was decided that the CDRS would create the startle stimuli by yelling at them to stop quickly. However, in real driving, the startle stimuli can be in various forms. According to the North Carolina Crash Database, the three most common types of startle situations are: a) panic stop to avoid collision; b) startle following loss of control of the vehicle; c) startle following an initial collision. These accounted for 89.5% of crashes related to startle response. The level of startle (how much the participants were startled) in the above mentioned situations could be very different from what was artificially created by the CDRS, so the participants' foot behaviors in the current study could also be different from that in realistic startle situations. Another factor that may reduce the representativeness of the startle-braking tasks (in terms of the real startle situation) is that the participants were pre-warned of the startle stimuli.

The participants were instructed to wear tennis shoes during the on-road assessement. However, drivers' footwear may vary in a real setting (e.g., heels, flip-flops, etc.) and the type of footwear worn by older drivers may be associated with PAE risk.

6.4.2 Future Work

Future research would potentially extend the perspectives gained from this study and allow more insight into pedal operation characteristics associated with risks of PAEs. Identified future work is as follows:

- The current study had a sample size of 26 participants. Because of equipment malfunctions or environmental variables (e.g., an open gate) mentioned previously, the sample size for specific hypotheses was furthered reduced.

Therefore, future work using a larger sample is needed to validate the results. In addition, experienced drivers were used in this study. As stated in Section 6.3, in startle-braking tasks, the action of braking for experienced drivers is an automatic process making it a well-practiced response. Future studies should also include novice drivers. For novice drivers, startle braking is a control response and will require more mental effort.

- To understand the reason why stature and shoe length affect the foot movement method, it is worth knowing the heel anchoring position on the vehicle floor relative to the pedals. In the current study, although a Tekscan map sensor was installed to measure the force on the vehicle floor, the floor mat on top of the sensor significantly reduced the accuracy; thus, the data collected by this sensor were not used. Future work should examine the use of a different covering material, which not only conceals the sensor from the participants but also does not wash out the sensed force applied on the vehicle floor.
- To better understand the effect of startle response on foot movement in future studies, it is recommended that participants be examined in a driving simulator with driving scenarios simulating those that could be encountered in real driving such as avoiding collisions. In addition, the level of startle when the participants are presented with the stimuli should be quantified and correlated with their foot movement characterisics such as foot placement. One way of measuring the level of startle is to have participants rate their level of startle on a Likert-scale chart after the startle-braking task. A more accurate alternative is to measure the eye-

blink component of the startle reflex by recording participants' electromyographic activity (EMG; Mühlberger et al., 2008).

- It is known that drivers' reaching out can affect foot placement. To provide design recommendations for the card reader or any curb-side device, such as its size and sensitivity, an in-depth study is warranted. Potential future studies should be carried out in a more controlled environment taking into account variables such as driver's arm length, card reader's sensitivity, and distance between the vehicle and the card reader.
- The current study looked into several driving scenarios that are associated with higher risk of PAEs for older drivers (e.g., startle-braking and forward parking). Future research should examine other driving scenarios, such as reversing in parking lots with less space, where drivers have to frequently alternate between the two pedals. It is also worth imposing the participants with a time limit on the tasks they carry out. Reversing tasks, similar to the tasks of reaching out to swipe a card, involve upper body movements and potential interruption of proprioception and foot-aiming position. When carrying out reversing tasks, participants' direction of gaze should be recorded to study the relationship between the gaze and the foot movement.
- Future research is warranted to understand why older drivers fail to correct PAEs and how drivers can be assisted when they have already pressed on the accelerator pedal unintentionally. In fact, drivers of various age groups make PAEs. The problem with older drivers can be more serious because they may be less likely to

correct the PAE once it occurs, compared with younger drivers. For example, when both younger and older drivers accidentally press the accelerator pedal, younger drivers may be able to move their foot back to the brake pedal quickly; however, the reaction time for older drivers is slower, due to their inability to react quickly as they age. Therefore, older drivers are more likely to be startled by both a sudden increased engine sound and vehicle speed, and less likely to respond appropriately in time (Schmidt, 1989). In other words, they need help not only with how to prevent PAEs before errors occur but also how to survive an ongoing PAE.

- The focus of this study was mainly the effect of different tasks on older drivers' pedal operation characteristics, rather than the effect of pedal configurations (i.e.,pedal size, separation, etc.) and vehicle types on drivers' performances. However, PAEs have been identified with vehicles other than sedans (Department of Transportation, 2012). It is worth measuring the pedal layout and study the foot movement characteristics using other types of vehicles.
- However, pedal configuration may impact the driver's performance as discussed in Section 6.3.2 and Chapter Two. A future study involving different pedal configurations would provide insight on this issue.

6.5 Conclusion

Understanding driver-pedal interaction encompasses a vast range of topics. The current study began with tracing the pedal evolution and collecting existing pedal design guidelines. Then older drivers' characteristics and existing research on PAEs were presented. Based on the research gaps identified from a literature review of past works and statistics on PAEs, 10 research questions were developed. The first research gap identified a need for establishing the baseline driver-pedal interaction characteristics. The other four research gaps established the need to examine three driving scenarios representative of higher PAE risk and to investigate the role of fatigue in foot movement performance of older drivers. The study was carried out by having older adults drive a 27-mile road of various conditions that exist in a neighborhood, urban streets, interstates and parking lots. The participants were involved in PAE-related driving tasks such as forward parking, startle-braking and reaching out to swipe card. During the course of driving, variables including participants' foot movements and force applied on the pedals were collected and analyzed. The contributions provided by this research include extending the understanding of an older driver's foot movement method in different driving scenarios, exploring lateral foot placement as an indication of PAE, investigating the relationship between reaching out and foot placement change, as well as pointing out the potential direction for future research.

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APPENDICES

APPENDIX A: CHECKLIST FOR PHONE SCREENING

DOT Pedal Application Phone Screen

Question	Answer	Qualify	
1. What is your age? 65-85		YES	NO
2. Do you have a valid Drivers' License? YES		YES	NO
3. Have you been driving at least 3 years? YES		YES	NO
4. Do you read and write in English? YES		YES	NO
5. Have you had an evaluation of your driving abilities by a driving rehabilitation specialist in the last year? NO		YES	NO
6. Do you have a sedan as your primary vehicle? YES		YES	NO
7. Does your sedan have 2 or 4 doors?			
8. Do you drive a van, SUV or truck as your primary vehicle? NO		YES	NO
9. Have you had orthopedic surgery on your right leg in the last year?			
10. If yes, what surgery did you have?			
11. What is your height? (If taller than 74 inches, or shorter than 48 inches they are excluded via phone screening)		YES	NO
12. Are you able to wear tennis shoes or walking shoes when you drive? YES		YES	NO
13. Do you wear a cast or brace on your right foot or ankle? NO		YES	NO
14. Has your doctor told you any reason you should not drive? NO		YES	NO
15. Have you ever been diagnosed with a stroke, seizure disorder or Parkinson's disease? NO		YES	NO

Does this referral meet study criteria? YES NO

APPENDIX B: MATLAB CODE TO IMPORT, ANALYZE AND EXPORT DATA COLLECTED FROM DEWETRON AND TEKSCAN

```
%%
% This file is used to import, process and analysis both DeweSoft and
Tekscan Data.
% v2 created on 10/14/2013
% v2 : 1.remove the codes in v1 that are not to be used; 2.tekscan data
% are no longer save in time series. A global time variable will be
% created for tekscan data; 3. dewetron data will be stored in a struct.
% v4 created on 4/13/2014: foot movement analysis was added
% v5 created on 5/6/2014: deleted unnecessary code sections
% v6 created on 6/17/2014: revised the dot click data storage so that
one
% does not need to repeatedly load the dot data
% v8 created on 7/24/2014: revised the section of importing foot dot
data
% so that it imports all the *xypts.csv files automatically

%% step 1 define constants, variables, structures, etc.
% -------------------------------------
C.freqbt = 500; % sampling frequency of brake pedal travel
C.freqat = 500;
C.freqaccel = 500; % sampling frequency of acceleration
C.freqrate = 500; % sampling frequency of rate
C.freqv = 36.9;
% -------------------------------------
C.spanv = 4; % smoothing window width for velocity
C.spantek = 3;
C.spandot = 5; % smoothing window width for digitized dot data
C.span = 100; % window span for data smoothing using moving average
method
% -------------------------------------
C.braketrigger = 10; % using 10% of pedal travel as the event trigger
C.acceltrigger = 2; % using 2% of pedal travel as the event trigger
% -------------------------------------
C.SENSEL_SIDE=12.7; % in mm; the side length of one sensel
C.BRAKE_W=114.3; % in mm, brake pedal width
C.BRAKE_L=38.1; % in mm, brake pedal length
C.brakesize=43.5483; % cm^2, brake size
C.accelsize=77.4192; % cm^2, accelerator size
C.D78 = 112.5; % [mm] the real distance (in mm) between dot 7 and dot 8.
will be used to scale the image
C.D910 = 210.1; % [mm] the real distance (in mm) between dot 9 and dot
10. will be used to scale the image
C.dot9line=93.1; % [mm] lateral distance from dot9 to seperation line
(on 9/10 of brake width, used to locate dot 5)
% -------------------------------------
C.event = {'reverse_anthony' 'reverse_garage1' 'reverse_garage2'
'reverse_staff' 'reverse_napa'...
```

```
            'gateaccess_garage' 'gateaccess_staff'...
            'straight_staff' 'straight_garage'...
            'startle'...
            'stopsign' 'stopleconte' 'stopchap' 'stoplowood'
'stopgarden'...
            'stopgarden2' 'stopchap2' 'stopoaks' 'stopoaks2'
'stopmichaux'...
            'initialpedalcal' 'finalpedalcal'};
% -------------------------------------
% C.h=fdesign.lowpass('fp,fst,ap,ast',3,10,1,50,80);
% filter=design(C.h,'equiripple');
% -------------------------------------
% [b,a]=butter(4,.3);
% -------------------------------------
folder = uigetdir('Y:\DOT_Pedal','Select the participant folder');
date=input('Please enter the date (yyyy-mm-dd): ', 's');

%% step 2.1 import dewetron data
% drop the *.mat file exported from dewesoft to the matlab workspace;
% extract the recording start time for all channels and store them in a
% struct; subtract the start time from all time points (elapsed time is
used in this section)
startTime.sys = Start_time; % system start time

startTime.at = Data1_time_Accel__Travel(1);
Data1_time_Accel__Travel = Data1_time_Accel__Travel-startTime.at; % [%]
accel travel

startTime.bt = Data1_time_Brake_Travel(1);
Data1_time_Brake_Travel = Data1_time_Brake_Travel-startTime.bt; % [%]
brake travel

startTime.la = Data1_time_X_accel__lat____late(1);
Data1_time_X_accel__lat____late = Data1_time_X_accel__lat____late-
startTime.la; % [g] lateral acceleration

startTime.longa = Data1_time_Y_accel__long____Lon(1);
Data1_time_Y_accel__long____Lon = Data1_time_Y_accel__long____Lon-
startTime.longa; % [g] longitudinal acceleration

startTime.va = Data1_time_Z_accel___Vertical(1);
Data1_time_Z_accel___Vertical = Data1_time_Z_accel___Vertical-
startTime.va; % [g] vertical acceleration

startTime.pr = Data1_time_X_rate__pitch____pit(1);
Data1_time_X_rate__pitch____pit = Data1_time_X_rate__pitch____pit-
startTime.pr; % [deg/s] pitch rate

startTime.rr = Data1_time_Y_rate__roll____roll(1);
Data1_time_Y_rate__roll____roll = Data1_time_Y_rate__roll____roll-
startTime.rr; % [deg/s] row rate
```

```
startTime.yr = Data1_time_Z_rate__yaw____yaw(1);
Data1_time_Z_rate__yaw____yaw = Data1_time_Z_rate__yaw____yaw-
startTime.yr; % [deg/s] yaw rate

startTime.x = Data1_time_X_absolute(1);
Data1_time_X_absolute = Data1_time_X_absolute - startTime.x; % GPS x
coordinate

startTime.y = Data1_time_Y_absolute(1);
Data1_time_Y_absolute = Data1_time_Y_absolute - startTime.y; % GPS y
coordinate

startTime.z = Data1_time_Z(1);
Data1_time_Z = Data1_time_Z - startTime.z; % GPS z coordinate

startTime.v = Data1_time_Velocity(1);
Data1_time_Velocity = Data1_time_Velocity-startTime.v; % [km/h]
velocity

startTime.dir = Data1_time_Direction(1);
Data1_time_Direction = Data1_time_Direction-startTime.dir; % Direction

startTime.db=Data1_time_Driver_Brake___for_m(1);
Data1_time_Driver_Brake___for_m=Data1_time_Driver_Brake___for_m-
startTime.db; % Driver brake

startTime.pb=Data1_time_Passenger_Brake(1);
Data1_time_Passenger_Brake=Data1_time_Passenger_Brake-startTime.pb; %
Passenger brake

startTime.lts=Data1_time_Left_Turn_Signal___f(1);
Data1_time_Left_Turn_Signal___f=Data1_time_Left_Turn_Signal___f-
startTime.lts; % Left turn signal

startTime.rts=Data1_time_Right_Turn_Signal___(1);
Data1_time_Right_Turn_Signal___=Data1_time_Right_Turn_Signal___-
startTime.rts; % Right turn signal
% ------------------------------------
% store data into struct: dewe
dewe.at=Data1_Accel__Travel;
dewe.timeat=Data1_time_Accel__Travel; % accelerator travel

dewe.bt=Data1_Brake_Travel;
dewe.timebt=Data1_time_Brake_Travel; % Brake Travel

dewe.dir=Data1_Direction;
dewe.timedir=Data1_time_Direction; % Direction

dewe.db=Data1_Driver_Brake___for_math_c;
dewe.timedb=Data1_time_Driver_Brake___for_m; % DriverBrake
% startTime.db = dewe.timedb(1);
```

```
% dewe.timedb = dewe.timedb-startTime.db;

dewe.pb=Data1_Passenger_Brake;
dewe.timepb=Data1_time_Passenger_Brake; % PassengerBrake

dewe.lts=Data1_Left_Turn_Signal___for_ma;
dewe.timelts=Data1_time_Left_Turn_Signal___f; % LeftTurnSignal

dewe.rts=Data1_Right_Turn_Signal___for_m;
dewe.timerts=Data1_time_Right_Turn_Signal___; % RightTurnSignal

dewe.v=Data1_Velocity;
dewe.timev=Data1_time_Velocity; % Velocity (km/h)

dewe.x=Data1_X_absolute;
dewe.timex=Data1_time_X_absolute; % X

dewe.y=Data1_Y_absolute;
dewe.timey=Data1_time_Y_absolute; % Y

dewe.z=Data1_Z;
dewe.timez=Data1_time_Z; % Z

dewe.la=Data1_X_accel__lat____lateral;
dewe.timela=Data1_time_X_accel__lat____late; % LatAccel

dewe.longa=Data1_Y_accel__long____Longitud;
dewe.timelonga=Data1_time_Y_accel__long____Lon; % Long Accel

dewe.va=Data1_Z_accel___Vertical;
dewe.timeva=Data1_time_Z_accel___Vertical; % Ver Accel

dewe.pr=Data1_X_rate__pitch____pitch;
dewe.timepr=Data1_time_X_rate__pitch____pit; % Pitch Rate

dewe.rr=Data1_Y_rate__roll____roll;
dewe.timerr=Data1_time_Y_rate__roll____roll; % Roll Rate

dewe.yr=Data1_Z_rate__yaw____yaw;
dewe.timeyr=Data1_time_Z_rate__yaw____yaw; % Yaw Rate

% -------------------------------------
% clear variables
clear  Data1_Brake_Travel Data1_time_Brake_Travel Data1_Direction
Data1_time_Direction...
    Data1_Driver_Brake Data1_time_Driver_Brake Data1_Passenger_Brake
Data1_time_Passenger_Brake Data1_Left_Turn_Signal...
    Data1_time_Left_Turn_Signal Data1_Right_Turn_Signal
Data1_time_Right_Turn_Signal Data1_Velocity Data1_time_Velocity
Data1_X_absolute Data1_time_X_absolute...
```

```
    Data1_Y_absolute Data1_time_Y_absolute Data1_Z Data1_time_Z
Data1_X_accel__lat____Lateral Data1_time_X_accel__lat____Late...
    Data1_X_rate__pitch Data1_time_X_rate__pitch
Data1_Y_accel__long____Longitud Data1_time_Y_accel__long____Lon
Data1_time_Sound...
    Data1_Y_rate__roll Data1_time_Y_rate__roll Data1_Z_accel___Vertical
Data1_time_Z_accel___Vertical Data1_Z_rate__yaw...
    Data1_time_Z_rate__yaw Data1_Current_sec Data1_X_NMEALog Data1Sound
Data1_Start Data1_Stop Data1_Used_satellites Data1_NMEALog...
    Data1_time_Current_sec Data1_Sound Data1_time_Start Data1_time_Stop
Data1_time_Used_satellites File_name Number_of_channels Sample_rate...
    Store_type Data1_Accel__Travel Data1_time_Accel__Travel
Data1_Frm2_Driver_Brake  Data1_time_Frm2_Driver_Brake  Data1_time_NMEALog;
clear Start_time; % clear system recording start time

%% step 2.2 Import tekscan data
% raw data units
% Force: [pounds]; Contact area: [cm^2]; Contact pressure: [KPa]

% match the files with pedal type
pedal02=input('please enter the pedal type for DOTPE02 (brake or accel):
', 's');
pedal03=input('please enter the pedal type for DOTPE03 (brake or accel):
', 's');

% DOTPE02
% -------------------------------------
DOTPE02_CoF = importfile([folder '\' 'DOTPE02_CoF.csv']); % create
timeseries of center of force (rows and columns)
st=DOTPE02_CoF{17}(end-12:end); % create variable: startTime (string)
startTimeT=[date st]; % create variable: (tekscan)start time
clear st;
sensitivity=str2double(DOTPE02_CoF{14}(end-1:end)); % create variable:
sensitivity

% -------------------------------------
% Obtain the number of frames
i=1; %row number used to look for 'END_FRAME'
while 1
    if length(DOTPE02_CoF{i})<length('END_FRAME')
        i=i+1; continue;
    end
    if strcmp(DOTPE02_CoF{i}(1:9),'END_FRAME')==1
        break;
    end
    i=i+1;
end
frameCt=str2double(DOTPE02_CoF{i}(11:end));

% -------------------------------------
% obtain the row number of the first row of data
startRow=1;
while 1
```

```
    if DOTPE02_CoF{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end

time=cell2mat(DOTPE02_CoF(startRow:startRow-1+frameCt,2)); % create
variable: time

cofr=cell2mat(DOTPE02_CoF(startRow:startRow-1+frameCt,4)); % obtain the
center of force row index (y);
cofc=cell2mat(DOTPE02_CoF(startRow:startRow-1+frameCt,6)); % obtain the
center of force column index (x); !!right most column
% identify invalid data from row and col
cofr(find(cofr==-1))=NaN;
cofc(find(cofc==-1))=NaN;
% remove DOTPE02_CoF
clearvars DOTPE02_CoF;

% ---------------------------------------
DOTPE02_Force = importfile([folder '\' 'DOTPE02_Force.csv']);% create
timeseries of force
% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE02_Force{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the force
force=cell2mat(DOTPE02_Force(startRow:startRow-1+frameCt,4)); %  [pounds]
% remove DOTPE02_Force
clearvars DOTPE02_Force;

% ---------------------------------------
DOTPE02_ContactArea = importfile([folder '\'
'DOTPE02_ContactArea.csv']); % create timeseries of contact area

% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE02_ContactArea{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the contact area
ca=cell2mat(DOTPE02_ContactArea(startRow:startRow-1+frameCt,4)); %
[cm^2]
% remove DOTPE02_ContactArea
clearvars DOTPE02_ContactArea;
```

```
% -------------------------------------
DOTPE02_ContactPressure = importfile([folder '\'
'DOTPE02_Pressure.csv']); % create timeseries of contact pressure
% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE02_ContactPressure{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the contact pressure
cp=cell2mat(DOTPE02_ContactPressure(startRow:startRow-1+frameCt,4)); %
[KPa]
% remove DOTPE02_ContactPressure
clearvars DOTPE02_Pressure;

% -------------------------------------
if strcmp(pedal02,'brake')==1
    brake=struct('cofr',cofr,'cofc',cofc,'ca',ca,'force',force,'cp',cp);
%     brake.fd=fd;
else
    accel=struct('cofr',cofr,'cofc',cofc,'ca',ca,'force',force,'cp',cp);
%     accel.fd=fd;
end

% DOTPE03
% -------------------------------------
DOTPE03_CoF = importfile([folder '\' 'DOTPE03_CoF.csv']);
% center of force
startRow=1;
while 1
    if DOTPE03_CoF{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end


cofr=cell2mat(DOTPE03_CoF(startRow:startRow-1+frameCt,4)); % obtain the
center of force row index (y)
cofc=cell2mat(DOTPE03_CoF(startRow:startRow-1+frameCt,6)); % obtain the
center of force column index (x)
% identify invalid data from row and col
cofr(find(cofr==-1))=NaN;
cofc(find(cofc==-1))=NaN;
% remove DOTPE02_CoF
clearvars DOTPE03_CoF;

% -------------------------------------
```

```
DOTPE03_Force = importfile([folder '\' 'DOTPE03_Force.csv']);% create
timeseries of force
% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE03_Force{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the force
force=cell2mat(DOTPE03_Force(startRow:startRow-1+frameCt,4));  %  [pounds]
% remove DOTPE03_Force
clearvars DOTPE03_Force;


% -------------------------------------
DOTPE03_ContactArea = importfile([folder '\'
'DOTPE03_ContactArea.csv']);% create timeseries of contact area
% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE03_ContactArea{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the contact area
ca=cell2mat(DOTPE03_ContactArea(startRow:startRow-1+frameCt,4)); %
[cm^2]
% remove DOTPE03_ContactArea
clearvars DOTPE03_ContactArea;


% -------------------------------------
DOTPE03_ContactPressure = importfile([folder '\'
'DOTPE02_Pressure.csv']);% create timeseries of contact pressure
% obtain the row number of the first row of data
startRow=1;
while 1
    if DOTPE03_ContactPressure{startRow}==1
        break;
    end
    startRow=startRow+1; % start frame number
end
% store the contact pressure
cp=cell2mat(DOTPE03_ContactPressure(startRow:startRow-1+frameCt,4)); %
[KPa]
% remove DOTPE03_ContactPressure

% -------------------------------------
if strcmp(pedal03,'brake')==1
    brake=struct('cofr',cofr,'cofc',cofc,'ca',ca,'force',force,'cp',cp);
```

```
%     brake.fd=fd;
else
    accel=struct('cofr',cofr,'cofc',cofc,'ca',ca,'force',force,'cp',cp);
%     accel.fd=fd;
end

% -------------------------------------
% store tekscan data in the struct
tekscan=struct('time',time,'startTime',startTimeT,'sen',sensitivity,'br
ake',brake,'accel',accel); %sensitivity is the noise threshold
clear accel brake ca cofc cofr cp force frame frameCt i pedal02 pedal03
sensitivity st startRow startTimeT time;
clearvars DOTPE03_ContactPressure DOTPE02_ContactPressure;

%% step 3 sync tekscan and dewetron data_step 1
figure;
plot(tekscan.time,tekscan.brake.force/max(tekscan.brake.force),'r');
hold on;
plot(tekscan.time,tekscan.accel.force/max(tekscan.accel.force),'g');
legend('brake force','accel force');

figure;
plot(dewe.timebt,dewe.bt/max(dewe.bt),'r');
hold on;
plot(dewe.timeat,dewe.at/max(dewe.at),'g');
legend('brake travel','accel travel');

%% step 3.2 sync tekscan and dewesoft_step 2

% !!!SAVE WORKSPACE VARIABLES BEFORE PROCEEDING!!!
% save('pathname\filename','-v7.3');

% compare the tekscan brake force and dewetron brake travel in matlab,
find out the
% dewetron sync time points using datestr(startTime.sys+brake pedal
sync time point/86400,'HH:MM:SS.FFF')
% and the tekscan sync time point
flag=input('Do you want to sync tekscan and dewesoft data? (y/n): ',
's');
if flag=='y'
    sync.tekscan=input('Please enter the tekscan sync time point
(seconds): ', 's');
    sync.dewe=input('Please enter the dewesoft sync time point
(hh:mm:ss.fff): ', 's');
else break;
end

startTimeTek = str2double(sync.tekscan) - (datenum([date ' '
sync.dewe])-datenum(startTime.sys))*86400;
% (datenum([date ' ' sync.dewe])-datenum(startTime.sys))*86400 = how
much time has elapsed from beginning of the dewetron recording to the
dewe sync time point
```

```
% tekscan time point that is associated with dewesoft start time
if startTimeTek > 0
    [timediff,tekid]=min(abs(tekscan.time-startTimeTek)); % find the
tekscan data index that is corresponding to the startTimeTek

    tekscan.brake.cofr(1:tekid-1)=[];
    tekscan.brake.cofc(1:tekid-1)=[];
    tekscan.brake.force(1:tekid-1)=[];
    tekscan.brake.ca(1:tekid-1)=[];
    tekscan.brake.cp(1:tekid-1)=[];

    tekscan.accel.cofr(1:tekid-1)=[];
    tekscan.accel.cofc(1:tekid-1)=[];
    tekscan.accel.force(1:tekid-1)=[];
    tekscan.accel.ca(1:tekid-1)=[];
    tekscan.accel.cp(1:tekid-1)=[];

    tekscan.time(end-tekid+2:end)=[];
else
    [timediff,tekid]=min(abs(tekscan.time-(-1)*startTimeTek));

    tekscan.brake.cofr=[zeros(tekid-1, 1); tekscan.brake.cofr];
    tekscan.brake.cofc=[zeros(tekid-1, 1); tekscan.brake.cofc];
    tekscan.brake.force=[zeros(tekid-1, 1); tekscan.brake.force];
    tekscan.brake.ca=[zeros(tekid-1, 1); tekscan.brake.ca];
    tekscan.brake.cp=[zeros(tekid-1, 1); tekscan.brake.cp];

    tekscan.accel.cofr=[zeros(tekid-1, 1); tekscan.accel.cofr];
    tekscan.accel.cofc=[zeros(tekid-1, 1); tekscan.accel.cofc];
    tekscan.accel.force=[zeros(tekid-1, 1); tekscan.accel.force];
    tekscan.accel.ca=[zeros(tekid-1, 1); tekscan.accel.ca];
    tekscan.accel.cp=[zeros(tekid-1, 1); tekscan.accel.cp];

    for nTekTime = 1:tekid-1
       tekscan.time(end+1) = tekscan.time(end)+(1/30);
    end
end

clear startTimeTek flag tekid timediff

% %% step 3.3 sync tekscan and dewesoft_step 3: check the sync
performance by comparing the brake/accel force and pedal travel data
% figure;
% plot(tekscan.time,tekscan.brake.force/max(tekscan.brake.force),'r');
% hold on;
% plot(tekscan.time,tekscan.accel.force/max(tekscan.accel.force),'g');
%
% plot(dewe.timebt*86400,dewe.bt/max(dewe.bt),'k');
% hold on;
% plot(dewe.timeat*86400,dewe.at/max(dewe.at),'b');
%
% legend('brake force','accel force','brake travel','accel travel');
```

```
%% step 3.3_v2 sync tekscan and dewesoft_step 3_v2: check how well the
dewetron and tekscan data were synced
tekscan.brake.force_n = tekscan.brake.force /
max(tekscan.brake.force)*100; % [lb] normalized
tekscan.accel.force_n = tekscan.accel.force /
max(tekscan.accel.force)*100; % [lb] normalized
figure;
plot(tekscan.time, tekscan.brake.force_n,'r');
hold on; grid on;
plot(dewe.timebt*86400,dewe.bt,'g');
% title('Brake force and travel');
legend('Brake force','Brake travel');

figure;
plot(tekscan.time, tekscan.accel.force_n,'r');
hold on; grid on;
plot(dewe.timeat*86400,dewe.at,'g');
% title('Accelerator force and travel');
legend('Accelerator force','Accelerator travel');

%% step 4 smooth dewetron and tekscan data
dewe.la2=smooth(dewe.la,C.freqaccel/10); % x (lateral) acceleration
dewe.longa2=smooth(dewe.longa,C.freqaccel/10); % y (longitudinal)
acceleration
dewe.va2=smooth(dewe.va,C.freqaccel/10);  % z (vertical) acceleration

dewe.yr2=smooth(dewe.yr,C.freqrate/10); % z (yaw) rate
dewe.rr2=smooth(dewe.rr,C.freqrate/10); % y (roll) rate
dewe.pr2=smooth(dewe.pr,C.freqrate/10); % x (pitch) rate

dewe.v2=smooth(dewe.v,C.spanv); % velocity

tekscan.brake.force2=smooth(tekscan.brake.force,C.spantek);
tekscan.accel.force2=smooth(tekscan.accel.force,C.spantek);
tekscan.brake.ca2=smooth(tekscan.brake.ca,C.spantek);
tekscan.accel.ca2=smooth(tekscan.accel.ca,C.spantek);
tekscan.brake.cp2=smooth(tekscan.brake.cp,C.spantek);
tekscan.accel.cp2=smooth(tekscan.accel.cp,C.spantek);

%% step 5.1 IMPORT EVENTS
% read driving event file_v1 (with event number)
% [filename,pathname] = uigetfile('*.xlsx','Select the DOT data
sheet',folder);
disp([pathname filename]);
[~,~,eventInfo.raw] = xlsread([pathname filename],'pedal');
event2txt = eventInfo.raw(2:end,1:5);
fileID = fopen([pathname 'Driving events.txt'],'w');
formatSpec = '%d\t%s\t%s\t%s\t%.3f\r\n';
[cols,~] = size(event2txt);
flag = 0;
for nRow = 1:cols
    if isnan(event2txt{nRow,3}) || isnan(event2txt{nRow,4})
```

```
        continue;
    end
    if nRow ~= event2txt{nRow,1} || event2txt{nRow,5} ~=
(event2txt{nRow,4}-event2txt{nRow,3})*86400
        disp(['Check event #' num2str(event2txt{nRow,1})]); % check and
make sure that the events were numbered
        % correctly and events durations were calculated correctly
        flag = 1;
    end
    event2txt{nRow,3} = datestr(event2txt{nRow,3},'HH:MM:SS.FFF');
    event2txt{nRow,4} = datestr(event2txt{nRow,4},'HH:MM:SS.FFF');
    fprintf(fileID,formatSpec,event2txt{nRow,:});
end
if flag == 0
    disp('Events checked.');
end
fclose(fileID);
clear event2txt cols nRow formatSpec fileID flag

% [filename,pathname,filterindex] = uigetfile('*.txt','Select the
driving event text file',folder);
fid=fopen([folder '\' 'Driving events.txt']);
event=textscan(fid,'%f %s %s %s %s','delimiter','\t');
fclose(fid);
field={'num','name','start','end','dur'};
eventInfo=cell2struct(event,field,2);
clear event fid filterindex field;
% obtain major and sub event index; eventInfo.major is a matrix. 1st
column
% is the # of major event and the 2nd column is the # of last sub event
for
% that major event
eventInfo.major(:,1) = find(strncmp(eventInfo.name,'m-',2)==1);
eventInfo.major(numel(eventInfo.major),2) = eventInfo.num(end);
eventInfo.major(1:end-1,2) = eventInfo.major(2:end,1)-1;

eventInfo.name = strrep(eventInfo.name,'@','_'); % replace @ with _
% create a structure to store the dot clicking data
for nMajor = 1 : length(eventInfo.major)
   dot.(C.event{nMajor}) = {}; % create a structure to store the dot
clicking data
end

clear nMajor

%% step 5.2 specify the interested driving event for manual
segmentation
% user specifies the event number
inputENum=str2double(input('please enter event number : ', 's')); %
inputENum is the user specified event number
% extract event info from variable eventInfo
i=find(eventInfo.num==inputENum);
% determine if the event is not available
```

```
while isempty(eventInfo.start{i})
    msgbox('The event you entered is /not available. Please check the
event list document and enter again.');
    inputENum=str2double(input('please enter event number : ', 's'));
end

eventName=eventInfo.name{i};
es.sys=[date ' ' eventInfo.start{i}]; % event start time
ee.sys=[date ' ' eventInfo.end{i}]; % event end time
% ed=eventInfo.dur{i}; % event duration

% obtain event info (start time, end time, index in the time series and
% time difference) from all channels

% accelerator travel
es.at=datenum(es.sys)-startTime.at; % event (forward and left) starting
time
ee.at=datenum(ee.sys)-startTime.at; % event ending time
% find the accel travel data section index for event 20
[td.esat,index.esat]=min(abs(dewe.timeat-es.at)); % find the index of
accel travel.time which is closest to the specified event starting time;
find the time difference
[td.eeat,index.eeat]=min(abs(dewe.timeat-ee.at)); % find the index of
accel travel.time which is closest to the specified event ending time;
find the time difference

% brake travel
es.bt=datenum(es.sys)-startTime.bt; % event (forward and left) starting
time
ee.bt=datenum(ee.sys)-startTime.bt; % event ending time
% find the accel travel data section index for event
[td.esbt,index.esbt]=min(abs(dewe.timebt-es.bt)); % find the index of
accel travel.time which is closest to the specified event starting time;
find the time difference; td:time difference
[td.eebt,index.eebt]=min(abs(dewe.timebt-ee.bt)); % find the index of
accel travel.time which is closest to the specified event ending time;
find the time difference

% tekscan force
es.tekscan=datenum(es.sys)-startTime.sys; % event20 start time of
tekscan
ee.tekscan=datenum(ee.sys)-startTime.sys; % event20 end time of tekscan
[td.estekscan,index.estekscan]=min(abs(tekscan.time-
es.tekscan*86400)); % find out the index of tekscan time variable
[td.eetekscan,index.eetekscan]=min(abs(tekscan.time-ee.tekscan*86400));

clear inputENum

% segment foot transfer AUTOMATICALLY
% option 1: smooth (local data) first and then remove offset
clear dewe.bt2 dewe.at2
dewe.bt2=smooth(dewe.bt(index.esbt:index.eebt),C.span);
```

```
dewe.at2=smooth(dewe.at(index.esat:index.eeat),C.span);
% -----------------------------
% display the pedal travel offset that's gonna be removed. The brake
pedal
% travel sensor has an offset of about 8%. If the number is
significantly
% greater than that, we need to check and make sure whether the offset
% that' s going to be removed represents the offset of pedal null
position.
fprintf('Brake travel offset: %.2f \n',min(dewe.bt2));
fprintf('Accelerator travel offset: %.2f \n',min(dewe.at2));

dewe.bt2 = dewe.bt2 - min(dewe.bt2);
dewe.at2 = dewe.at2 - min(dewe.at2);
figure;
subplot(3,1,1);
plot(dewe.at(index.esat:index.eeat),'g');hold
on;plot(dewe.bt(index.esbt:index.eebt),'r');
grid on;
title([num2str(eventInfo.num(i)) ' ' eventName '-original']);
% plot(datenum(es.sys)+(1/C.freqat)/86400*(1:index.eeat-
index.esat+1),dewe.at2,'g');
% datetick('x','hh:mm:ss.fff');
subplot(3,1,2);
plot(dewe.at2,'g');hold on;plot(dewe.bt2,'r');
grid on;
title('smooth first and then remove offset');

plot([0 length(dewe.bt2)],[C.braketrigger C.braketrigger]);
plot([0 length(dewe.at2)],[C.acceltrigger C.acceltrigger]);

% find out start/end of foot transfer from pedal to pedal
[td.bt2,index.bt2] = min(abs(dewe.bt2-C.braketrigger));
[td.at2,index.at2] = min(abs(dewe.at2-C.acceltrigger)); % find out when
the pedal travel is closest to the trigger

if index.bt2 < index.at2 % if foot from brake to gas,
index.bt2<index.at2; if foot from gas to brake, index.at2<index.bt2
%     eventInfo.start{i} = datestr(datenum(es.sys)+(index.bt2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
%     eventInfo.end{i} = datestr(datenum(es.sys)+(index.at2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
    subplot(3,1,3);
    plot(dewe.bt2(index.bt2:index.at2),'r'); hold on;
    plot(dewe.at2(index.bt2:index.at2),'g');grid on; % check to make
sure the segmentation did what we want
    plot([0 length(dewe.bt2)],[C.braketrigger C.braketrigger]);
    plot([0 length(dewe.at2)],[C.acceltrigger C.acceltrigger]);
    fprintf('%s\t',datestr(datenum(es.sys)+(index.bt2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));
    fprintf('%s\n',datestr(datenum(es.sys)+(index.at2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));
```

```
else
%     eventInfo.start{i} = datestr(datenum(es.sys)+(index.at2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
%     eventInfo.end{i} = datestr(datenum(es.sys)+(index.bt2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
    subplot(3,1,3);
    plot(dewe.bt2(index.at2:index.bt2),'r'); hold on;
    plot(dewe.at2(index.at2:index.bt2),'g');grid on; % check to make
sure the segmentation did what we want
    plot([0 length(dewe.bt2)],[C.braketrigger C.braketrigger]);
    plot([0 length(dewe.at2)],[C.acceltrigger C.acceltrigger]);
    fprintf('%s\t',datestr(datenum(es.sys)+(index.at2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));
    fprintf('%s\n',datestr(datenum(es.sys)+(index.bt2 *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));
end

%% step 5.3 segment foot transfer MANUALLY by typing in the index (for
foot hovering and others)
clear dewe.bt2 dewe.at2
dewe.bt2=smooth(dewe.bt(index.esbt:index.eebt),C.span);
dewe.at2=smooth(dewe.at(index.esat:index.eeat),C.span);
dewe.bt2 = dewe.bt2 - min(dewe.bt2);
dewe.at2 = dewe.at2 - min(dewe.at2);
% figure;
% subplot(2,1,1);
% plot(dewe.at2,'g');hold on;plot(dewe.bt2,'r');
% grid on;
% C.pedaltrigger = 5; % using 5% of pedal travel as the trigger
% plot([0 length(dewe.bt2)],[C.pedaltrigger C.pedaltrigger]);

index.pts = str2double(input('please enter event start index : ',
's')); % event start index of foot hovering (find it in the plot)
index.pte = str2double(input('please enter event end index : ', 's')); %
event end index of foot hovering (find it in the plot)
% eventInfo.start{i} = datestr(datenum(es.sys)+(index.pts *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
% eventInfo.end{i} = datestr(datenum(es.sys)+(index.pte *
(1/C.freqbt))/86400,'HH:MM:SS.FFF');
% subplot(2,1,2);
% plot(dewe.bt2(index.pts:index.pte),'r'); hold on;
% plot(dewe.at2(index.pts:index.pte),'g');grid on; % check to make sure
the segmentation did what we want

fprintf('%s\t',datestr(datenum(es.sys)+(index.pts *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));
fprintf('%s\n',datestr(datenum(es.sys)+(index.pte *
(1/C.freqbt))/86400,'HH:MM:SS.FFF'));

%% step 6.1 import digitized foot movement data (from excelsheet
created by DLTdv5)
clear rawdata
```

```
%-----------------------------------------------------------------------
----
% obtain the existing dot clicking files (files that end with
*xyptx.csv)
cd(folder); % change the current folder to the participant's folder
filedot = dir('*xypts.csv');

for nFD = 1:numel(filedot)

    rawdata = csvread([folder '\' filedot(nFD).name],1,0);
    event = strrep(filedot(nFD).name,'@','_'); % because the character
'@' cannot be in a valid field name, it needs to be replaced by '_'
    event = event(13:end-9);
    dot.(event) = {}; % when overwriting, clear dot data within the
specified event first
    %-------------------------------------------------------------------
--------
    % map the data with sub events (identify the section of data for
each sub
    % event)
    dot.(event).enums = find(strcmp(eventInfo.name,['m-' event])==1,
1); % auto find the imported event starting index

    if dot.(event).enums ~= eventInfo.major(end,1)
        dot.(event).enume = eventInfo.major(find(eventInfo.major(:,1)
== dot.(event).enums)+1,1)-1;
    else
        dot.(event).enume = eventInfo.num(end);
    end % auto find the imported event ending index; if the imported
event is the last major event on the list, use the last event number as
the ending index
    %-------------------------------------------------------------------
--------
    % time
    for i = 1 : length(rawdata(:,1))
        dot.(event).time(i,:) = (1/30) * (i-1);
    end
    %-------------------------------------------------------------------
--------
    % dot.(event).startTime = datenum(eventInfo.start{1});
    for i = dot.(event).enums : dot.(event).enume
        [td.esdm,eventInfo.indexesdm(i,:)] =
min(abs(datenum(eventInfo.start(i)) -
datenum(eventInfo.start(dot.(event).enums)) - dot.(event).time/86400));
        % eventInfo.indexesdm/indexeedm (i) refers to the index of
digitized marker data
        % that are associated with the eventInfo.num(i); the index can
be used
        % to identify the sub events
        [td.eedm,eventInfo.indexeedm(i,:)] =
min(abs(datenum(eventInfo.end(i)) -
datenum(eventInfo.start(dot.(event).enums)) - dot.(event).time/86400));
```

```
        % dm: digitized marker data; td.dms/dme: the time difference
between
        % event start time and the time variable of digitized marker
data
    end

    %-----------------------------------------------------------------
--------
    % obtain dot's coordinates
    dot.(event).x1raw = rawdata(1:end,1);
    dot.(event).y1raw = rawdata(1:end,2);
    dot.(event).x2raw = rawdata(1:end,3);
    dot.(event).y2raw = rawdata(1:end,4);
    dot.(event).x3raw = rawdata(1:end,5);
    dot.(event).y3raw = rawdata(1:end,6);
    dot.(event).x4raw = rawdata(1:end,7);
    dot.(event).y4raw = rawdata(1:end,8);
    dot.(event).x5raw = rawdata(1:end,9);
    dot.(event).y5raw = rawdata(1:end,10);
    dot.(event).x6raw = rawdata(1:end,11);
    dot.(event).y6raw = rawdata(1:end,12);
    %-----------------------------------------------------------------
--------
    % smoothing/filtering; suffix 'f' means filtered
    dot.(event).x1f = smooth(dot.(event).x1raw,C.spandot);
    dot.(event).y1f = smooth(dot.(event).y1raw,C.spandot);
    dot.(event).x2f = smooth(dot.(event).x2raw,C.spandot);
    dot.(event).y2f = smooth(dot.(event).y2raw,C.spandot);
    dot.(event).x3f = smooth(dot.(event).x3raw,C.spandot);
    dot.(event).y3f = smooth(dot.(event).y3raw,C.spandot);
    dot.(event).x4f = smooth(dot.(event).x4raw,C.spandot);
    dot.(event).y4f = smooth(dot.(event).y4raw,C.spandot);
    dot.(event).x5f = smooth(dot.(event).x5raw,C.spandot);
    dot.(event).y5f = smooth(dot.(event).y5raw,C.spandot);
    dot.(event).x6f = smooth(dot.(event).x6raw,C.spandot);
    dot.(event).y6f = smooth(dot.(event).y6raw,C.spandot);

    % dot#7 8 9 10 are fixed dot, they might not be visible on the
first frame.
    % we need to look for them in the array
    ind = find(~isnan(rawdata(:,13))); dot.(event).x7raw =
rawdata(ind(1),13);
    ind = find(~isnan(rawdata(:,14))); dot.(event).y7raw =
rawdata(ind(1),14);
    ind = find(~isnan(rawdata(:,15))); dot.(event).x8raw =
rawdata(ind(1),15);
    ind = find(~isnan(rawdata(:,16))); dot.(event).y8raw =
rawdata(ind(1),16);
    ind = find(~isnan(rawdata(:,17))); dot.(event).x9raw =
rawdata(ind(1),17);
    ind = find(~isnan(rawdata(:,18))); dot.(event).y9raw =
rawdata(ind(1),18);
```

```
    ind = find(~isnan(rawdata(:,19))); dot.(event).x10raw =
rawdata(ind(1),19);
    ind = find(~isnan(rawdata(:,20))); dot.(event).y10raw =
rawdata(ind(1),20);
    ind = find(~isnan(rawdata(:,21))); dot.(event).cam1x =
rawdata(ind(1),21); % camera view 1 origin x lower left, in pixel
    ind = find(~isnan(rawdata(:,22))); dot.(event).cam1y =
rawdata(ind(1),22); % camera view 1 origin y, in pixel
    ind = find(~isnan(rawdata(:,23))); dot.(event).cam2x =
rawdata(ind(1),23); % camera view 2 origin x, in pixel
    ind = find(~isnan(rawdata(:,24))); dot.(event).cam2y =
rawdata(ind(1),24); % camera view 2 origin y, in pixel

    %-----------------------------------------------------------------------
--------
    % calculate the scale factor of camera view 1; 'sf' refers to scale
factor
    d910 = sqrt((dot.(event).x10raw-
dot.(event).x9raw)^2+(dot.(event).y10raw-dot.(event).y9raw)^2); %
distance between dot 9 and dot 10 measured in the camera view
    dot.(event).sf1 = C.D910/d910;
    % calculate the camera view adjustment angle of camera view 1
    dot.(event).angle910 = atan((dot.(event).y10raw-
dot.(event).y9raw)/(dot.(event).x10raw-dot.(event).x9raw)) ; % in
radians, to accommodate for the camera angle differences in camera view
1

    % calculate the scale factor of camera view 2
    d78 = sqrt((dot.(event).x8raw-
dot.(event).x7raw)^2+(dot.(event).y8raw-dot.(event).y7raw)^2); %
distance between dot 7 and dot 8 measured in the camera view
    dot.(event).sf2 = C.D78/d78; % scale factor used to scale the
camera view 2
    % calculate the camera view adjustment angle of camera view 1
    dot.(event).angle78 = atan((dot.(event).y8raw-
dot.(event).y7raw)/(dot.(event).x8raw-dot.(event).x7raw)) ; % in
radians, to accommodate for the camera angle differences in camera view
2

    clear d78 d910 ind

    %-----------------------------------------------------------------------
--------
    % This section is dedicated to adjust the dots' coordinates. The
actions
    % include:
    %     'zeroing (make all coordinates relative to the origin of the
camera views/self-defined coordinate system)'
    %      scaling (pixel to mm; scale the pic up to the realistic
scale)
    %      rotation (to accommodate for camera angles).
```

```
    % camera view 2 (dot 1 2 3 4 7 8); sufix -zs means that these are
coordinates
    % that have been zeroed and scaled (but not rotated yet)
    dot.(event).x1zs = (dot.(event).x1f - dot.(event).cam2x) *
dot.(event).sf2; % x coordinate of dot 1 in its camera view 2 (cal
refers to calibrated)
    dot.(event).y1zs = (dot.(event).y1f - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 1 in its camera view 2
    dot.(event).x2zs = (dot.(event).x2f - dot.(event).cam2x) *
dot.(event).sf2; % x coordinate of dot 2 in its camera view 2
    dot.(event).y2zs = (dot.(event).y2f - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 2 in its camera view 2
    dot.(event).x3zs = (dot.(event).x3f - dot.(event).cam2x) *
dot.(event).sf2; % y coordinate of dot 3 in its camera view 2
    dot.(event).y3zs = (dot.(event).y3f - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 3 in its camera view 2
    dot.(event).x4zs = (dot.(event).x4f - dot.(event).cam2x) *
dot.(event).sf2; % x coordinate of dot 4 in its camera view 2
    dot.(event).y4zs = (dot.(event).y4f - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 4 in its camera view 2
    dot.(event).x7zs = (dot.(event).x7raw - dot.(event).cam2x) *
dot.(event).sf2; % x coordinate of dot 7 in its camera view 2
    dot.(event).y7zs = (dot.(event).y7raw - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 7 in its camera view 2
    dot.(event).x8zs = (dot.(event).x8raw - dot.(event).cam2x) *
dot.(event).sf2; % x coordinate of dot 8 in its camera view 2
    dot.(event).y8zs = (dot.(event).y8raw - dot.(event).cam2y) *
dot.(event).sf2; % y coordinate of dot 8 in its camera view 2
    % camera view 1 (dot 5,6,9,10); sufix -zs means that these are
coordinates
    % that have been zeroed and scaled (but not rotated yet)
    dot.(event).x5zs = (dot.(event).x5f - dot.(event).cam1x) *
dot.(event).sf1; % dot 5 and dot 6 are on camera view 1
    dot.(event).y5zs = (dot.(event).y5f - dot.(event).cam1y) *
dot.(event).sf1; % y coordinate of dot 5 in its camera view 1
    dot.(event).x6zs = (dot.(event).x6f - dot.(event).cam1x) *
dot.(event).sf1; % x coordinate of dot 6 in its camera view 1
    dot.(event).y6zs = (dot.(event).y6f - dot.(event).cam1y) *
dot.(event).sf1; % y coordinate of dot 6 in its camera view 1
    dot.(event).x9zs = (dot.(event).x9raw - dot.(event).cam1x) *
dot.(event).sf1; %
    dot.(event).y9zs = (dot.(event).y9raw - dot.(event).cam1y) *
dot.(event).sf1; % y coordinate of dot 9 in its camera view 1
    dot.(event).x10zs = (dot.(event).x10raw - dot.(event).cam1x) *
dot.(event).sf1; % x coordinate of dot 10 in its camera view 1
    dot.(event).y10zs = (dot.(event).y10raw - dot.(event).cam1y) *
dot.(event).sf1; % y coordinate of dot 10 in its camera view 1


    % coordinates rotation to accommodate camera angle difference; 'ra'
refers
    % to camera view rotational angle
    dot.(event).ra1 = -dot.(event).angle910; %NEED TO CUSTOMIZE
```

```
    dot.(event).ra2 = -dot.(event).angle78; %NEED TO CUSTOMIZE
    % dot.(event).ra1 = 0; %NEED TO CUSTOMIZE
    % dot.(event).ra2 = 0; %NEED TO CUSTOMIZE
    % rotMat2 = [cos(dot.(event).ra2) -sin(dot.(event).ra2);
    %            sin(dot.(event).ra2) cos(dot.(event).ra2)];
    % rotMat1 = [cos(dot.(event).ra1) -sin(dot.(event).ra1);
    %            sin(dot.(event).ra1) cos(dot.(event).ra1)];

    % camera view 2
    dot.(event).x1 = dot.(event).x1zs*cos(dot.(event).ra2) -
dot.(event).y1zs*sin(dot.(event).ra2);
    dot.(event).y1 = dot.(event).x1zs*sin(dot.(event).ra2) +
dot.(event).y1zs*cos(dot.(event).ra2);
    dot.(event).x2 = dot.(event).x2zs*cos(dot.(event).ra2) -
dot.(event).y2zs*sin(dot.(event).ra2);
    dot.(event).y2 = dot.(event).x2zs*sin(dot.(event).ra2) +
dot.(event).y2zs*cos(dot.(event).ra2);
    dot.(event).x3 = dot.(event).x3zs*cos(dot.(event).ra2) -
dot.(event).y3zs*sin(dot.(event).ra2);
    dot.(event).y3 = dot.(event).x3zs*sin(dot.(event).ra2) +
dot.(event).y3zs*cos(dot.(event).ra2);
    dot.(event).x4 = dot.(event).x4zs*cos(dot.(event).ra2) -
dot.(event).y4zs*sin(dot.(event).ra2);
    dot.(event).y4 = dot.(event).x4zs*sin(dot.(event).ra2) +
dot.(event).y4zs*cos(dot.(event).ra2);
    dot.(event).x7 = dot.(event).x7zs*cos(dot.(event).ra2) -
dot.(event).y7zs*sin(dot.(event).ra2);
    dot.(event).y7 = dot.(event).x7zs*sin(dot.(event).ra2) +
dot.(event).y7zs*cos(dot.(event).ra2);
    dot.(event).x8 = dot.(event).x8zs*cos(dot.(event).ra2) -
dot.(event).y8zs*sin(dot.(event).ra2);
    dot.(event).y8 = dot.(event).x8zs*sin(dot.(event).ra2) +
dot.(event).y8zs*cos(dot.(event).ra2);
    % camera view 1
    dot.(event).x5 = dot.(event).x5zs*cos(dot.(event).ra1) -
dot.(event).y5zs*sin(dot.(event).ra1);
    dot.(event).y5 = dot.(event).x5zs*sin(dot.(event).ra1) +
dot.(event).y5zs*cos(dot.(event).ra1);
    dot.(event).x6 = dot.(event).x6zs*cos(dot.(event).ra1) -
dot.(event).y6zs*sin(dot.(event).ra1);
    dot.(event).y6 = dot.(event).x6zs*sin(dot.(event).ra1) +
dot.(event).y6zs*cos(dot.(event).ra1);
    dot.(event).x9 = dot.(event).x9zs*cos(dot.(event).ra1) -
dot.(event).y9zs*sin(dot.(event).ra1);
    dot.(event).y9 = dot.(event).x9zs*sin(dot.(event).ra1) +
dot.(event).y9zs*cos(dot.(event).ra1);
    dot.(event).x10= dot.(event).x10zs*cos(dot.(event).ra1) -
dot.(event).y10zs*sin(dot.(event).ra1);
    dot.(event).y10= dot.(event).x10zs*sin(dot.(event).ra1) +
dot.(event).y10zs*cos(dot.(event).ra1);

    %-----------------------------------------------------------------
--------
```

```
    % this section is about all kinds of calculations using the
coordinates
    % obtained above

    % ankle velocity (dot 2 moving velocity)
    for i = 1 : length(dot.(event).x2)-1
        dot.(event).x2_v(i,:) = (dot.(event).x2(i+1)-
dot.(event).x2(i))/(1/30); % dot 2 x velcoty
        dot.(event).y2_v(i,:) = (dot.(event).y2(i+1)-
dot.(event).y2(i))/(1/30); % dot 2 y velcoty
        dot.(event).v2(i,:) = sqrt(dot.(event).x2_v(i)^2 +
dot.(event).y2_v(i)^2); % dot 2 velocity
    end
    %--------------------------------
    % dot.(event).v2f =
smooth(dot.(event).v2,length(dot.(event).v2)/C.spandot); % filtered
    %--------------------------------
    % f = fft(dot.(event).v2);
    % f(length(dot.(event).v2)/2+1-C.dotfft :
length(dot.(event).v2)/2+C.dotfft) = zeros(2*C.dotfft,1);
    % dot.(event).v2f = real(ifft(f));
    %--------------------------------
    % dot.(event).v2f = filtfilt(filter.Numerator,1,dot.(event).v2);
    %--------------------------------
    % dot.(event).v2f = filtfilt(b,a,dot.(event).v2);

    %--------------------------------
    % side view distal dot (dot#4)
    for i = 1 : length(dot.(event).x4)-1
        dot.(event).x4_v(i,:) = (dot.(event).x4(i+1)-
dot.(event).x4(i))/(1/30); % x velocity of dot 4 in its camera view
        dot.(event).y4_v(i,:) = (dot.(event).y4(i+1)-
dot.(event).y4(i))/(1/30); % y velocity of dot 4 in its camera view
        dot.(event).v4(i,:) = sqrt(dot.(event).x4_v(i)^2 +
dot.(event).y4_v(i)^2); % velocity of dot 4 in its camera view
    end
    %--------------------------------
    % top view distal dot (dot#5)
    for i = 1 : length(dot.(event).x5)-1
        dot.(event).x5_v(i,:) = (dot.(event).x5(i+1)-
dot.(event).x5(i))/(1/30); % x velocity of dot 4 in its camera view
        dot.(event).y5_v(i,:) = (dot.(event).y5(i+1)-
dot.(event).y5(i))/(1/30); % y velocity of dot 4 in its camera view
        dot.(event).v5(i,:) = sqrt(dot.(event).x5_v(i)^2 +
dot.(event).y5_v(i)^2); % velocity of dot 4 in its camera view
    end

    %-----------------------------------------------------------------
--------
    % foot internal/external rotational angle and angular rate
    % dot.(event).angsweep = acos((dot.(event).x5-
dot.(event).x6)./sqrt((dot.(event).x5-
```

```
dot.(event).x6).^2+(dot.(event).y5-dot.(event).y6).^2)) * (180/pi); %
foot internal-external angle (sweeep angle)
    dot.(event).angsweep = 90 - atan2(dot.(event).y5-
dot.(event).y6,dot.(event).x5-dot.(event).x6) * (180/pi);
    %---------------------------------

    for i = 1: length(dot.(event).angsweep)-1
        dot.(event).angratsweep(i,:) = (dot.(event).angsweep(i+1)-
dot.(event).angsweep(i)) / (1/30); % foot internal-external angular
rate (sweep angular rate)
    end
    %---------------------------------
    % foot dorsal/plantar rotational angle and angular rate
        % dot.(event).vtibia = [dot.(event).x1,dot.(event).y1]-
[dot.(event).x2,dot.(event).y2];
        % dot.(event).vfoot = [dot.(event).x4,dot.(event).y4]-
[dot.(event).x3,dot.(event).y3];
        % dot.(event).angankle =
mod(det([dot.(event).vtibia;dot.(event).vfoot;]),dot(dot.(event).vtibia
,dot.(event).vfoot),2*pi)*(180/pi);
    dot.(event).angankle = mod(atan2((dot.(event).x1-
dot.(event).x2).*(dot.(event).y4-dot.(event).y3)-(dot.(event).y1-
dot.(event).y2).*(dot.(event).x4-dot.(event).x3),...
        (dot.(event).x1-dot.(event).x2).*(dot.(event).x4-
dot.(event).x3)+(dot.(event).y1-dot.(event).y2).*(dot.(event).y4-
dot.(event).y3)),2*pi)*(180/pi)-90;
        % dot.(event).angankle = (acos(((dot.(event).x1-
dot.(event).x4).^2+(dot.(event).y1-dot.(event).y4).^2-(dot.(event).x2-
dot.(event).x4).^2-(dot.(event).y2-dot.(event).y4).^2-(dot.(event).x1-
dot.(event).x2).^2-(dot.(event).y1-dot.(event).y2).^2)./(-
2*sqrt((dot.(event).x1-dot.(event).x2).^2+(dot.(event).y1-
dot.(event).y2).^2).*sqrt((dot.(event).x2-
dot.(event).x4).^2+(dot.(event).y2-dot.(event).y4).^2)))) * (180/pi) -
96.5; % [deg] ankle angle
    %---------------------------------
    dot.(event).angratankle = diff(dot.(event).angankle) / (1/30);%
[deg/s] ankle angular rate
    % for i = 1 : length(dot.(event).angankle)-1
    %     dot.(event).angratankle(i,:) = (dot.(event).angankle(i+1)-
dot.(event).angankle(i)) / (1/30); % [deg/s] ankle angular rate
    % end
    %---------------------------------
    end

clear filedot
%% Plot the specified event
%----------------------------------------------------------------------
----
% digitized markers
i=str2double(input('Please enter the event # you are intereted: ',
's')); % after loading the digitized dot coordinates files, we need to
tell the system when is the
```

```
for nME = 1:length(eventInfo.major)
    if i >= eventInfo.major(nME)
        event = eventInfo.name{eventInfo.major(nME)}(3:end);
    else break;
    end
end% find the major event name

figure('name',[num2str(eventInfo.num(i)) ' ' eventInfo.name{i}]);
clear title xlabel ylabel
subplot(2,5,1); % distal dot moving path: dot#4
hold on;
grid on;
plot(dot.(event).x4(eventInfo.indexesdm(i):eventInfo.indexeedm(i)),dot.
(event).y4(eventInfo.indexesdm(i):eventInfo.indexeedm(i)));
plot(dot.(event).x7,dot.(event).y7,'ko',dot.(event).x8,dot.(event).y8,'
ko');
set(gca,'DataAspectRatio',[1 1 1]);
xlabel('X Axis (mm)');
ylabel('Y Axis (mm)');
title('Side View Distal Dot (Dot#4) Moving Path');

subplot(2,5,2); % ankle dot path: dot#2
grid on;
hold on;
plot(dot.(event).x2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)),dot.
(event).y2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)));
plot(dot.(event).x7,dot.(event).y7,'ko',dot.(event).x8,dot.(event).y8,'
ko');
set(gca,'DataAspectRatio',[1 1 1]);
xlabel('X Axis (mm)');
ylabel('Y Axis (mm)');
title('Side View Ankle Dot (Dot#2) Moving Path');

subplot(2,5,3); % dot#5 moving path
grid on;
hold on;
plot(dot.(event).x5(eventInfo.indexesdm(i):eventInfo.indexeedm(i)),dot.
(event).y5(eventInfo.indexesdm(i):eventInfo.indexeedm(i)));% dot#5
moving path
plot(dot.(event).x9,dot.(event).y9,'ko',dot.(event).x10,dot.(event).y10
,'ko');
set(gca,'DataAspectRatio',[1 1 1]);
xlabel('X Axis (mm)');
ylabel('Y Axis (mm)');
title('Top View Distal Dot (Dot#5) Moving Path');

subplot(2,5,6); % distal dot moving velocity: dot#4
grid on;
axis([min(dot.(event).time) max(dot.(event).time) min(dot.(event).v4)
max(dot.(event).v4)]);
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1),dot.(event).v4(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
xlabel('Time (s)');
```

```
ylabel('Velocity (mm/s)');
title('Distal Dot (Dot#4) Moving Velocity');

subplot(2,5,7); % ankle dot (dot2) velocty
grid on;hold on;
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1),dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1),100,'g');
xlabel('Time (s)');
ylabel('Ankle Dot (Dot#2) Moving Velocity (mm/s)');
title('Ankle Dot (Dot#2) Moving Velocity');

subplot(2,5,8); % dot#5 moving velocity
grid on;hold on;
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1),dot.(event).v5(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1)); %
dot#5 moving velocity
xlabel('Time (s)');
ylabel('Front View Distal Dot (dot#5) Moving Velocity (mm/s)');
title('Front View Distal Dot (dot#5) Moving Velocity');

subplot(2,5,4); % ankle angle
grid on;hold on;
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)),do
t.(event).angankle(eventInfo.indexesdm(i):eventInfo.indexeedm(i)));
xlabel('Time (s)');
ylabel('Ankle Angle (deg)');
title('Ankle Angle (Ankle formed by Dot# 1, 2 & 4)');

subplot(2,5,9); % ankle angle rate
grid on;hold on;
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1),dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.indexeedm(i
)-1));
xlabel('Time (s)');
ylabel('Ankle Angle Rate (deg/s)');
title('Ankle Angle Rate');

subplot(2,5,5);
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)),
dot.(event).angsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(i)));
xlabel('Time (s)');
ylabel('Internal/External Rotational Angle (deg)');
title('Internal/External Rotational Angle');

subplot(2,5,10);
plot(dot.(event).time(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1),
dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1));
xlabel('Time (s)');
ylabel('Internal/External Rotational Angle Rate(deg/s)');
```

```
title('Internal/External Rotational Angle Rate');

% subplot(2,2,3);
% grid on;
% Hs=spectrum.periodogram;
% psd(Hs,v5,'Fs',30)
% title('Power Spectrum - dot#5')
clear nME i

%-----------------------------------------------------------------------
----
%% Calculate metrics (digitized markers, dewetron/tekscan, condensed
metrics) and Export to DOT data sheet
% Calculate marker metrics
% calculate the metics required from the dot pedal data sheet; need to
% accommodate for the missing dot values due to invisibility of the dot
% for some participants in some period of times, some dots were not
visible
% from the camera view thus not be able to digitized. There were 'NaN's
% values on the digitized dots spreadsheet. If the 'NaN's apprear in
the
% middle of the driving events, we won't be able to calculate certain
% metrics such as the mean, min and max (because the values that are
not
% 'NaN' won't be able to represent the event. For example, a 'foot from
% brake to gas' has 30 time points. if for the last 10 time points the
dot
% 1 and 2 are not visible and there are 'NaN's on these two columns.
% Therefore we won't be able to calculate the mean, max or min.
% dorsal-plantar angles. Matlab will still give you a value (mean, max
or
% min) but that's the mean, max or min without the 'NaN's and they
cannot
% represent the event.

% specify the DOT data sheet
[filename,pathname] = uigetfile('*.xlsx','Select the DOT data
sheet',folder);

for nME = 1 : numel(C.event)
    event =  C.event{nME}; % ME: major event
    if isempty(dot.(event))
        continue
    end
    for i = dot.(event).enums : dot.(event).enume
        if eventInfo.indexesdm(i) == eventInfo.indexeedm(i) % select
gear event will be left out
            dot.(event).v2_mean(i) = NaN;
            dot.(event).v4_mean(i) = NaN;
            dot.(event).v5_mean(i) = NaN;
            dot.(event).angsweep_start(i) = NaN;
            dot.(event).angsweep_end(i) = NaN;
            dot.(event).angsweep_mean(i) = NaN;
```

```
            dot.(event).angsweep_min(i) = NaN;
            dot.(event).angsweep_max(i) = NaN;
            dot.(event).angratsweep_min(i) = NaN;
            dot.(event).angratsweep_max(i) = NaN;
            dot.(event).angratsweep_mean(i) = NaN;
            dot.(event).banda(i) = NaN;
            dot.(event).bandb(i) = NaN;
            dot.(event).bandc(i) = NaN;
            dot.(event).angankle_start(i) = NaN;
            dot.(event).angankle_end(i) = NaN;
            dot.(event).angankle_mean(i) = NaN;
            dot.(event).angankle_min(i) = NaN;
            dot.(event).angankle_max(i) = NaN;
            dot.(event).angratankle_min(i) = NaN;
            dot.(event).angratankle_max(i) = NaN;
            dot.(event).angratankle_mean(i) = NaN;
            dot.(event).eff(i) = NaN;
            dot.(event).v2pks(i) = NaN;
            dot.(event).v2fast(i) = NaN;
            dot.(event).dot5left(i)=NaN;
            continue
        end
        %-----------------------------------------------------------------
------------
        % need to detect if there are any NaNs in the coordinates (due
to
        % invisibility of the dot in camera view). for each dot, only
one
        % axis(either x or y) is needed to be detected for NaNs.
        %-----------------------------------------------------------------
------------
        % dot moving speed #2
        if
sum(isnan(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1))) ~= 0
            dot.(event).v2_mean(i) = NaN;
            dot.(event).v2pks(i) = NaN;
            dot.(event).v2fast(i) = NaN;
        elseif eventInfo.indexeedm(i)-1-eventInfo.indexesdm(i) < 3
            dot.(event).v2_mean(i) =
mean(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
            dot.(event).v2pks(i) = 0;
            dot.(event).v2fast(i) =
sum(abs(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1)) >  100) / (eventInfo.indexeedm(i)-eventInfo.indexesdm(i));
        else
            dot.(event).v2_mean(i) =
mean(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
            dot.(event).v2pks(i) =
length(findpeaks(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1),'MINPEAKHEIGHT',100));% number of peaks in ankle velocity
            dot.(event).v2fast(i) =
sum(abs(dot.(event).v2(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1)) >  100) / (eventInfo.indexeedm(i)-eventInfo.indexesdm(i));
```

```
        end
        % dot moving speed #4
        if
sum(isnan(dot.(event).v4(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1))) ~= 0
            dot.(event).v4_mean(i) = NaN;
        else
            dot.(event).v4_mean(i) =
mean(dot.(event).v4(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
        end
        % dot moving speed #5
        if
sum(isnan(dot.(event).v5(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-
1))) ~= 0
            dot.(event).v5_mean(i) = NaN;
        else
            dot.(event).v5_mean(i) =
mean(dot.(event).v5(eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1));
        end

        %-----------------------------------------------------------------
------------
        % foot internal-external angle_start
        if isnan(dot.(event).angsweep(eventInfo.indexesdm(i))) ~= 0
            dot.(event).angsweep_start(i) = NaN;
        else
            dot.(event).angsweep_start(i) =
dot.(event).angsweep(eventInfo.indexesdm(i));
        end
        % foot internal-external angle_end
        if isnan(dot.(event).angsweep(eventInfo.indexeedm(i))) ~= 0
            dot.(event).angsweep_end(i) = NaN;
        else
            dot.(event).angsweep_end(i) =
dot.(event).angsweep(eventInfo.indexeedm(i));
        end
        % foot internal-external angle_mean, min and max
        if
sum(isnan(dot.(event).angsweep(eventInfo.indexesdm(i):eventInfo.indexee
dm(i)))) ~= 0
            dot.(event).angsweep_mean(i) = NaN;
            dot.(event).angsweep_min(i) = NaN;
            dot.(event).angsweep_max(i) = NaN;
        else
            dot.(event).angsweep_mean(i) =
mean(dot.(event).angsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(i)
));
            dot.(event).angsweep_min(i) =
min(dot.(event).angsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
);
            dot.(event).angsweep_max(i) =
max(dot.(event).angsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
);
```

```
        end
        %-------------------------------------------------------------
------------
        % foot internal-external angular rate AND percent duration in
bands
        if
sum(isnan(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.inde
xeedm(i)-1))) ~= 0
            dot.(event).angratsweep_min(i) = NaN;
            dot.(event).angratsweep_max(i) = NaN;
            dot.(event).angratsweep_mean(i) = NaN;
            dot.(event).banda(i) = NaN;
            dot.(event).bandb(i) = NaN;
            dot.(event).bandc(i) = NaN;
        else
            if
min(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(
i)-1))<0 &&
max(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexeedm(
i)-1))>0
                dot.(event).angratsweep_min(i) = 0;
            else dot.(event).angratsweep_min(i) =
min(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)));
            end
            dot.(event).angratsweep_max(i) =
max(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)));
            dot.(event).angratsweep_mean(i) =
mean(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.index
eedm(i)-1)));
            % percent duration in bands
            dot.(event).banda(i) =
sum(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)) >  30) / (eventInfo.indexeedm(i)-eventInfo.indexesdm(i));
            dot.(event).bandb(i) =
sum(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)) >=
(1/2)*max(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.
indexeedm(i)-1)))) / (eventInfo.indexeedm(i)-eventInfo.indexesdm(i));
            dot.(event).bandc(i) =
sum(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)) <
(1/2)*max(abs(dot.(event).angratsweep(eventInfo.indexesdm(i):eventInfo.
indexeedm(i)-1)))) / (eventInfo.indexeedm(i)-eventInfo.indexesdm(i));
        end
        %-------------------------------------------------------------
------------
        % foot dorsal-plantar angle_start
        if isnan(dot.(event).angankle(eventInfo.indexesdm(i))) == 0
            dot.(event).angankle_start(i) =
dot.(event).angankle(eventInfo.indexesdm(i));
        else
            dot.(event).angankle_start(i) = NaN;
```

```
        end
        % foot dorsal-plantar angle_end
        if isnan(dot.(event).angankle(eventInfo.indexeedm(i))) == 0
            dot.(event).angankle_end(i) =
dot.(event).angankle(eventInfo.indexeedm(i));
        else
            dot.(event).angankle_end(i) = NaN;
        end
        % foot dorsal-plantar angle_mean, min and max
        if
sum(isnan(dot.(event).angankle(eventInfo.indexesdm(i):eventInfo.indexee
dm(i)))) == 0
            dot.(event).angankle_mean(i) =
mean(dot.(event).angankle(eventInfo.indexesdm(i):eventInfo.indexeedm(i)
));
            dot.(event).angankle_min(i) =
min(dot.(event).angankle(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
);
            dot.(event).angankle_max(i) =
max(dot.(event).angankle(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
);
        else
            dot.(event).angankle_mean(i) = NaN;
            dot.(event).angankle_min(i) = NaN;
            dot.(event).angankle_max(i) = NaN;
        end
        %---------------------------------------------------------------
------------
        % foot dorsal-plantar angular rate
        if
sum(isnan(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.inde
xeedm(i)-1))) == 0
            if
min(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.indexeedm(
i)-1))<0 &&
max(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.indexeedm(
i)-1))>0
                dot.(event).angratankle_min(i) = 0;
            else dot.(event).angratankle_min(i) =
min(abs(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)));
            end
            dot.(event).angratankle_max(i) =
max(abs(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.indexe
edm(i)-1)));
            dot.(event).angratankle_mean(i) =
mean(abs(dot.(event).angratankle(eventInfo.indexesdm(i):eventInfo.index
eedm(i)-1)));
        else
            dot.(event).angratankle_min(i) = NaN;
            dot.(event).angratankle_max(i) = NaN;
            dot.(event).angratankle_mean(i) = NaN;
        end
```

```
        %-----------------------------------------------------------------
------------
        % foot movement efficiency = (actual path - shortest
path)/shortest path
        % duration in amplitude band
        dot.(event).path4 = 0;  % the path length of dot#4
        dot.(event).path5 = 0;  % the path length of dot#5

        if
sum(isnan(dot.(event).x4(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
)) == 0 &&...

sum(isnan(dot.(event).x5(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
)) == 0% some events are treated as an 'instant' event such as 'select
gear'

            for j = eventInfo.indexesdm(i):eventInfo.indexeedm(i)-1
                dot.(event).d4 = sqrt((dot.(event).x4(j+1)-
dot.(event).x4(j))^2 + (dot.(event).y4(j+1)-dot.(event).y4(j))^2);
                dot.(event).path4 = dot.(event).path4 + dot.(event).d4;
                dot.(event).d5 = sqrt((dot.(event).x5(j+1)-
dot.(event).x5(j))^2 + (dot.(event).y5(j+1)-dot.(event).y5(j))^2);
                dot.(event).path5 = dot.(event).path5 + dot.(event).d5;
            end

            dot.(event).path5short =
sqrt((dot.(event).x5(eventInfo.indexeedm(i))-
dot.(event).x5(eventInfo.indexesdm(i)))^2+(dot.(event).y5(eventInfo.ind
exeedm(i))-dot.(event).y5(eventInfo.indexesdm(i)))^2); % the linear
length of dot 5 between its starting position and ending position
            dot.(event).path4short =
sqrt((dot.(event).x4(eventInfo.indexeedm(i))-
dot.(event).x4(eventInfo.indexesdm(i)))^2+(dot.(event).y4(eventInfo.ind
exeedm(i))-dot.(event).y4(eventInfo.indexesdm(i)))^2); % the linear
length of dot 5 between its starting position and ending position
            dot.(event).eff(i) = (dot.(event).path4short /
dot.(event).path4 + dot.(event).path5short / dot.(event).path5) / 2;
        else
            dot.(event).eff(i) = NaN;
        end
        %-----------------------------------------------------------------
------------
        % [%] the time dot 5 falls into the left portion of the pedal
area with
        % the seperation line defined as the line at 9/10 of brake
width
        % from brake pedal left edge
        if
sum(isnan(dot.(event).x5(eventInfo.indexesdm(i):eventInfo.indexeedm(i))
)) == 0

dot.(event).dot5left(i)=sum((dot.(event).x5(eventInfo.indexesdm(i):even
```

```
tInfo.indexeedm(i))-dot.(event).x9)<C.dot9line) /
(eventInfo.indexeedm(i)-eventInfo.indexesdm(i)+1); % [%]
        else
            dot.(event).dot5left(i)=NaN;
        end
    end
end
clear nME i

%-----------------------------------------------------------------------
----
% Calculate dewetron&tekscan metrics
% ------------------------------------
% delete the existing data
clear deweexp tekscanexp
% ------------------------------------
for i = 1 : length(eventInfo.num)
    event = ['Event_' num2str(i)];
    % ------------------------------------
    es.sys=[date ' ' eventInfo.start{i}]; % event start time
    ee.sys=[date ' ' eventInfo.end{i}]; % event end time
    % accelerator travel
    es.at=datenum(es.sys)-startTime.at; % event (forward and left)
starting time
    ee.at=datenum(ee.sys)-startTime.at; % event ending time
    % find the accel travel data section index for event 20
    [td.esat,index.esat]=min(abs(dewe.timeat-es.at)); % find the index
of accel travel.time which is closest to the specified event starting
time; find the time difference
    [td.eeat,index.eeat]=min(abs(dewe.timeat-ee.at)); % find the index
of accel travel.time which is closest to the specified event ending
time; find the time difference

    % brake travel
    es.bt=datenum(es.sys)-startTime.bt; % event (forward and left)
starting time
    ee.bt=datenum(ee.sys)-startTime.bt; % event ending time
    % find the accel travel data section index for event
    [td.esbt,index.esbt]=min(abs(dewe.timebt-es.bt)); % find the index
of accel travel.time which is closest to the specified event starting
time; find the time difference; td:time difference
    [td.eebt,index.eebt]=min(abs(dewe.timebt-ee.bt)); % find the index
of accel travel.time which is closest to the specified event ending
time; find the time difference

    % lateral acceleration
    es.la=datenum(es.sys)-startTime.la;
    ee.la=datenum(ee.sys)-startTime.la;
    [td.esla,index.esla]=min(abs(dewe.timela-es.la));
    [td.eela,index.eela]=min(abs(dewe.timela-ee.la));

    % longitudinal acceleration
    es.longa=datenum(es.sys)-startTime.longa;
```

```
    ee.longa=datenum(ee.sys)-startTime.longa;
    [td.eslonga,index.eslonga]=min(abs(dewe.timelonga-es.longa));
    [td.eelonga,index.eelonga]=min(abs(dewe.timelonga-ee.longa));

    % vertical acceleration
    es.va=datenum(es.sys)-startTime.va;
    ee.va=datenum(ee.sys)-startTime.va;
    [td.esva,index.esva]=min(abs(dewe.timeva-es.va));
    [td.eeva,index.eeva]=min(abs(dewe.timeva-ee.va));

    % velocity
    es.v=datenum(es.sys)-startTime.v; % event starting time for
variable: velocity
    ee.v=datenum(ee.sys)-startTime.v; % event ending time for variable:
velocity
    [td.esv,index.esv]=min(abs(dewe.timev-es.v)); % find the index of
velocity.time which is closest to the specified event starting time
    [td.eev,index.eev]=min(abs(dewe.timev-ee.v)); % find the index of
velocity.time which is closest to the specified event ending time

    % Pitch rate Data1_X_rate__pitch, Data1_time_X_rate__pitch
    es.pr=datenum(es.sys)-startTime.pr;
    ee.pr=datenum(ee.sys)-startTime.pr;
    [td.espr,index.espr]=min(abs(dewe.timepr-es.pr));
    [td.espr,index.eepr]=min(abs(dewe.timepr-ee.pr));

    % Roll rate Data1_Y_rate__roll, Data1_time_Y_rate__roll
    es.rr=datenum(es.sys)-startTime.rr;
    ee.rr=datenum(ee.sys)-startTime.rr;
    [td.esrr,index.esrr]=min(abs(dewe.timerr-es.rr));
    [td.eerr,index.eerr]=min(abs(dewe.timerr-ee.rr));

    % yaw rate Data1_Z_rate__yaw, Data1_time_Z_rate__yaw
    es.yr=datenum(es.sys)-startTime.yr;
    ee.yr=datenum(ee.sys)-startTime.yr;
    [td.esyr,index.esyr]=min(abs(dewe.timeyr-es.yr));
    [td.eeyr,index.eeyr]=min(abs(dewe.timeyr-ee.yr));

    % tekscan force
    es.tekscan=datenum(es.sys)-startTime.sys; % event20 start time of
tekscan
    ee.tekscan=datenum(ee.sys)-startTime.sys; % event20 end time of
tekscan
    [td.estekscan,index.estekscan]=min(abs(tekscan.time-
es.tekscan*86400)); % find out the index of tekscan time variable
    [td.eetekscan,index.eetekscan]=min(abs(tekscan.time-
ee.tekscan*86400));

    % GPS X coordinates
    es.x = datenum(es.sys) - startTime.x;
    ee.x = datenum(ee.sys) - startTime.x;
    [td.esx, index.esx] = min(abs(dewe.timex - es.x));
```

```
    [td.eex, index.eex] = min(abs(dewe.timex - ee.x));

    % GPS Y coordinates
    es.y = datenum(es.sys) - startTime.y;
    ee.y = datenum(ee.sys) - startTime.y;
    [td.esy, index.esy] = min(abs(dewe.timey - es.y));
    [td.eey, index.eey] = min(abs(dewe.timey - ee.y));

    % GPS Z coordinates
    es.z = datenum(es.sys) - startTime.z;
    ee.z = datenum(ee.sys) - startTime.z;
    [td.esz, index.esz] = min(abs(dewe.timez - es.z));
    [td.eez, index.eez] = min(abs(dewe.timez - ee.z));

    deweexp.(event).num = eventInfo.num(i);
    deweexp.(event).name = eventInfo.name{i};
% -------------------------------------
% calculate the metrics; deweexp=dewetron export
    deweexp.(event).btdiff = max(dewe.bt(index.esbt:index.eebt))-
min(dewe.bt(index.esbt:index.eebt));% [%]brake travel range
    deweexp.(event).atdiff = max(dewe.at(index.esat:index.eeat))-
min(dewe.at(index.esat:index.eeat));% [%]accelerator travel range
    deweexp.(event).vs = dewe.v2(index.esv);% [km/h]velocity at start
of event
    deweexp.(event).ve = dewe.v2(index.eev);% [km/h]velocity at end of
event
    deweexp.(event).vmean = mean(dewe.v2(index.esv:index.eev));%
[km/h]velocity mean
    deweexp.(event).ysdeg = fix(dewe.y(index.esy)/60);
    deweexp.(event).ysmin = abs(dewe.y(index.esy)/60-
fix(dewe.y(index.esy)/60))*60;% start GPS Y deg and min
    deweexp.(event).xsdeg = fix(dewe.x(index.esx)/60);
    deweexp.(event).xsmin = abs(dewe.x(index.esx)/60-
fix(dewe.x(index.esx)/60))*60;% start GPS X deg and min
    deweexp.(event).yedeg = fix(dewe.y(index.eey)/60);
    deweexp.(event).yemin = abs(dewe.y(index.eey)/60-
fix(dewe.y(index.eey)/60))*60;% end GPS Y deg and min
    deweexp.(event).xedeg = fix(dewe.x(index.eex)/60);
    deweexp.(event).xemin = abs(dewe.x(index.eex)/60-
fix(dewe.x(index.eex)/60))*60;% end GPS X deg and min
    deweexp.(event).longamean =
mean(dewe.longa2(index.eslonga:index.eelonga));% [g]longitudinal(y)
acceleration
    deweexp.(event).las = dewe.la2(index.esla); % [g] lateral
acceleration start
    deweexp.(event).longas = dewe.longa2(index.eslonga); % [g]
longitudinal acceleration start
    deweexp.(event).vas = dewe.va2(index.esva); % [g] vertical
acceleration start
    deweexp.(event).lae = dewe.la2(index.eela); % [g] lateral
acceleration end
    deweexp.(event).longae = dewe.longa2(index.eelonga); % [g]
longitudinal acceleration end
```

```
    deweexp.(event).vae = dewe.va2(index.eeva); % [g] vertical
acceleration end
    deweexp.(event).lamax = max(dewe.la2(index.esla:index.eela)); % [g]
lateral acceleration max
    deweexp.(event).longamax =
max(dewe.longa2(index.eslonga:index.eelonga));% [g] longitudinal
acceleration max
    deweexp.(event).vamax = max(dewe.va2(index.esva:index.eeva)); % [g]
vertical acceleration max
    tekscanexp.(event).bfmean =
mean(tekscan.brake.force2(index.estekscan:index.eetekscan)); % [lb]
mean brake force
    tekscanexp.(event).afmean =
mean(tekscan.accel.force2(index.estekscan:index.eetekscan)); % [lb]
mean accelerator force
    tekscanexp.(event).bfmin =
min(tekscan.brake.force2(index.estekscan:index.eetekscan)); % [lb] min
brake force
    tekscanexp.(event).afmin =
min(tekscan.accel.force2(index.estekscan:index.eetekscan)); % [lb] min
accelerator force
    tekscanexp.(event).bfmax =
max(tekscan.brake.force2(index.estekscan:index.eetekscan)); % [lb] max
brake force
    tekscanexp.(event).afmax =
max(tekscan.accel.force2(index.estekscan:index.eetekscan)); % [lb] max
accelerator force
    tekscanexp.(event).bfrange = tekscanexp.(event).bfmax-
tekscanexp.(event).bfmin; % [lb] range of brake force
    tekscanexp.(event).afrange = tekscanexp.(event).afmax-
tekscanexp.(event).afmin; % [lb] range of accelerator force
    tekscanexp.(event).bfs = tekscan.brake.force2(index.estekscan); %
[lb] brake force at start of event
    tekscanexp.(event).afs = tekscan.accel.force2(index.estekscan); %
[lb] accelerator force at start of event
    tekscanexp.(event).bfe = tekscan.brake.force2(index.eetekscan); %
[lb] brake force at end of event
    tekscanexp.(event).afe = tekscan.accel.force2(index.eetekscan); %
[lb] accelerator force at end of event
    tekscanexp.(event).bfdiff = tekscanexp.(event).bfe-
tekscanexp.(event).bfs; % [lb] brake force at end of event
    tekscanexp.(event).afdiff = tekscanexp.(event).afe-
tekscanexp.(event).afs; % [lb] accelerator force at end of event
    tekscanexp.(event).bcofwmean =
(nanmean(tekscan.brake.cofr(index.estekscan:index.eetekscan))-
4.5)/4.5; % [%] mean foot placement over brake width (refer to ppt)
    tekscanexp.(event).bcoflmean = (2.5-
nanmean(tekscan.brake.cofc(index.estekscan:index.eetekscan)))/1.5;  %  [%]
mean foot placement over brake length (positive: lower half brake;
negative: upper half brake)
    tekscanexp.(event).bcofwmin =
(min(tekscan.brake.cofr(index.estekscan:index.eetekscan))-4.5)/4.5; %
[%] LEFT MOST foot placement over brake width (refer to ppt)
```

```
    tekscanexp.(event).bcoflmin = (2.5-
min(tekscan.brake.cofc(index.estekscan:index.eetekscan)))/1.5; % [%]
LOWEST foot placement over brake length (positive: lower half brake;
negative: upper half brake)
    tekscanexp.(event).bcofwmax =
(max(tekscan.brake.cofr(index.estekscan:index.eetekscan))-4.5)/4.5; %
[%] RIGHT MOST foot placement over brake width (refer to ppt)
    tekscanexp.(event).bcoflmax = (2.5-
max(tekscan.brake.cofc(index.estekscan:index.eetekscan)))/1.5; % [%]
HIGHEST foot placement over brake length (positive: lower half brake;
negative: upper half brake)
    tekscanexp.(event).bcofwrange = tekscanexp.(event).bcofwmax-
tekscanexp.(event).bcofwmin; % [%] RANGE OF foot placement over brake
width (refer to ppt)
    tekscanexp.(event).bcoflrange = tekscanexp.(event).bcoflmax-
tekscanexp.(event).bcoflmin; % [%] RANGE OF foot placement over brake
length (positive: lower half brake; negative: upper half brake)
    tekscanexp.(event).bcofws = (tekscan.brake.cofr(index.estekscan)-
4.5)/4.5; % [%] foot placement over brake width at the start of
event(refer to ppt)
    tekscanexp.(event).bcofls = (2.5-
tekscan.brake.cofc(index.estekscan))/1.5; % [%] foot placement over
brake length at the start of event
    tekscanexp.(event).bcofwe = (tekscan.brake.cofr(index.eetekscan)-
4.5)/4.5; % [%] foot placement over brake width at the end of
event(refer to ppt)
    tekscanexp.(event).bcofle = (2.5-
tekscan.brake.cofc(index.eetekscan))/1.5; % [%] foot placement over
brake length at the end of event
    tekscanexp.(event).bcofwdiff = tekscanexp.(event).bcofwe-
tekscanexp.(event).bcofws; % [%] CHANGE OF foot placement over brake
width in a driving event
    tekscanexp.(event).bcofldiff = tekscanexp.(event).bcofle-
tekscanexp.(event).bcofls; % [%] CHANGE OF foot placement over brake
length in a driving event
    tekscanexp.(event).acofwmean =
nanmean((tekscan.accel.cofc(index.estekscan:index.eetekscan)-4))/2; %
[%] mean foot placement over accelerator width (like it done for brake;
positive: right half of accelerator; negative: left half of brake)
    tekscanexp.(event).acoflmean =
nanmean(tekscan.accel.cofr(index.estekscan:index.eetekscan)-6.5)/6.5;%
[%] mean foot placement over accelerator length
    tekscanexp.(event).acofwe = (tekscan.accel.cofc(index.eetekscan)-
4)/2; % [%] foot placement over accelerator width at the end of event
    tekscanexp.(event).acofle = (tekscan.accel.cofr(index.eetekscan)-
6.5)/6.5; % [%] foot placement over accelerator length at the end of
event
    tekscanexp.(event).bcamean =
mean(tekscan.brake.ca2(index.estekscan:index.eetekscan))/C.brakesize;%
[%] MEAN brake contact area over brake size
    tekscanexp.(event).bcamin =
min(tekscan.brake.ca2(index.estekscan:index.eetekscan))/C.brakesize;%
[%] MIN brake contact area over brake size
```

```
    tekscanexp.(event).bcamax =
max(tekscan.brake.ca2(index.estekscan:index.eetekscan))/C.brakesize;%
[%] MAX brake contact area over brake size
    tekscanexp.(event).bcarange = tekscanexp.(event).bcamax-
tekscanexp.(event).bcamin;% [%] RANGE OF  brake contact area over brake
size
    tekscanexp.(event).bcas =
tekscan.brake.ca2(index.estekscan)/C.brakesize;% [%] brake contact area
over brake size at the START of event
    tekscanexp.(event).bcae =
tekscan.brake.ca2(index.eetekscan)/C.brakesize;% [%] brake contact area
over brake size at the END of event
    tekscanexp.(event).bcadiff = tekscanexp.(event).bcae-
tekscanexp.(event).bcas;% [%] CHANGE OF brake contact area over brake
size
    tekscanexp.(event).acamean =
mean(tekscan.accel.ca2(index.estekscan:index.eetekscan))/C.accelsize;%
[%] accel contact area over brake size
    tekscanexp.(event).acae =
tekscan.accel.ca2(index.eetekscan)/C.accelsize;% [%] accel contact area
over brake size at the END of the event

    clear event
end
% -------------------------------------
% # of trials -- one trial is defined as the drive's foot moves off
from and back to the
% brake. To count the number of trials in the whole route:
deweexp.trial=0;
dewe.db2=interp1(dewe.timedb,dewe.db,dewe.timeat);
dewe.db_diff=diff(dewe.db2);
dewe.indrise=find(dewe.db_diff==1);
dewe.indfall=find(dewe.db_diff==-1);
if dewe.indrise(1)<dewe.indfall(1) % if the driver brake signal start
with a rising edge
    if dewe.indrise(end)<dewe.indfall(end)% if signal ends with a
falling edge
        for i = 1:length(dewe.indrise);
            if range(dewe.at(dewe.indrise(i)+1:dewe.indfall(i)))>10
                deweexp.trial=deweexp.trial+1;
            end
        end
    else % if signal ends with a rising edge
        for i = 1:length(dewe.indrise)-1;
            if range(dewe.at(dewe.indrise(i)+1:dewe.indfall(i)))>10
                deweexp.trial=deweexp.trial+1;
            end
        end
    end
else % if the driver brake signal start with a falling edge
    if dewe.indrise(end)<dewe.indfall % if signal ends with a falling
edge
        for i = 1:length(dewe.indrise);
```

```
            if range(dewe.at(dewe.indrise(i)+1:dewe.indfall(i+1)))>10
                deweexp.trial=deweexp.trial+1;
            end
        end
    else % if signal ends with a rising edge
        for i = 1:length(dewe.indrise)-1;
            if range(dewe.at(dewe.indrise(i)+1:dewe.indfall(i+1)))>10
                deweexp.trial=deweexp.trial+1;
            end
        end
    end
end
% -------------------------------------
clear td ee es
dewe=rmfield(dewe,{'db2' 'db_diff' 'indrise' 'indfall'});


% ---------------------------------------------------------------------
----
% Calculate condensed metrics
% conMet: condensed metrics
clear conMet
% ---------------------------------------------------------------------
----
% stopsign
% -------------------------------------
% determine if the event exists (the participant might skip some
driving
% events)
if str2double(eventInfo.dur(find(strcmp('m-stopsign',eventInfo.name))))
~= 0
    % -------------------------------------
    % index
    conMet.stop.Nmajor = find(strcmp('m-
stopsign',eventInfo.name(eventInfo.major(:,1)))); % the current event
is the nth element in eventInfo.major
    conMet.stop.enums = eventInfo.major(conMet.stop.Nmajor,1); % the #
of the first event
    conMet.stop.enume = eventInfo.major(conMet.stop.Nmajor,2); % the #
of the last event
    conMet.stop.nmove = conMet.stop.enums-1+find(strcmp('move gas to
brake',eventInfo.name(conMet.stop.enums:conMet.stop.enume))==1); %
event index of 'move gas to brake'
    if numel(conMet.stop.nmove)>1
        disp('!More than one foot transfer movement from gas to brake
during three way stop!');
    end
    conMet.stop.nhover = conMet.stop.enums-1+find(strcmp('hover
brake',eventInfo.name(conMet.stop.enums:conMet.stop.enume))==1); %
event index of 'hover brake'
    conMet.stop.nstayb = conMet.stop.enums-1+find(strcmp('stay
brake',eventInfo.name(conMet.stop.enums:conMet.stop.enume))==1); %
event index of 'stay brake'
```

```
    % -------------------------------------
    % metrics
    conMet.stop.tmove =
sprintf('%.2f',str2double(eventInfo.dur(conMet.stop.nmove))); % [s]
foot transfer time from gas to brake
    conMet.stop.ftplace = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.stop.nmove)]).bcofwe)) '%']; % [%] foot placement on
brake pedal
    if strcmp(eventInfo.name{conMet.stop.nmove+1},'stay brake')
        conMet.stop.ca = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.stop.nmove+1)]).bcamean)) '%'];% [%] foot contact area
on brake pedal
    else disp('Please enter foot contact area for ''stopsign''
manually');
    end
        % -------------------------------------
        % foot contact area on brake pedal (contact area over brake
pedal size)
        conMet.stop.bca = 0;
        for nStayb = 1:numel(conMet.stop.nstayb)
            conMet.stop.bca = conMet.stop.bca+tekscanexp.(['Event_'
num2str(conMet.stop.nstayb(nStayb))]).bcamean; % [%]foot contact area
on brake pedal
        end
        conMet.stop.bca =
[num2str(round(100*conMet.stop.bca/numel(conMet.stop.nstayb))) '%'];
        % -------------------------------------
        % digitized marker metrics
        if ~isempty(dot.stopsign)
            conMet.stop.vmove =
sprintf('%.1f',dot.stopsign.v5_mean(conMet.stop.nmove)*0.039);  %  [in./s]
average front view distal dot moving speed during foot transfer from
gas to brake
            conMet.stop.effmove =
[num2str(round(100*dot.stopsign.eff(conMet.stop.nmove))) '%']; % [%]
deviation of actual foot moving path from the linear path from gas to
brake
        else
            conMet.stop.vmove = 'n/a';
            conMet.stop.effmove = 'n/a';
        end

    if ~isempty(conMet.stop.nhover)
        conMet.stop.athover =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.stop.nhover)))); %
[s] average duration of hovering
        conMet.stop.tthover =
sprintf('%.2f',sum(str2double(eventInfo.dur(conMet.stop.nhover)))); %
[s] total duration of hovering
    else conMet.stop.athover = 'n/a';
         conMet.stop.tthover = 'n/a';
    end
```

```
    % --------------------------------------
    % export
    conMet.expstop = {
        'Three way stop at Seven Oaks and Michaux','Units',[];
        'Is there any preceding vehicles? (0=no, 1=yes)','',[];
        'Type of foot movement from gas to brake (1=pivot, 
2=lift)','',[];
        'Foot transfer time from gas to brake','s',conMet.stop.tmove;
        'Average front view distal dot moving speed during foot 
transfer from gas to brake','inch/s',conMet.stop.vmove;
        'Foot placement on brake pedal (cof to right edge over brake 
pedal width)','%',conMet.stop.ftplace;
        'Deviation of actual foot moving path from the linear path from 
gas to brake','%',conMet.stop.effmove;
        'Foot contact area on brake pedal (contact area over brake 
pedal size)','%',conMet.stop.bca;
        'Number of foot hovering movements', ' ', 
numel(conMet.stop.nhover);
        'Average duration of hovering', 's', conMet.stop.athover;
        'Total duration of hovering', 's', conMet.stop.tthover;
                   }; % data export in NON-metric units

    conMet.expstopm = {
        'Three way stop at Seven Oaks and Michaux','Units',[];
        'Type of foot movement from gas to brake (1=pivot, 
2=lift)','',[];
        'Foot transfer time from gas to brake','s',conMet.stop.tmove;
        'Foot placement on brake pedal (cof to right edge over brake 
pedal width)','%',conMet.stop.ftplace;
        'Foot contact area on brake pedal (contact area over brake 
pedal size)','%',conMet.stop.bca;
        'Number of foot hovering movements', ' ', 
numel(conMet.stop.nhover);
        'Average duration of hovering', 's', conMet.stop.athover;
        'Total duration of hovering', 's', conMet.stop.tthover;
                   }; % data export in metric units

else
    conMet.expstop = {
        'Three way stop at Seven Oaks and Michaux','','Driving event 
not available';
        'Is there any preceding vehicles? (0=no, 1=yes)','','n/a';
        'Type of foot movement from gas to brake (1=pivot, 
2=lift)','','n/a';
        'Foot transfer time from gas to brake','s','n/a';
        'Average front view distal dot moving speed during foot 
transfer from gas to brake','inch/s','n/a';
        'Foot placement on brake pedal (cof to right edge over brake 
pedal width)','%','n/a';
        'Deviation of actual foot moving path from the linear path from 
gas to brake','%','n/a';
        'Foot contact area on brake pedal (contact area over brake 
pedal size)','%','n/a';
```

```
        'Number of foot hovering movements', ' ', 'n/a'
        'Average duration of hovering', 's', 'n/a';
        'Total duration of hovering', 's', 'n/a';
                   }; % data export in NON-metric units

    conMet.expstopm = {
        'Three way stop at Seven Oaks and Michaux','Units','Driving
event not available';
        'Type of foot movement from gas to brake (1=pivot,
2=lift)','','n/a';
        'Foot transfer time from gas to brake','s','n/a';
        'Foot placement on brake pedal (cof to right edge over brake
pedal width)','%','n/a';
        'Foot contact area on brake pedal (contact area over brake
pedal size)','%','n/a';
        'Number of foot hovering movements', ' ', 'n/a';
        'Average duration of hovering', 's', 'n/a';
        'Total duration of hovering', 's', 'n/a';
                   }; % data export in metric units

end

% ----------------------------------------------------------------------
----
% neighborhood stop sign events. this was added because we need a
baseline
% braking event. All stopsign events were found during neighborhood
% driving. The three way stop at 7 Oaks and Michaux is not listed
within
% this group because it is a event DOT wants coded specifically.

for Nstop = 12:20
    event = C.event{Nstop};
    % ------------------------------------
    % determine if the event exists (the participant might skip some
driving
    % events)
    if str2double(eventInfo.dur(find(strcmp(['m-'
event],eventInfo.name)))) == 0
    % ------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units','Driving event not available';
        'Type of foot movement from gas to brake (1=pivot,
2=lift)','','n/a';
        'Foot transfer time from gas to brake','s','n/a';
        'Foot placement on brake pedal (cof to right edge over brake
pedal width)','%','n/a';
        'Foot contact area on brake pedal at the end of transfer
(contact area over brake pedal size)','%','n/a'; % at the end of foot
movement from gas to brake
        'Number of foot hovering movements', ' ', 'n/a';
        'Average duration of hovering', 's', 'n/a';
```

```
        'Total duration of hovering', 's', 'n/a';
                            };
        continue;
    end
    % ------------------------------------
    % index
    conMet.(event).Nmajor = find(strcmp(['m-'
event],eventInfo.name(eventInfo.major(:,1)))); % the current event is
the nth element in eventInfo.major
    conMet.(event).enums = eventInfo.major(conMet.(event).Nmajor,1); %
the # of the first event
    conMet.(event).enume = eventInfo.major(conMet.(event).Nmajor,2); %
the # of the last event

    conMet.(event).nmove = conMet.(event).enums-1+find(strcmp('move gas
to
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'move gas to brake'
    conMet.(event).nhover = conMet.(event).enums-1+find(strcmp('hover
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'hover brake'
    % ------------------------------------
    % metrics

    % [s] average transfer time from gas to brake
    if ~isempty(conMet.(event).nmove)
        conMet.(event).atmove =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nmove))));
    else conMet.(event).atmove = 'n/a';
    end

    % [%] foot placement on brake pedal
    conMet.(event).ftplace = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.(event).nmove(1))]).bcofwe)) '%'];
    % [%]foot contact area on brake pedal
    conMet.(event).bca = [num2str(round(100*(tekscanexp.(['Event_'
num2str(conMet.(event).nmove(1))]).bcae))) '%'];

    if ~isempty(conMet.(event).nhover)
        conMet.(event).athover =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nhover))));
 % [s] average duration of hovering
        conMet.(event).tthover =
sprintf('%.2f',sum(str2double(eventInfo.dur(conMet.(event).nhover))));  %
[s] total duration of hovering
    else conMet.(event).athover = 'n/a';
         conMet.(event).tthover = 'n/a';
    end

    % ------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units',[];
```

```
        'Type of foot movement from gas to brake (1=pivot,
2=lift)','',[];
        'Foot transfer time from gas to
brake','s',conMet.(event).atmove;
        'Foot placement on brake pedal (cof to right edge over brake
pedal width)','%',conMet.(event).ftplace;
        'Foot contact area on brake pedal at the end of transfer
(contact area over brake pedal size)','%',conMet.(event).bca; % at the
end of foot movement from gas to brake
        'Number of foot hovering movements', ' ',
numel(conMet.(event).nhover);
        'Average duration of hovering', 's', conMet.(event).athover;
        'Total duration of hovering', 's', conMet.(event).tthover;
                            };
end
clear Nstop
% -----------------------------------------------------------------------
----
% reverse
for Nreverse = 1:5
    event = C.event{Nreverse};
    % -------------------------------------
    % determine if the event exists (the participant might skip some
driving
    % events)
    if str2double(eventInfo.dur(find(strcmp(['m-'
event],eventInfo.name)))) == 0
    % -------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units','Driving event not available';
        'Number of foot transfer movements from gas to brake',' ','n/a';
        'Number of foot hovering movements', ' ', 'n/a';
        'Average transfer time of foot from gas to brake pedal', 's',
'n/a';
        'Average duration of hovering', 's', 'n/a';
        'Total duration of hovering', 's', 'n/a';
        'Deviation of actual foot moving path from the linear path from
gas to brake', '%' ,'n/a';
        'Total duration of looking to the left (left mirror/left
window)', 's', 'n/a';
        'Total duration of looking to the right (center mirror/right
window/right mirror/rear)', 's', 'n/a';
        'Foot contact area on brake pedal (contact area over brake
pedal size)','%','n/a';
                            };
        continue;
    end
    % -------------------------------------
    % index
    conMet.(event).Nmajor = find(strcmp(['m-'
event],eventInfo.name(eventInfo.major(:,1)))); % the current event is
the nth element in eventInfo.major
```

```
    conMet.(event).enums = eventInfo.major(conMet.(event).Nmajor,1); %
the # of the first event
    conMet.(event).enume = eventInfo.major(conMet.(event).Nmajor,2); %
the # of the last event

    conMet.(event).nmove = conMet.(event).enums-1+find(strcmp('move gas
to
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'move gas to brake'
    conMet.(event).nhover = conMet.(event).enums-1+find(strcmp('hover
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'hover brake'
    conMet.(event).nleft = conMet.(event).enums-1+find(strcmp('look
left',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1); %
index of event 'look left'
    conMet.(event).nright = conMet.(event).enums-1+find(strcmp('look
right',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'look right'
    conMet.(event).nstayb = conMet.(event).enums-1+find(strcmp('stay
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'look right'
    % ------------------------------------
    % metrics
    if ~isempty(conMet.(event).nmove)
        conMet.(event).atmove =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nmove))));  %
[s] average transfer time from gas to brake
    else conMet.(event).atmove = 'n/a';
    end

    if ~isempty(conMet.(event).nhover)
        conMet.(event).athover =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nhover))));
 % [s] average duration of hovering
        conMet.(event).tthover =
sprintf('%.2f',sum(str2double(eventInfo.dur(conMet.(event).nhover))));  %
[s] total duration of hovering
    else conMet.(event).athover = 'n/a';
         conMet.(event).tthover = 'n/a';
    end

    conMet.(event).ttleft =
sum(str2double(eventInfo.dur(conMet.(event).nleft))); % [s] total
duration of looking left
    conMet.(event).ttright =
sum(str2double(eventInfo.dur(conMet.(event).nright))); % [s] total
duration of looking right
        % ------------------------------------
        % foot contact area on brake pedal (contact area over brake
pedal size)
        conMet.(event).bca = 0;
        for nStayb = 1:numel(conMet.(event).nstayb)
```

```
            conMet.(event).bca =
conMet.(event).bca+tekscanexp.(['Event_'
num2str(conMet.(event).nstayb(nStayb))]).bcamean; % [%]foot contact
area on brake pedal
        end
        conMet.(event).bca =
[num2str(round(100*conMet.(event).bca/numel(conMet.(event).nstayb)))
'%'];
        % ------------------------------------
        if ~isempty(conMet.(event).nmove) && strcmp(event,
'reverse_napa') == 0 && ~isempty(dot.(event))
            conMet.(event).effmove =
[num2str(round(100*mean(dot.(event).eff(conMet.(event).nmove)))) '%'];%
[%] deviation of actual foot moving path from the linear path from gas
to brake
        else conMet.(event).effmove = 'n/a';
        end
    % ------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units',[];
        'Number of foot transfer movements from gas to brake','
',numel(conMet.(event).nmove);
        'Number of foot hovering movements', ' ',
numel(conMet.(event).nhover);
        'Average transfer time of foot from gas to brake pedal', 's',
conMet.(event).atmove;
        'Average duration of hovering', 's', conMet.(event).athover;
        'Total duration of hovering', 's', conMet.(event).tthover;
        'Deviation of actual foot moving path from the linear path from
gas to brake', '%' ,conMet.(event).effmove;
        'Total duration of looking to the left (left mirror/left
window)', 's', conMet.(event).ttleft;
        'Total duration of looking to the right (center mirror/right
window/right mirror/rear)', 's', conMet.(event).ttright;
        'Foot contact area on brake pedal (contact area over brake
pedal size)','%',conMet.(event).bca;
                             };
end

clear Nreverse
% -----------------------------------------------------------------------
----
% straight
for Nstraight = 8:9
    event = C.event{Nstraight};
    % ------------------------------------
    % determine if the event exists (the participant might skip some
driving
    % events)
    if str2double(eventInfo.dur(find(strcmp(['m-'
event],eventInfo.name)))) == 0
        % ------------------------------------
```

```
        % export
        conMet.(['exp' event]) = {
            event,'Units','Driving event not available';
            'Number of foot transfer movements from gas to brake','
','n/a';
            'Number of foot hovering movements', ' ', 'n/a';
            'Average transfer time of foot from gas to brake pedal',
's', 'n/a';
            'Average duration of hovering', 's', 'n/a';
            'Total duration of hovering', 's', 'n/a';
            'Total duration of looking to the left (left mirror/left
window)', 's', 'n/a';
            'Total duration of looking to the right (center
mirror/right window/right mirror/rear)', 's', 'n/a';
            'Foot contact area on brake pedal (contact area over brake
pedal size)','%','n/a';
                                };
        continue;
    end
    % ------------------------------------
    % index
    conMet.(event).Nmajor = find(strcmp(['m-'
event],eventInfo.name(eventInfo.major(:,1)))); % the current event is
the nth element in eventInfo.major
    conMet.(event).enums = eventInfo.major(conMet.(event).Nmajor,1); %
the # of the first event
    conMet.(event).enume = eventInfo.major(conMet.(event).Nmajor,2); %
the # of the last event

    conMet.(event).nmove = conMet.(event).enums-1+find(strcmp('move gas
to
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'move gas to brake'
    conMet.(event).nhover = conMet.(event).enums-1+find(strcmp('hover
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'hover brake'
    conMet.(event).nleft = conMet.(event).enums-1+find(strcmp('look
left',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1); %
index of event 'look left'
    conMet.(event).nright = conMet.(event).enums-1+find(strcmp('look
right',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'look right'
    conMet.(event).nstayb = conMet.(event).enums-1+find(strcmp('stay
brake',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);  %
index of event 'look right'
    % ------------------------------------
    % metrics
    if ~isempty(conMet.(event).nmove)
        conMet.(event).atmove =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nmove))));  %
[s] average transfer time from gas to brake
    else conMet.(event).atmove = 'n/a';
    end
```

```
    if ~isempty(conMet.(event).nhover)
        conMet.(event).athover =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nhover))));
 % [s] average duration of hovering
        conMet.(event).tthover =
sprintf('%.2f',sum(str2double(eventInfo.dur(conMet.(event).nhover))));  %
[s] total duration of hovering
    else conMet.(event).athover = 'n/a';
         conMet.(event).tthover = 'n/a';
    end

    conMet.(event).ttleft =
sum(str2double(eventInfo.dur(conMet.(event).nleft))); % [s]total
duration of looking left
    conMet.(event).ttright =
sum(str2double(eventInfo.dur(conMet.(event).nright))); % [s]total
duration of looking right
        % -------------------------------------
        % foot contact area on brake pedal (contact area over brake
pedal size)
        conMet.(event).bca = 0;
        for nStayb = 1:numel(conMet.(event).nstayb)
            conMet.(event).bca =
conMet.(event).bca+tekscanexp.(['Event_'
num2str(conMet.(event).nstayb(nStayb))]).bcamean; % [%]foot contact
area on brake pedal
        end
        conMet.(event).bca =
[num2str(round(100*conMet.(event).bca/numel(conMet.(event).nstayb)))
'%'];
    % -------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units',[];
        'Number of foot transfer movements from gas to brake','
',numel(conMet.(event).nmove);
        'Number of foot hovering movements', ' ',
numel(conMet.(event).nhover);
        'Average transfer time of foot from gas to brake pedal', 's',
conMet.(event).atmove;
        'Average duration of hovering', 's', conMet.(event).athover;
        'Total duration of hovering', 's', conMet.(event).tthover;
        'Total duration of looking to the left (left mirror/left
window)', 's', conMet.(event).ttleft;
        'Total duration of looking to the right (center mirror/right
window/right mirror/rear)', 's', conMet.(event).ttright;
        'Foot contact area on brake pedal (contact area over brake
pedal size)','%',conMet.(event).bca;
                            };
end
clear Nstraight
```

```
% -----------------------------------------------------------------------
----
% gate access
for Ngate = 6:7
    event = C.event{Ngate};
    % -------------------------------------
    % determine if the event exists (the participant might skip some
driving
    % events)
    if str2double(eventInfo.dur(find(strcmp(['m-'
event],eventInfo.name)))) == 0
        % -------------------------------------
        % export
        conMet.(['exp' event]) = {
            event,'Units','Driving event not available';
            'Did the participant reposition the car?',[],[];
            'Did the participant select the parking gear?',[],[];
            'Did the participant unbuckle the seatbelt?',[],[];
            'Did the participant open the door?',[],[];
            'Did the participant step out of the car?',[],[];
            'Average duration of unsuccessful reach&swipe','s',[];
            'Average duration of successful reach&swipe','s',[];
            'Average foot internal-external angle NOT during
reach&swipe (if foot is on brake)','deg',[];
            'Average foot internal-external angle during reach&swipe
(if foot is on brake)','deg',[];
            'Average force on the brake pedal NOT during reach&swipe
(if foot is on brake)','lb',[];
            'Average force on the brake pedal during reach&swipe (if
foot is on brake)','lb',[];
            'Average foot placement on brake pedal NOT during
reach&swipe (if foot is on brake)','%',[];
            'Average foot placement on brake pedal during reach&swipe
(if foot is on brake)','%',[];
            'Average foot contact area on brake pedal NOT during
reach&swipe the card (if foot is on brake)','%',[];
            'Average foot contact area on brake pedal during
reach&swipe (if foot is on brake)','%',[];
                                    }; % condensed metrics in NON-METRIC
units
        conMet.(['exp' event 'm']) = {
            event,'Units','Driving event not available';
            'Did the participant reposition the car?',[],[];
            'Did the participant select the parking gear?',[],[];
            'Did the participant unbuckle the seatbelt?',[],[];
            'Did the participant open the door?',[],[];
            'Did the participant step out of the car?',[],[];
            'Average duration of unsuccessful reach&swipe','s',[];
            'Average duration of successful reach&swipe','s',[];
            'Average foot internal-external angle NOT during
reach&swipe (if foot is on brake)','deg',[];
            'Average foot internal-external angle during reach&swipe
(if foot is on brake)','deg',[];
```

```
            'Average force on the brake pedal NOT during reach&swipe
(if foot is on brake)','N',[];
            'Average force on the brake pedal during reach&swipe (if
foot is on brake)','N',[];
            'Average foot placement on brake pedal NOT during
reach&swipe (if foot is on brake)','%',[];
            'Average foot placement on brake pedal during reach&swipe
(if foot is on brake)','%',[];
            'Average foot contact area on brake pedal NOT during
reach&swipe the card (if foot is on brake)','%',[];
            'Average foot contact area on brake pedal during
reach&swipe (if foot is on brake)','%',[];
                                }; % condensed metrics in METRIC units
        continue;
    end
    % -------------------------------------
    % index
    % reach out_ab: "a" indicates whether the swipe is successful
(0:unsuccessful; 1:successful)
    %               "b" indicates whether the driver's foot is on brake
during the entire reaching out (0:no; 1:yes)
    conMet.(event).Nmajor = find(strcmp(['m-'
event],eventInfo.name(eventInfo.major(:,1)))); % the current event is
the nth element in eventInfo.major
    conMet.(event).enums = eventInfo.major(conMet.(event).Nmajor,1); %
the # of the first event
    conMet.(event).enume = eventInfo.major(conMet.(event).Nmajor,2); %
the # of the last event

    conMet.(event).nreach00 = conMet.(event).enums-1+find(strcmp('reach
out_00',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);
 % index of event 'reach out'
    conMet.(event).nreach01 = conMet.(event).enums-1+find(strcmp('reach
out_01',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);
 % index of event 'reach out'
    conMet.(event).nreach10 = conMet.(event).enums-1+find(strcmp('reach
out_10',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);
 % index of event 'reach out'
    conMet.(event).nreach11 = conMet.(event).enums-1+find(strcmp('reach
out_11',eventInfo.name(conMet.(event).enums:conMet.(event).enume))==1);
 % index of event 'reach out'
    conMet.(event).nreach0 = conMet.(event).enums-1+find(strncmp('reach
out_0',eventInfo.name(conMet.(event).enums:conMet.(event).enume),11)==1
); % index of event 'reach out'
    conMet.(event).nreach1 = conMet.(event).enums-1+find(strncmp('reach
out_1',eventInfo.name(conMet.(event).enums:conMet.(event).enume),11)==1
); % index of event 'reach out'
    % -------------------------------------
    % metrics
    if ~isempty(conMet.(event).nreach0)
        conMet.(event).atfail =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nreach0))))
; % [s] average unsuccessful reach and swipe duration
```

```
    else conMet.(event).atfail = 'n/a';
    end

    if ~isempty(conMet.(event).nreach1)
        conMet.(event).atsuccess =
sprintf('%.2f',mean(str2double(eventInfo.dur(conMet.(event).nreach1))))
; % [s] average successful reach and swipe duration
    else conMet.(event).atsuccess = 'n/a';
    end

    if ~isempty(conMet.(event).nreach11)
        if ~isempty(dot.(event))
            conMet.(event).angsweeps =
sprintf('%.1f',dot.(event).angsweep_start(conMet.(event).nreach11)); %
[deg] foot internal-external angle BEFORE reach and swipe
            conMet.(event).angsweepmean =
sprintf('%.1f',dot.(event).angsweep_mean(conMet.(event).nreach11)); %
[deg] AVERAGE foot internal-external angle during reach and swipe
        else
            conMet.(event).angsweeps = 'n/a';
            conMet.(event).angsweepmean = 'n/a';
        end
        conMet.(event).bfs = sprintf('%.1f',tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bfs);% [lb] brake pedal force BEFORE
reach and swipe
        conMet.(event).bfmean = sprintf('%.1f',tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bfmean);% [lb] AVERAGE brake pedal
force during reach and swipe

        conMet.(event).bcofws =
[num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bcofws)),'%'];% [%] lateral foot
placement BEFORE reach and swipe
        conMet.(event).bcofwmean =
[num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bcofwmean)),'%'];% [%] AVERAGE
lateral foot placement during reach and swipe

        conMet.(event).bcas = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bcas)),'%'];% [%] foot contact area
on brake pedal BEFORE reach and swipe
        conMet.(event).bcamean =
[num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.(event).nreach11)]).bcamean)),'%'];% [%] AVERAGE foot
contact area on brake pedal during reach and swipe

    else
        conMet.(event).angsweeps = 'n/a';
        conMet.(event).angsweepmean = 'n/a';

        conMet.(event).bfs = 'n/a';
        conMet.(event).bfmean = 'n/a';
```

```
        conMet.(event).bcofws = 'n/a';
        conMet.(event).bcofwmean = 'n/a';

        conMet.(event).bcas = 'n/a';
        conMet.(event).bcamean = 'n/a';
    end
    % ------------------------------------
    % export
    conMet.(['exp' event]) = {
        event,'Units',[];
        'Did the participant reposition the car?',[],[];
        'Did the participant select the parking gear?',[],[];
        'Did the participant unbuckle the seatbelt?',[],[];
        'Did the participant open the door?',[],[];
        'Did the participant step out of the car?',[],[];
        'Average duration of unsuccessful
reach&swipe','s',conMet.(event).atfail;
        'Average duration of successful
reach&swipe','s',conMet.(event).atsuccess;
        'Average foot internal-external angle NOT during reach&swipe
(if foot is on brake)','deg',conMet.(event).angsweeps;
        'Average foot internal-external angle during reach&swipe (if
foot is on brake)','deg',conMet.(event).angsweepmean;
        'Average force on the brake pedal NOT during reach&swipe (if
foot is on brake)','lb',conMet.(event).bfs;
        'Average force on the brake pedal during reach&swipe (if foot
is on brake)','lb',conMet.(event).bfmean;
        'Average foot placement on brake pedal NOT during reach&swipe
(if foot is on brake)','%',conMet.(event).bcofws;
        'Average foot placement on brake pedal during reach&swipe (if
foot is on brake)','%',conMet.(event).bcofwmean;
        'Average foot contact area on brake pedal NOT during
reach&swipe the card (if foot is on brake)','%',conMet.(event).bcas;
        'Average foot contact area on brake pedal during reach&swipe
(if foot is on brake)','%',conMet.(event).bcamean;
                        };
    conMet.(['exp' event 'm']) = {
        event,'Units',[];
        'Did the participant reposition the car?',[],[];
        'Did the participant select the parking gear?',[],[];
        'Did the participant unbuckle the seatbelt?',[],[];
        'Did the participant open the door?',[],[];
        'Did the participant step out of the car?',[],[];
        'Average duration of unsuccessful
reach&swipe','s',conMet.(event).atfail;
        'Average duration of successful
reach&swipe','s',conMet.(event).atsuccess;
        'Foot internal-external angle before reach&swipe (if foot is on
brake)','deg',conMet.(event).angsweeps;
        'Average foot internal-external angle during reach&swipe (if
foot is on brake)','deg',conMet.(event).angsweepmean;
```

```
        'Force on the brake pedal before reach&swipe (if foot is on
brake)','N',sprintf('%.1f',str2double(conMet.(event).bfs)*4.45);
        'Average force on the brake pedal during reach&swipe (if foot
is on
brake)','N',sprintf('%.1f',str2double(conMet.(event).bfmean)*4.45);
        'Foot placement on brake pedal before reach&swipe (if foot is
on brake)','%',conMet.(event).bcofws;
        'Average foot placement on brake pedal during reach&swipe (if
foot is on brake)','%',conMet.(event).bcofwmean;
        'Foot contact area on brake pedal before reach&swipe the card
(if foot is on brake)','%',conMet.(event).bcas;
        'Average foot contact area on brake pedal during reach&swipe
(if foot is on brake)','%',conMet.(event).bcamean;
                            };
end
clear Ngate
% -----------------------------------------------------------------------
----
% startle
% -------------------------------------
% determine if the event exists (the participant might skip some
driving
% events)
if str2double(eventInfo.dur(find(strcmp('m-startle',eventInfo.name))))
~= 0
    % -------------------------------------
    % index
    conMet.startle.Nmajor = find(strcmp('m-
startle',eventInfo.name(eventInfo.major(:,1)))); % the current event is
the nth element in eventInfo.major
    conMet.startle.enums = eventInfo.major(conMet.startle.Nmajor,1); %
the # of the first event
    conMet.startle.enume = eventInfo.major(conMet.startle.Nmajor,2); %
the # of the last event

    conMet.startle.nmove = conMet.startle.enums-1+find(strcmp('move gas
to
brake',eventInfo.name(conMet.startle.enums:conMet.startle.enume))==1);  %
index of event 'move gas to brake'
    if numel(conMet.startle.nmove)>1
        disp('!More than one foot transfer movement from gas to brake
during startle braking!');
    end
    conMet.startle.ninst = conMet.startle.enums-
1+find(strcmp('instruction',eventInfo.name(conMet.startle.enums:conMet.
startle.enume))==1); % index of event 'move gas to brake'
    conMet.startle.nstay = conMet.startle.enums-1+find(strcmp('stay
brake',eventInfo.name(conMet.startle.enums:conMet.startle.enume))==1);  %
index of event 'look right'
    if numel(conMet.startle.nstay)>1
        disp('!More than one foot on brake during startle braking!');
    end
    % -------------------------------------
```

```
    % metrics
    conMet.startle.treact =
sprintf('%.2f',(datenum(eventInfo.start(conMet.startle.nmove))-
datenum(eventInfo.start(conMet.startle.ninst)))*86400); % [s] from
instruction to foot movement initiation
    conMet.startle.tmove =
sprintf('%.2f',str2double(eventInfo.dur(conMet.startle.nmove))); %
[s]average transfer time from gas to brake
    if strcmp(eventInfo.name{conMet.startle.nmove+1},'stay brake')
        conMet.startle.af = sprintf('%.1f',tekscanexp.(['Event_'
num2str(conMet.startle.nmove+1)]).bfmean);% [lb] average brake pedal
force during the startle braking
        conMet.startle.ftplace =
[num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.startle.nmove+1)]).bcofwmean)),'%']; % [%] foot
placement on brake pedal
        conMet.startle.ftplacee =
[num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.startle.nmove)]).bcofwe)),'%']; % [%] lateral foot
placement on brake pedal at the end of foot transfer
        conMet.startle.bcae = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.startle.nmove)]).bcae)),'%']; % [%] lateral foot
placement on brake pedal at the end of foot transfer
    else
        conMet.startle.af = 'enter manually';
        conMet.startle.ftplace = 'enter manually';
        conMet.startle.ftplacee = 'enter manually';
        conMet.startle.bcae = 'enter manually';
    end
    if ~isempty(dot.startle)
        conMet.startle.effmove =
[num2str(round(100*dot.startle.eff(conMet.startle.nmove))),'%'];% [%]
deviation of actual foot moving path from the linear path from gas to
brake
    else
        conMet.startle.effmove = 'n/a';
    end
    conMet.startle.ca = [num2str(round(100*tekscanexp.(['Event_'
num2str(conMet.startle.nstay)]).bcamean)),'%']; % [%]average foot
contact area on brake pedal during startle braking
    conMet.startle.maxf = sprintf('%.1f',tekscanexp.(['Event_'
num2str(conMet.startle.nstay)]).bfmax);
    % ------------------------------------
    % export
    conMet.expstartle = {
        'Startle braking', 'Units', [];
        'Duration from instruction to foot movement initiation', 's',
conMet.startle.treact;
        'Foot transfer movement time from gas to brake', 's',
conMet.startle.tmove;
        'Average brake pedal force during the startle braking', 'lb',
conMet.startle.af;
        'Did the driver pivot or lift foot during startle braking
(1=pivot, 2=lift)', ' ', [];
```

```
        'Foot movement efficiency index for startle braking', '%',
conMet.startle.effmove;
        'Foot placement on brake pedal during startle braking (if foot
is on brake)', '%', conMet.startle.ftplace;
        'Average foot contact area on brake pedal during startle
braking', '%', conMet.startle.ca;
        'Maximum brake pedal force during startle braking', 'lb',
conMet.startle.maxf;
                        };
    conMet.expstartlem = {
        'Startle braking', 'Units', [];
        'Foot transfer movement time from gas to brake', 's',
conMet.startle.tmove;
        'Did the driver pivot or lift foot during startle braking
(1=pivot, 2=lift)', ' ', [];
        'Foot placement on brake pedal at foot-pedal contact (if foot
is on brake)', '%', conMet.startle.ftplacee;
        'Foot placement on brake pedal during startle braking (if foot
is on brake)', '%', conMet.startle.ftplace;
        'Foot contact area on brake pedal at foot-pedal contact', '%',
conMet.startle.bcae;
        'Average foot contact area on brake pedal during startle
braking', '%', conMet.startle.ca;
                        };

else
    conMet.expstartle = {
        'Startle braking', 'Units', 'Driving event not available';
        'Duration from instruction to foot movement initiation', 's',
'n/a';
        'Foot transfer movement time from gas to brake', 's',  'n/a';
        'Average brake pedal force during the startle braking', 'lb',
'n/a';
        'Did the driver pivot or lift foot during startle braking
(1=pivot, 2=lift)', ' ', 'n/a';
        'Foot movement efficiency index for startle braking', '%',
'n/a';
        'Foot placement on brake pedal during startle braking (if foot
is on brake)', '%', 'n/a';
        'Average foot contact area on brake pedal during startle
braking', '%', 'n/a';
        'Maximum brake pedal force during startle braking', 'lb', 'n/a';
                        };
    conMet.expstartlem = {
        'Startle braking', 'Units', [];
        'Foot transfer movement time from gas to brake', 's', [];
        'Did the driver pivot or lift foot during startle braking
(1=pivot, 2=lift)', ' ', [];
        'Foot placement on brake pedal at foot-pedal contact (if foot
is on brake)', '%', [];
        'Foot placement on brake pedal during startle braking (if foot
is on brake)', '%', [];
```

```
        'Foot contact area on brake pedal at foot-pedal contact', '%',
[];
        'Average foot contact area on brake pedal during startle
braking', '%', [];
                        };
end

% -----------------------------------------------------------------------
----
% initial pedal calibration
% -------------------------------------
% determine if the event exists (the participant might skip some
driving
% events)
if str2double(eventInfo.dur(find(strcmp('m-
initialpedalcal',eventInfo.name)))) ~= 0
    % -------------------------------------
    % index
    nPedalcal = find(strcmp('m-
initialpedalcal',eventInfo.name(eventInfo.major(:,1))));
%     conMet.initialpedalcal.nmove =
eventInfo.major(nPedalcal,1)+1:eventInfo.major(nPedalcal,2);
    conMet.initialpedalcal.nmove =
eventInfo.major(nPedalcal,1)+find(strcmp('move gas to
brake',eventInfo.name(eventInfo.major(nPedalcal,1)+1:eventInfo.major(nP
edalcal,2)))==1); % index of event 'move gas to brake'
    % -------------------------------------
    % metrics
    conMet.initialpedalcal.at =
sprintf('%.2f',mean(str2double((eventInfo.dur(eventInfo.major(nPedalcal
,1)+1:eventInfo.major(nPedalcal,2))))));

    conMet.initialpedalcal.ftplacee = 0;
    for Nmoveinitial = 1:numel(conMet.initialpedalcal.nmove)
        conMet.initialpedalcal.ftplacee =
conMet.initialpedalcal.ftplacee+tekscanexp.(['Event_'
num2str(conMet.initialpedalcal.nmove(Nmoveinitial))]).bcofwe;
    end
    conMet.initialpedalcal.ftplacee =
[num2str(round(100*conMet.initialpedalcal.ftplacee/numel(conMet.initial
pedalcal.nmove))),'%']; % [%] average lateral foot placement on brake
pedal in initial pedal calibration

    conMet.initialpedalcal.bcae = 0;
    for Nmoveinitial = 1:numel(conMet.initialpedalcal.nmove)
        conMet.initialpedalcal.bcae =
conMet.initialpedalcal.bcae+tekscanexp.(['Event_'
num2str(conMet.initialpedalcal.nmove(Nmoveinitial))]).bcae;
    end
    conMet.initialpedalcal.bcae =
[num2str(round(100*conMet.initialpedalcal.bcae/numel(conMet.initialpeda
lcal.nmove))),'%']; % [%] average lateral foot placement on brake pedal
in initial pedal calibration
```

```
    % -------------------------------------
    % export
    conMet.expinitialpedalcal = {
        'initial pedal calibration','Units',[];
        'Average foot transfer time in pedal
calibration','s',conMet.initialpedalcal.at;
        'Average lateral foot placement on brake pedal at the end of
foot transfer','%',conMet.initialpedalcal.ftplacee;
        'Average foot contact area on brake pedal at the end of foot
transfer','%',conMet.initialpedalcal.bcae;
                            };
else
    conMet.expinitialpedalcal = {
        'initial pedal calibration','Units',[];
        'Average foot transfer time in pedal calibration','s',[];
        'Average lateral foot placement on brake pedal at the end of
foot transfer','%',[];
        'Average foot contact area on brake pedal at the end of foot
transfer','%',[];
                            };
end

clear Nmoveinitial nPedalcal

% ---------------------------------------------------------------------
----
% final pedal calibration
% -------------------------------------
% determine if the event exists (the participant might skip some
driving
% events)
if str2double(eventInfo.dur(find(strcmp('m-
finalpedalcal',eventInfo.name)))) ~= 0
    % -------------------------------------
    % index
    nPedalcal = find(strcmp('m-
finalpedalcal',eventInfo.name(eventInfo.major(:,1))));
%     conMet.finalpedalcal.nmove =
eventInfo.major(nPedalcal,1)+1:eventInfo.major(nPedalcal,2);
    conMet.finalpedalcal.nmove =
eventInfo.major(nPedalcal,1)+find(strcmp('move gas to
brake',eventInfo.name(eventInfo.major(nPedalcal,1)+1:eventInfo.major(nP
edalcal,2)))==1); % index of event 'move gas to brake'
    % -------------------------------------
    % metrics
    conMet.finalpedalcal.at =
sprintf('%.2f',mean(str2double((eventInfo.dur(eventInfo.major(nPedalcal
,1)+1:eventInfo.major(nPedalcal,2))))));

    conMet.finalpedalcal.ftplacee = 0;
    for Nmovefinal = 1:numel(conMet.finalpedalcal.nmove)
```

```
        conMet.finalpedalcal.ftplacee =
conMet.finalpedalcal.ftplacee+tekscanexp.(['Event_'
num2str(conMet.finalpedalcal.nmove(Nmovefinal))]).bcofwe;
    end
    conMet.finalpedalcal.ftplacee =
[num2str(round(100*conMet.finalpedalcal.ftplacee/numel(conMet.finalpeda
lcal.nmove))),'%']; % [%] average lateral foot placement on brake pedal
in final pedal calibration

    conMet.finalpedalcal.bcae = 0;
    for Nmovefinal = 1:numel(conMet.finalpedalcal.nmove)
        conMet.finalpedalcal.bcae =
conMet.finalpedalcal.bcae+tekscanexp.(['Event_'
num2str(conMet.finalpedalcal.nmove(Nmovefinal))]).bcae;
    end
    conMet.finalpedalcal.bcae =
[num2str(round(100*conMet.finalpedalcal.bcae/numel(conMet.finalpedalcal
.nmove))),'%']; % [%] average lateral foot placement on brake pedal in
final pedal calibration

    % -------------------------------------
    % export
    conMet.expfinalpedalcal = {
        'final pedal calibration','Units',[];
        'Average foot transfer time in pedal
calibration','s',conMet.finalpedalcal.at;
        'Average lateral foot placement on brake pedal at the end of
foot transfer','%',conMet.finalpedalcal.ftplacee;
        'Average foot contact area on brake pedal at the end of foot
transfer','%',conMet.finalpedalcal.bcae;
                            };
else
    conMet.expfinalpedalcal = {
        'final pedal calibration','Units',[];
        'Average foot transfer time in pedal calibration','s',[];
        'Average lateral foot placement on brake pedal at the end of
foot transfer','%',[];
        'Average foot contact area on brake pedal at the end of foot
transfer','%',[];
                            };
end

clear Nmovefinal nPedalcal

% ---------------------------------------------------------------------
----
% overall
% index
% nPedalcal = find(strcmp('m-
initialpedalcal',eventInfo.name(eventInfo.major(:,1))));
% conMet.initialpedalcal.at =
sprintf('%.2f',mean(str2double((eventInfo.dur(eventInfo.major(nPedalcal
,1)+1:eventInfo.major(nPedalcal,2))))));
```

```
% clear nPedalcal
% ---------------------------------------
conMet.expoverall = {
    'Overall', 'Units',' ';
    'Number of trials',' ', deweexp.trial;
    'Average transfer time in initial pedal calibration','s',
conMet.initialpedalcal.at;
                     };

clear Nreverse Nstraight Ngate nStayb


% ---------------------------------------------------------------------------
----
% Export data to DOT data sheet
clear i j
% open the activex server and checks to see if the file already exists
Excel = actxserver ('Excel.Application');
File=[pathname filename];
if ~exist(File,'file')
    ExcelWorkbook = Excel.workbooks.Add;
    ExcelWorkbook.SaveAs(File,1);
    ExcelWorkbook.Close(false);
end
% invoke(Excel.Workbooks,'Open',File);
ExcelWorkbook = Excel.workbooks.Open(File); % to replace the previous
command

%----------------------------------------------------------------------------
----
% clear the existing data on the data sheet by writing empty cells to
the
% existing ones
sheets_clear = {'dot_nm' 'dot_m' 'dewe_nm' 'dewe_m' 'Condensed
Metrics_auto_nm' 'Condensed Metrics_auto_m'};
for nSheet = 1:numel(sheets_clear)
    [~,sheets] = xlsfinfo(File);
    if ~ismember(sheets_clear{nSheet},sheets)
        continue
    end
    [~,~,sheetrange] = xlsread(File,sheets_clear{nSheet});
    eraser = cell(size(sheetrange));
    xlswrite1(File,eraser,sheets_clear{nSheet});
end
clear sheets_clear nSheet eraser sheetrange sheets

%----------------------------------------------------------------------------
----
% export DIGITIZED DOT data onto the NON-METRIC dot pedal data sheet
% ---------------------------------------
% write header
header.dot_nm = {
```

```
        'Dot moving speed#2(inch/s)' '# of peaks (>10cm/s) in dot#2
moving speed' 'Percent Duration of ankle velocity over 10cm/s'...
        'Dot moving speed#4(inch/s)' 'Dot moving speed#5(inch/s)'...
        'Foot internal-external rotational angle_start(deg)' 'Foot
internal-external rotational angle_end(deg)'...
        'Foot internal-external rotational angle_diff(deg)'...
        'Foot internal-external rotational angle_mean(deg)'...
        'Foot internal-external rotational angle_min(deg)' 'Foot
internal-external rotational angle_max(deg)'...
        'Foot internal-external rotational angular rate_min(deg/s)'...
        'Foot internal-external rotational angular rate_max(deg/s)'...
        'Foot internal-external rotational angular rate_mean(deg/s)'...
        'Foot dorsal-plantar rotational angle_start(deg)' 'Foot dorsal-
plantar rotational angle_end(deg)'...
        'Foot dorsal-plantar rotational angle_mean(deg)'...
        'Foot dorsal-plantar rotational angle_min(deg)' 'Foot dorsal-
plantar rotational angle_max(deg)'...
        'Foot dorsal-plantar rotational angular rate_min(deg/s)' 'Foot
dorsal-plantar rotational angular rate_max(deg/s)'...
        'Foot movement efficiency(%)'
         };
% [filename,pathname] = uigetfile('*.xlsx','Select the driving event
text file',folder);
xlswrite1([pathname filename],header.dot_nm,'dot_nm','A1'); % write
data header
clear output filterindex;

% -------------------------------------
% export data
%
for nME = 1 : numel(C.event)
    event = C.event{nME};
    if isempty(dot.(event))
        continue
    end
    for i = dot.(event).enums : dot.(event).enume
        rowstart = ['A' num2str(i+1)];
        output = {
                 dot.(event).v2_mean(i)*0.039, dot.(event).v2pks(i),
dot.(event).v2fast(i)...
                 dot.(event).v4_mean(i)*0.039,
dot.(event).v5_mean(i)*0.039...% dot moving speed #2#4#5
                 dot.(event).angsweep_start(i),
dot.(event).angsweep_end(i)...
                 dot.(event).angsweep_end(i)-
dot.(event).angsweep_start(i)...
                 dot.(event).angsweep_mean(i),
dot.(event).angsweep_min(i), dot.(event).angsweep_max(i)...
                 dot.(event).angratsweep_min(i),
dot.(event).angratsweep_max(i), dot.(event).angratsweep_mean(i)...%
internal-external angle/angular rate
                 dot.(event).angankle_start(i),
dot.(event).angankle_end(i)...
```

```
                 dot.(event).angankle_mean(i),
dot.(event).angankle_min(i), dot.(event).angankle_max(i)...
                 dot.(event).angratankle_min(i)
dot.(event).angratankle_max(i)...% dorsal-plantar angle/angular rate
                 dot.(event).eff(i)...% percent duration in each band
and foot moving efficiency
                 };
        xlswrite1([pathname filename],output,'dot_nm',rowstart);
%         pause(1.5);
    end
end

%-----------------------------------------------------------------------
----
% export DIGITIZED DOT data onto the METRIC dot pedal data sheet
% -------------------------------------
% write header
% -------------------------------------
header.dot_m = {
        'Event Num' 'Event Name' 'Event Start Time' 'Event End Time'
'Event Duration'...
        'Dot moving speed#2(mm/s)' '# of peaks (>10cm/s) in dot#2
moving speed' 'Percent Duration of ankle velocity over 10cm/s'...
        'Dot moving speed#4(mm/s)' 'Dot moving speed#5(mm/s)'...
        'Foot internal-external rotational angle_start(deg)' 'Foot
internal-external rotational angle_end(deg)'...
        'Foot internal-external rotational angle_diff(deg)'...
        'Foot internal-external rotational angle_mean(deg)'...
        'Foot internal-external rotational angle_min(deg)' 'Foot
internal-external rotational angle_max(deg)'...
        'Foot internal-external rotational angle_range(deg)'...
        'Foot internal-external rotational angular rate_min(deg/s)'...
        'Foot internal-external rotational angular rate_max(deg/s)'...
        'Foot internal-external rotational angular rate_mean(deg/s)'...
        'Foot dorsal-plantar rotational angle_start(deg)' 'Foot dorsal-
plantar rotational angle_end(deg)'...
        'Foot dorsal-plantar rotational angle_diff(deg)'...
        'Foot dorsal-plantar rotational angle_mean(deg)'...
        'Foot dorsal-plantar rotational angle_min(deg)' 'Foot dorsal-
plantar rotational angle_max(deg)'...
        'Foot dorsal-plantar rotational angle_range(deg)'...
        'Foot dorsal-plantar rotational angular rate_min(deg/s)'...
        'Foot dorsal-plantar rotational angular rate_max(deg/s)'...
        'Foot dorsal-plantar rotational angular rate_mean(deg/s)'...
        'Percent duration of internal-external rotational angular rate
over 30deg/s'...
        'Percent duration of internal-external rotational angular rate
over half max'...
        'Percent duration of internal-external rotational angular rate
below half max'...
        'Foot movement efficiency(%)'
         };
```

```
xlswrite1([pathname filename],header.dot_m,'dot_m','A1'); % write data
header
clear output;
% ------------------------------------
% export data
for nME = 1 : numel(C.event)
    event = C.event{nME};
    if isempty(dot.(event))
        continue
    end
    for i = dot.(event).enums : dot.(event).enume
        rowstart = ['A' num2str(i+1)];
        output = {
                 eventInfo.num(i), eventInfo.name{i},
eventInfo.start{i}, eventInfo.end{i}, eventInfo.dur{i}...
                 dot.(event).v2_mean(i), dot.(event).v2pks(i),
dot.(event).v2fast(i)...
                 dot.(event).v4_mean(i), dot.(event).v5_mean(i)...% dot
moving speed #2#4#5
                 dot.(event).angsweep_start(i),
dot.(event).angsweep_end(i)...
                 dot.(event).angsweep_end(i)-
dot.(event).angsweep_start(i)...
                 dot.(event).angsweep_mean(i)...
                 dot.(event).angsweep_min(i),
dot.(event).angsweep_max(i)...
                 dot.(event).angsweep_max(i)-
dot.(event).angsweep_min(i)...
                 dot.(event).angratsweep_min(i),
dot.(event).angratsweep_max(i), dot.(event).angratsweep_mean(i)...%
internal-external angle/angular rate
                 dot.(event).angankle_start(i),
dot.(event).angankle_end(i)...
                 dot.(event).angankle_end(i)-
dot.(event).angankle_start(i)...
                 dot.(event).angankle_mean(i),
dot.(event).angankle_min(i), dot.(event).angankle_max(i)...
                 dot.(event).angankle_max(i)-
dot.(event).angankle_min(i)...
                 dot.(event).angratankle_min(i)
dot.(event).angratankle_max(i) dot.(event).angratankle_mean(i)...%
dorsal-plantar angle/angular rate
                 dot.(event).banda(i), dot.(event).bandb(i),
dot.(event).bandc(i), dot.(event).eff(i)...% percent duration in each
band and foot moving efficiency
                 };
        xlswrite1([pathname filename],output,'dot_m',rowstart);
    end
end

%----------------------------------------------------------------------
----
% export DEWETRON/TEKSCAN data onto the NON-METRIC dot pedal data sheet
```

```
% ------------------------------------
% write header
% ------------------------------------
header.dewe_nm = {
         'Velocity_start (mph)' 'Velocity_end (mph)' 'Velocity_mean
(mph)'...
         'GPS Latitude(Y) deg_start' 'GPS Latitude(Y) min_start'...
         'GPS Longtitude(X) deg_start' 'GPS Longtitude(X) min_start'...
         'GPS Latitude(Y) deg_end' 'GPS Latitude(Y) min_end'...
         'GPS Longtitude(X) deg_end' 'GPS Longtitude(X) min_end'...
         'Start Lateral Acceleration (g)' 'Start Longitudinal
Acceleration (g)' 'Start Vertical Acceleration (g)'...
         'End Lateral Acceleration (g)' 'End Longitudinal Acceleration
(g)' 'End Vertical Acceleration (g)'...
         'Max Lateral Acceleration (g)' 'Max Longitudinal Acceleration
(g)' 'Max Vertical Accleration (g)'...
         'Force_brake_mean(lb)' 'Force_brake_max(lb)'
'Force_accelerator_mean(lb)'...
         'Force_brake_end(lb)' 'Force_accelerator_end(lb)'...
         'CoF_brake_mean (%)' 'CoF_brake_end (%)' 'Contact_brake (%)'...
         '# of trials'...
         }; % data header

% [filename,pathname,filterindex] = uigetfile('*.xlsx','Select the
driving event text file',folder);
xlswrite1([pathname filename],header.dewe_nm,'dewe_nm','A1'); % write
data header
% ------------------------------------
% export data
for nE = 1 : length(eventInfo.num)
    event = ['Event_' num2str(nE)]; % nE: number of event
    rowstart = ['A' num2str(nE+1)];
    output = {
             deweexp.(event).vs*0.621, deweexp.(event).ve*0.621,
deweexp.(event).vmean*0.621...
             deweexp.(event).ysdeg, deweexp.(event).ysmin...
             deweexp.(event).xsdeg, deweexp.(event).xsmin...
             deweexp.(event).yedeg, deweexp.(event).yemin...
             deweexp.(event).xedeg, deweexp.(event).xemin...
             deweexp.(event).las, deweexp.(event).longas,
deweexp.(event).vas...
             deweexp.(event).lae, deweexp.(event).longae,
deweexp.(event).vae...
             deweexp.(event).lamax, deweexp.(event).longamax,
deweexp.(event).vamax...
             tekscanexp.(event).bfmean, tekscanexp.(event).bfmax,
tekscanexp.(event).afmean...
             tekscanexp.(event).bfe, tekscanexp.(event).afe...
             tekscanexp.(event).bcofwmean, tekscanexp.(event).bcofwe,
tekscanexp.(event).bcamean...
             deweexp.trial...
             };
    xlswrite1([pathname filename],output,'dewe_nm',rowstart);
```

```
end

% -------------------------------------
% export dewesoft/tekscan data onto the DOT pedal data sheet (Metric
% units)
% -------------------------------------
% data header for dewesoft/tekscan data in Metric units
header.dewe_m = {
         'Event Num' 'Event Name' 'Event Start Time' 'Event End Time'
'Event Duration'...
         'Brake Pedal Travel Range (%)' 'Accelerator Pedal Travel Range
(%)'...
         'Velocity_start (km/h)' 'Velocity_end (km/h)' 'Velocity_mean
(km/h)'...
         'GPS Latitude(Y) deg_start' 'GPS Latitude(Y) min_start'...
         'GPS Longtitude(X) deg_start' 'GPS Longtitude(X) min_start'...
         'GPS Latitude(Y) deg_end' 'GPS Latitude(Y) min_end'...
         'GPS Longtitude(X) deg_end' 'GPS Longtitude(X) min_end'...
         'Start Lateral Acceleration (g)' 'Start Longitudinal
Acceleration (g)' 'Start Vertical Acceleration (g)'...
         'End Lateral Acceleration (g)' 'End Longitudinal Acceleration
(g)' 'End Vertical Acceleration (g)'...
         'Max Lateral Acceleration (g)' 'Max Longitudinal Acceleration
(g)' 'Max Vertical Accleration (g)'...
         'Acceleration_Longtitudinal(Y)_mean (g)'...
         'Force_brake_mean(N)' 'Force_brake_min(N)'
'Force_brake_max(N)' 'Force_brake_range(N)'...
         'Force_brake_start(N)' 'Force_brake_end(N)'
'Force_brake_diff(N)'...
         'Force_accelerator_mean(N)' 'Force_accelerator_min(N)'
'Force_accelerator_max(N)' 'Force_accelerator_range(N)'...
         'Force_accelerator_start(N)' 'Force_accelerator_end(N)'
'Force_accelerator_diff(N)'...
         'CoF_brake_width_mean(%)' 'CoF_brake_width_left(%)'
'CoF_brake_width_right(%)' 'CoF_brake_width_range(%)'...
         'CoF_brake_width_start(%)' 'CoF_brake_width_end(%)'
'CoF_brake_width_diff(%)'...
         'CoF_brake_length_mean(%)' 'CoF_brake_length_low(%)'
'CoF_brake_length_high(%)' 'CoF_brake_length_range(%)'...
         'CoF_brake_length_start(%)' 'CoF_brake_length_end(%)'
'CoF_brake_length_diff(%)'...
         'CoF_accelerator_width_mean(%)'
'CoF_accelerator_width_end(%)'...
         'CoF_accelerator_length_mean(%)'
'CoF_accelerator_length_end(%)'...
         'Contact_brake_mean(%)' 'Contact_brake_min(%)'
'Contact_brake_max(%)' 'Contact_brake_range(%)'...
         'Contact_brake_start(%)' 'Contact_brake_end(%)'
'Contact_brake_diff(%)'...
         'Contact_accelerator_mean(%)' 'Contact_accelerator_end(%)'...
         }; % data header
xlswrite1([pathname filename],header.dewe_m,'dewe_m','A1'); % write
data header
```

```
clear output;
% -------------------------------------
% export data
for nE = 1 : length(eventInfo.num)
    event = ['Event_' num2str(nE)];
    rowstart = ['A' num2str(nE+1)];
    output = {
             eventInfo.num(nE), eventInfo.name{nE}, eventInfo.start{nE},
eventInfo.end{nE}, eventInfo.dur{nE}...
             deweexp.(event).btdiff, deweexp.(event).atdiff...
             deweexp.(event).vs, deweexp.(event).ve,
deweexp.(event).vmean...
             deweexp.(event).ysdeg, deweexp.(event).ysmin...
             deweexp.(event).xsdeg, deweexp.(event).xsmin...
             deweexp.(event).yedeg, deweexp.(event).yemin...
             deweexp.(event).xedeg, deweexp.(event).xemin...
             deweexp.(event).las, deweexp.(event).longas,
deweexp.(event).vas...
             deweexp.(event).lae, deweexp.(event).longae,
deweexp.(event).vae...
             deweexp.(event).lamax, deweexp.(event).longamax,
deweexp.(event).vamax...
             deweexp.(event).longamean...
             tekscanexp.(event).bfmean*4.4482,
tekscanexp.(event).bfmin*4.4482, tekscanexp.(event).bfmax*4.4482,
tekscanexp.(event).bfrange*4.4482...
             tekscanexp.(event).bfs*4.4482,
tekscanexp.(event).bfe*4.4482, tekscanexp.(event).bfdiff*4.4482...
             tekscanexp.(event).afmean*4.4482,
tekscanexp.(event).afmin*4.4482, tekscanexp.(event).afmax*4.4482,
tekscanexp.(event).afrange*4.4482...
             tekscanexp.(event).afs*4.4482,
tekscanexp.(event).afe*4.4482, tekscanexp.(event).afdiff*4.4482...
             tekscanexp.(event).bcofwmean, tekscanexp.(event).bcofwmin,
tekscanexp.(event).bcofwmax, tekscanexp.(event).bcofwrange...
             tekscanexp.(event).bcofws, tekscanexp.(event).bcofwe,
tekscanexp.(event).bcofwdiff...
             tekscanexp.(event).bcoflmean, tekscanexp.(event).bcoflmin,
tekscanexp.(event).bcoflmax, tekscanexp.(event).bcoflrange...
             tekscanexp.(event).bcofls, tekscanexp.(event).bcofle,
tekscanexp.(event).bcofldiff...
             tekscanexp.(event).acofwmean, tekscanexp.(event).acofwe...
             tekscanexp.(event).acoflmean, tekscanexp.(event).acofle...
             tekscanexp.(event).bcamean, tekscanexp.(event).bcamin,
tekscanexp.(event).bcamax, tekscanexp.(event).bcarange...
             tekscanexp.(event).bcas, tekscanexp.(event).bcae,
tekscanexp.(event).bcadiff...
             tekscanexp.(event).acamean, tekscanexp.(event).acae...
             };
    xlswrite1([pathname filename],output,'dewe_m',rowstart);
end

% Export condensed metrics to DOT data sheet
```

```
% ------------------------------------------------------------------------
----
% Export condensed metrics to NON-METRIC DOT data sheet
% -------------------------------------
% stopsign
[nrows,~] = size(conMet.expstop);
Nrowstart=2;
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname filename],conMet.expstop(Nrow,:),'Condensed
Metrics_auto_nm',rowstart);
    Nrowstart=Nrowstart+1;
end
Nrowstart=Nrowstart+1;
% -------------------------------------
% reverse*4
for Nreverse = 1:4
    event = C.event{Nreverse};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_nm',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% -------------------------------------
% straight*2
for Nstraight = 8:9
    event = C.event{Nstraight};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_nm',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% -------------------------------------
% gate access*2
for Ngate = 6:7
    event = C.event{Ngate};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_nm',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% -------------------------------------
```

```
% startle
[nrows,~] = size(conMet.expstartle);
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname filename],conMet.expstartle(Nrow,:),'Condensed
Metrics_auto_nm',rowstart);
    Nrowstart=Nrowstart+1;
end
% -------------------------------------
% overall
Nrowstart=Nrowstart+1;
[nrows,~] = size(conMet.expoverall);
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname filename],conMet.expoverall(Nrow,:),'Condensed
Metrics_auto_nm',rowstart);
    Nrowstart=Nrowstart+1;
end

% ---------------------------------------------------------------------
----
% Export condensed metrics to METRIC DOT data sheet
% -------------------------------------
% stopsign
[nrows,~] = size(conMet.expstopm);
Nrowstart=2;
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname filename],conMet.expstopm(Nrow,:),'Condensed
Metrics_auto_m',rowstart);
    Nrowstart=Nrowstart+1;
end
Nrowstart=Nrowstart+1;
% -------------------------------------
% stop*9
for Nstop = 12:20
    event = C.event{Nstop};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_m',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% -------------------------------------
% reverse*5
for Nreverse = 1:5
    event = C.event{Nreverse};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
```

```
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_m',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% ------------------------------------
% straight*2
for Nstraight = 8:9
    event = C.event{Nstraight};
    [nrows,~] = size(conMet.(['exp' event]));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp'
event])(Nrow,:),'Condensed Metrics_auto_m',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% ------------------------------------
% gate access*2
for Ngate = 6:7
    event = C.event{Ngate};
    [nrows,~] = size(conMet.(['exp' event 'm']));
    for Nrow = 1:nrows
        rowstart = ['B' num2str(Nrowstart)];
        xlswrite1([pathname filename],conMet.(['exp' event
'm'])(Nrow,:),'Condensed Metrics_auto_m',rowstart);
        Nrowstart=Nrowstart+1;
    end
    Nrowstart=Nrowstart+1;
end
% ------------------------------------
% startle
[nrows,~] = size(conMet.expstartlem);
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname filename],conMet.expstartlem(Nrow,:),'Condensed
Metrics_auto_m',rowstart);
    Nrowstart=Nrowstart+1;
end
% ------------------------------------
% initial
Nrowstart=Nrowstart+1;
[nrows,~] = size(conMet.expinitialpedalcal);
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname
filename],conMet.expinitialpedalcal(Nrow,:),'Condensed
Metrics_auto_m',rowstart);
    Nrowstart=Nrowstart+1;
end
% ------------------------------------
% final
```

```
Nrowstart=Nrowstart+1;
[nrows,~] = size(conMet.expfinalpedalcal);
for Nrow = 1:nrows
    rowstart = ['B' num2str(Nrowstart)];
    xlswrite1([pathname
filename],conMet.expfinalpedalcal(Nrow,:),'Condensed
Metrics_auto_m',rowstart);
    Nrowstart=Nrowstart+1;
end

clear Nreverse Nstraight Ngate nrows ncols Nrowstart Nrow
% ----------------------------------------------------------------------
----

ExcelWorkbook.Save
ExcelWorkbook.Close(false) % Close Excel workbook.
Excel.Quit;
delete(Excel);
```

APPENDIX C: INSTRUMENTED VEHICLE MANUAL

Shayne McConomy

3/22/2012

This document was created by Shayne McConomy as part of his work as a Research Assistant.

Contents

How to Turn on the System

These steps demonstrate how to turn on all the equipment, load the calibration files for the Tekscan sensors, and leave the equipment ready for a data collection session. These steps begin with the operator outside the vehicle.

Prior to Data Collection

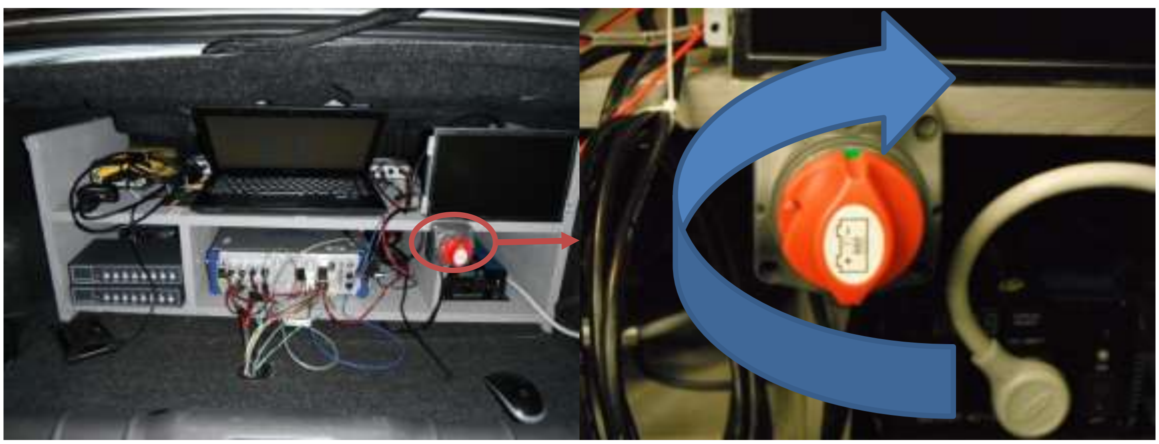
The following steps are completed before data collection:

1. Find the button to open the trunk.

2. Press the button to open the trunk.
3. Find the location of the trunk.

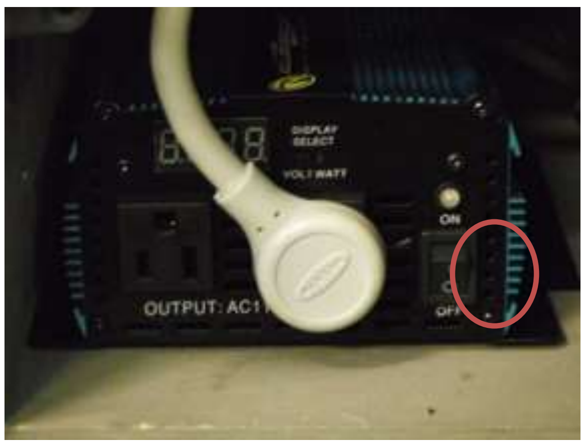
4. Walk to the trunk.
5. Lift the deck lid to the fully open position.

6. Inside the trunk, find the switch mounted on the face of the equipment rack.



7. Turn the switch one-quarter turn in the clockwise direction to the ON position. In other words, turn the "grip" of the switch so that the "grip" has turned from the vertical position and ends in the horizontal position.

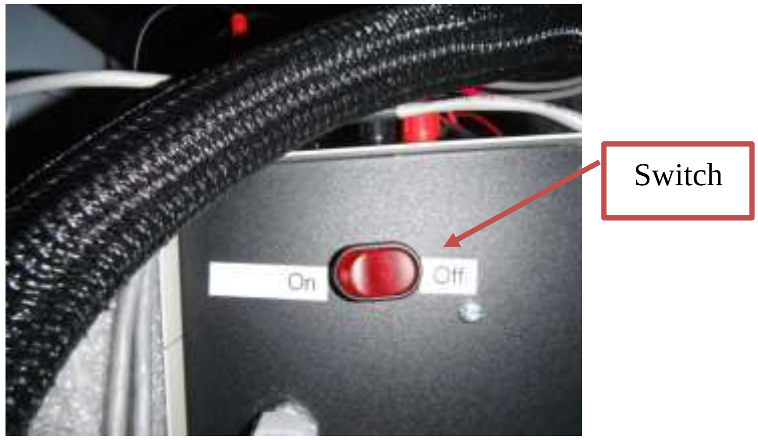
8. Locate the power inverter (inverter) in the bottom right of the equipment box.
9. Locate the power toggle switch on the face of the inverter.



10. Place the inverter's power toggle switch in the "on" position.
11. Locate the accessory power box in the spare tire well.

Switch on the Right Side

12. Locate the power toggle switch on the right side of the accessory power box.
13. Place the power toggle switch in the "on" position.



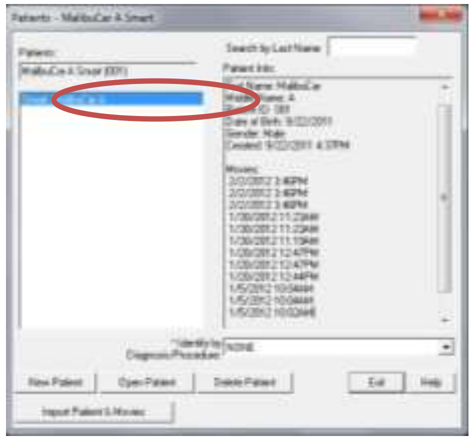
14. Locate the Dell laptop computer (Dell) in the top center of the equipment rack.

15. Turn on the Dell laptop.

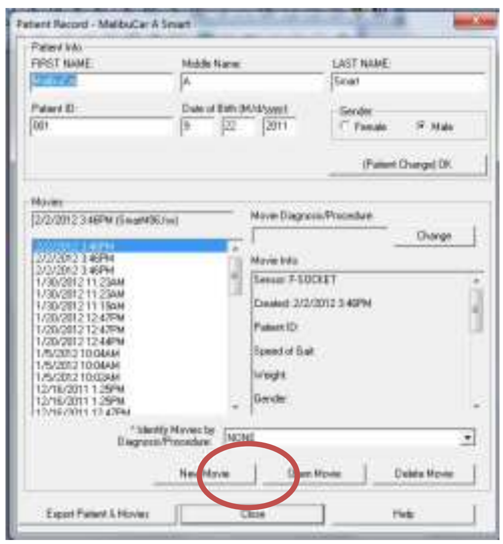
Windows Operating System will boot and the Tekscan F-Socket Research Software will open afterwards.

Tekscan F-Socket Research Software

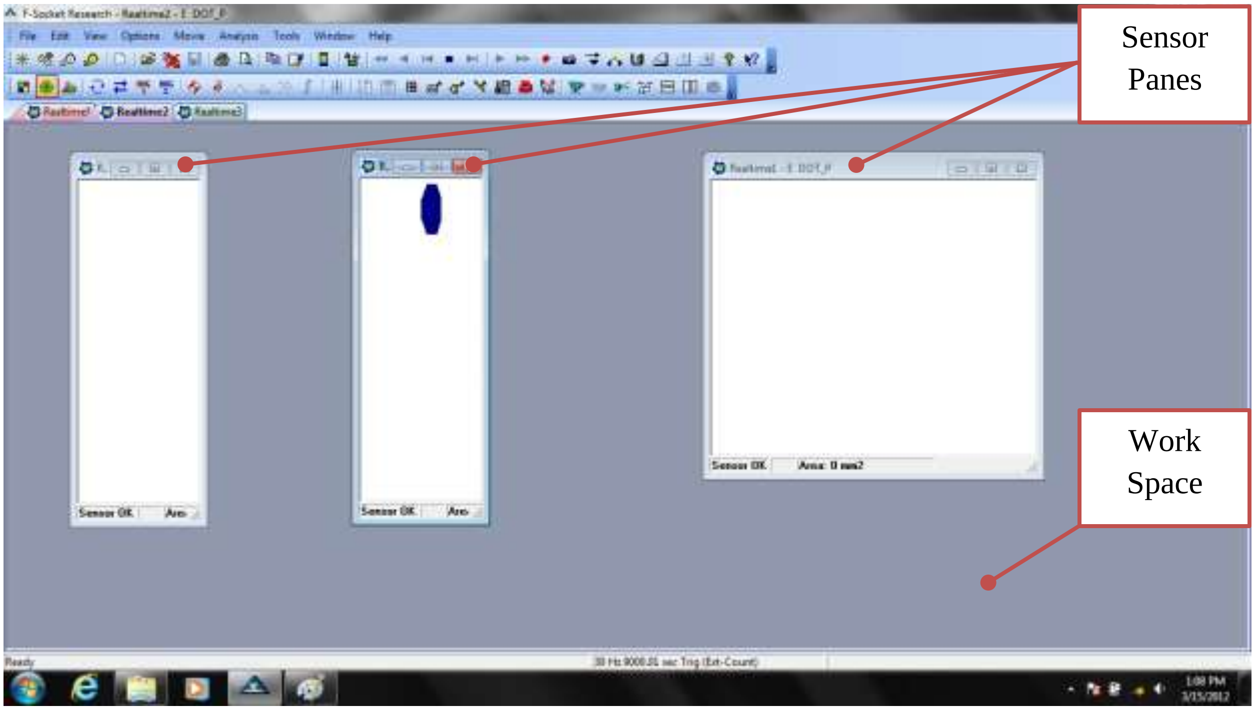
16. Double click the proper *Patient ID* in the left field of the patient dialog box.



17. Push the *New Movie* button.



18. Note the three sensor panes in the work space.

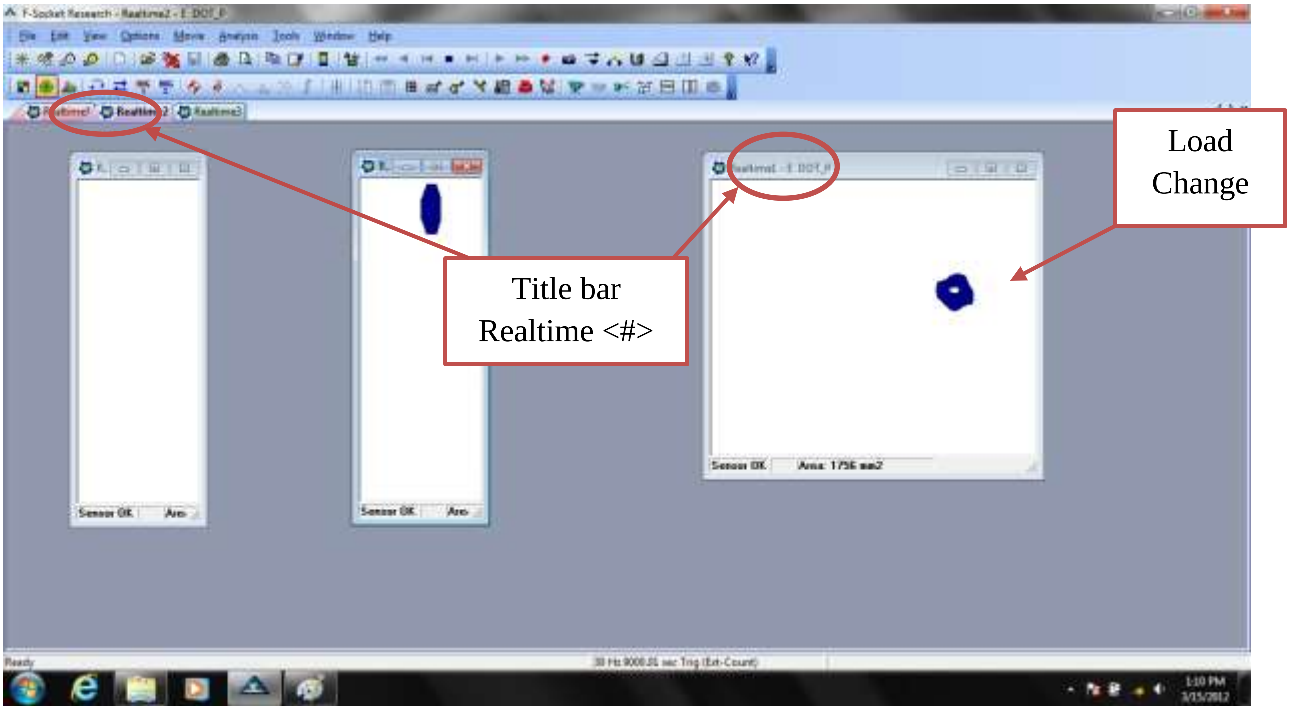


Tekscan Sensor Identification
The “square” pane is the floor mat sensor, and the rectangle panes are the brake and accelerator pedal sensors. Confirm the sensors by placing a load on the sensor and checking the readings using the following steps:

Floor Mat

19. Note the original loadings on the sensor panes.
20. Place a weight on the driver side floor mat.

21. Re-examine the sensor pane and note the change in loading.

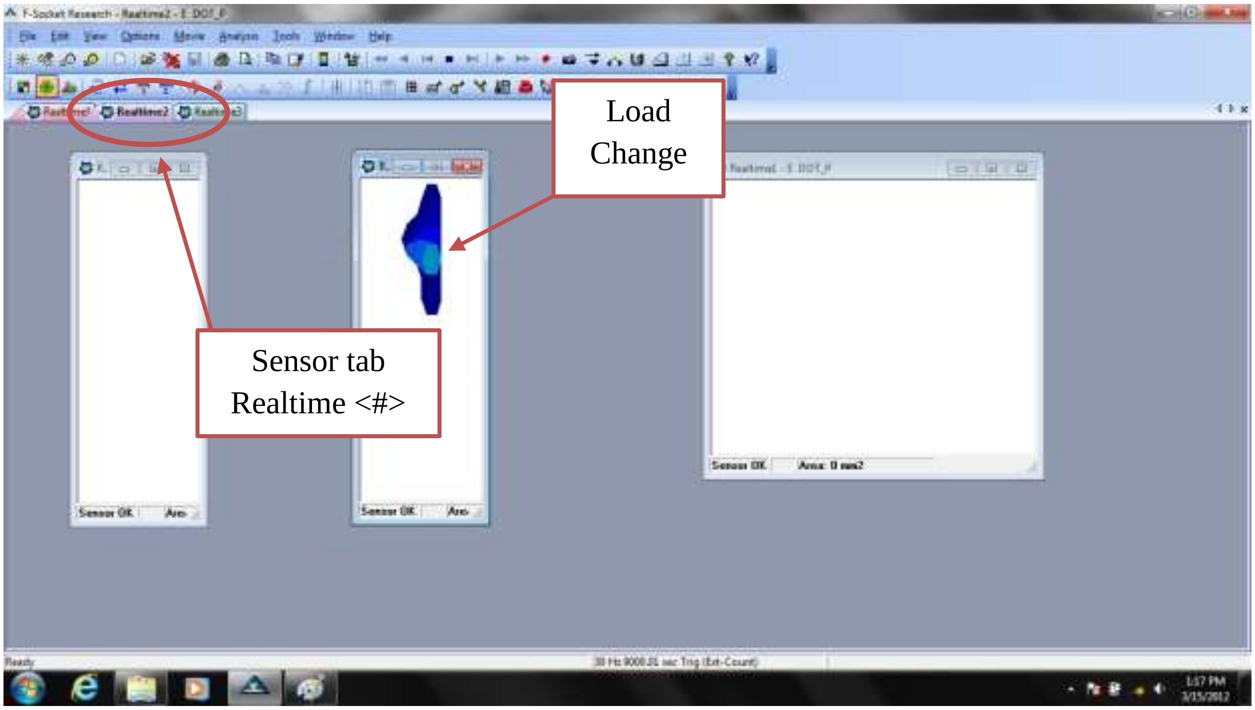


22. Note the name of the sensor pane in the title bar *(Realtime <#>)*. **The title bar name needs to be associated with the name "*mat sensor*" to complete the calibration process starting in step 29**.

Brake and Accelerator Pedal

23. Remove the weight from floor mat.
24. Place a spring clamp on the brake pedal.


25. Re-examine the sensor pane and note the change in loading.



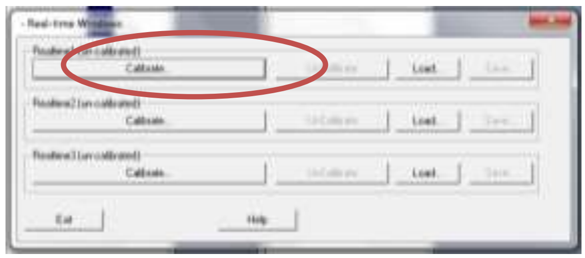
26. Note the name of the sensor pane in the sensor tab *(Realtime <#>)*. **The sensor tab name needs to be associated with the name "*brake sensor*" to complete the calibration process starting in step 29**.
27. The remaining sensor is the accelerator pedal. Note the name of the sensor pane in the title bar *(Realtime #)*. **The title bar name needs to be associated with the name "*gas sensor*" to complete the calibration process starting in step 29**.
28. Remove the spring clamp from the brake pedal.

Calibrating the Sensors

29. Select the *Tools* drop down menu.

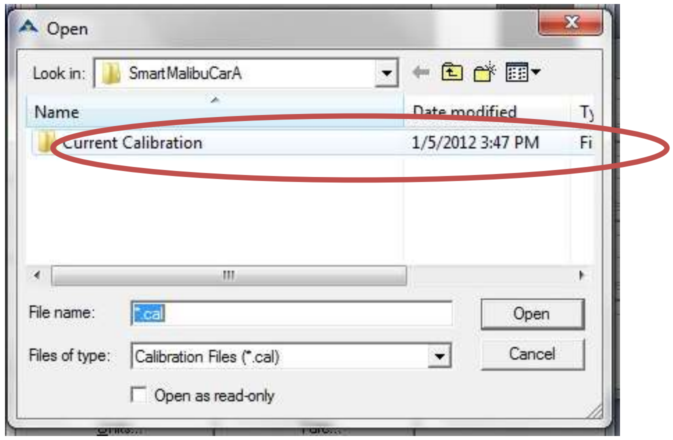
30. Select *Calibration…*

31. Push the *calibrate…* button for the Realtime <#> sensor. (Remember the sensor names from steps 22, 26, and 27.)

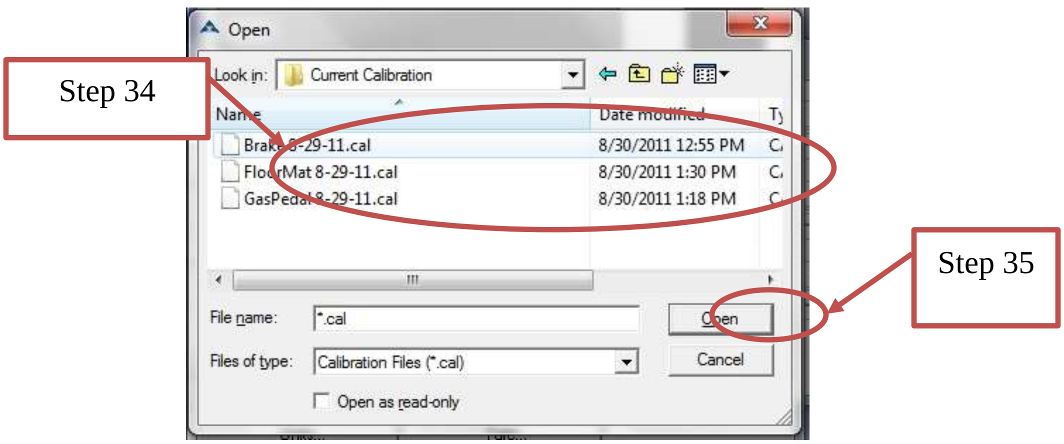


32. In the sensor calibration dialog box, press the *Load Cal. File…* button. (Remember the title bar and sensor names from steps 22, 26, and 27.)

33. From the Open dialog box, navigate to the "*Current Calibration*" file location.

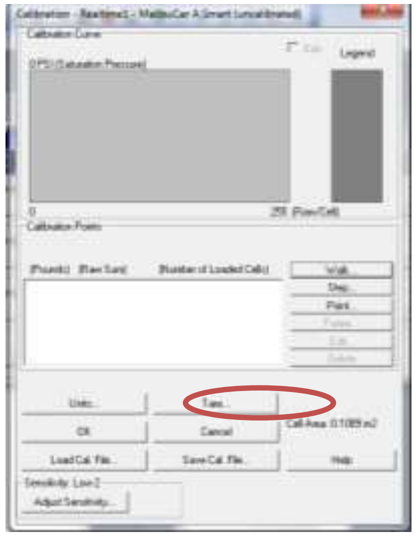


34. Select the current and proper sensor calibration file.



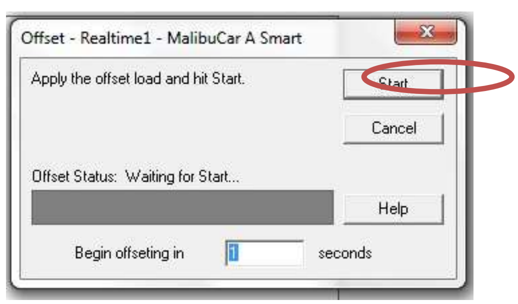
35. Press the *Open* button.
36. Press the *OK* button to confirm the pop-up dialog box.

37. Press the Tare… button to open the Tare dialog box.

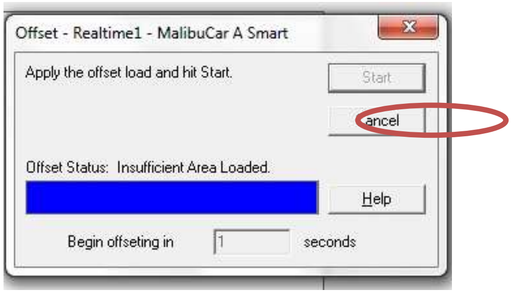


38. Press the New… button.

39. Press the Start button.

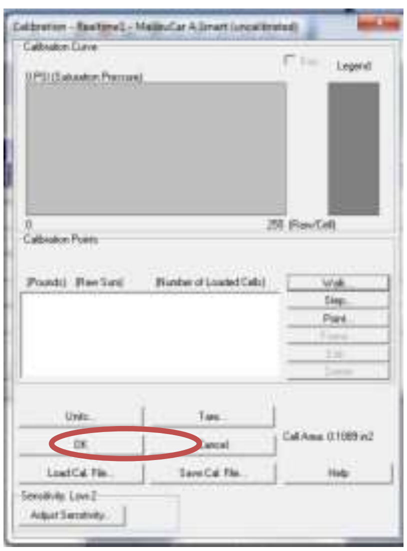


40. If the *loading bar* does not finish loading and the *Offset Status* reads “Insufficient Area Loaded”, press the *Cancel* button and proceed to the next step. Otherwise, proceed to the next step.



41. Press the OK button to exit the Tare dialog box.

42. Press the OK button to exit the sensor calibration dialog box.



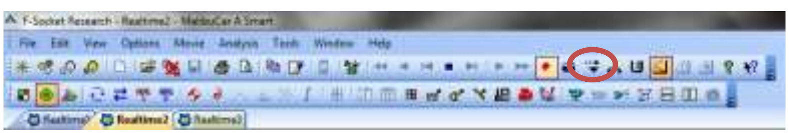
43. **Repeat for the remaining Tekscan sensors. (Steps 31 - 42 are reprinted below without images.)**

    31. Push the *calibrate*… button for the Realtime <#> sensor. (Remember the sensor names from steps 22, 26, and 27.)

32. In the sensor calibration dialog box, press the *Load Cal. File…* button. (Remember the title bar and sensor names from steps 22, 26, and 27.)
33. From the Open dialog box, navigate to the "*Current Calibration*" file location.
34. Select the current and proper senor calibration file.
35. Press the *Open* button.
36. Press the *OK* button to confirm the pop-up dialog box.
37. Press the Tare… button to open the Tare dialog box.
38. Press the New… button.
39. Press the Start button.
40. If the *loading bar* does not finish loading and the *Offset Status* reads "Insufficient Area Loaded", press the *Cancel* button and proceed to the next step. Otherwise, proceed to the next step.
41. Press the OK button to exit Tare dialog box.
42. Press the OK button to exit the sensor calibration dialog box.
43. **Repeat for the remaining Tekscan sensors.**

44. Press *Exit* in the Calibration dialog box.

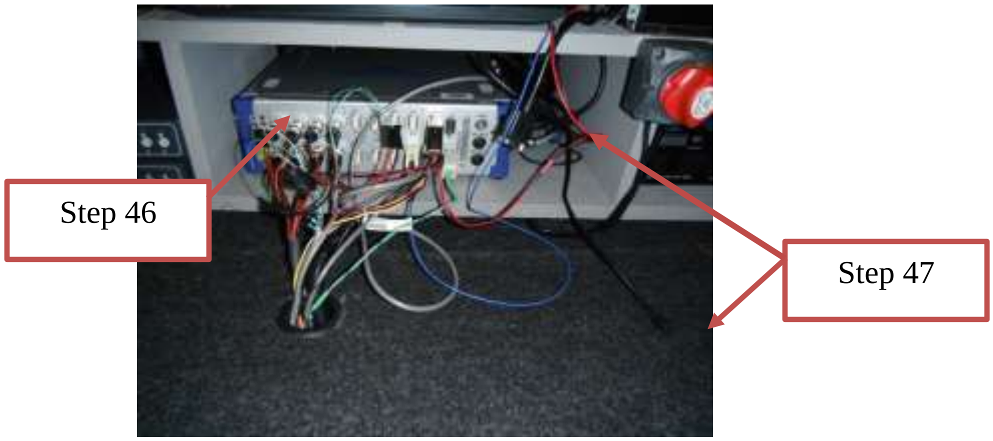
45. From the Main tool bar, press the *Record* button.



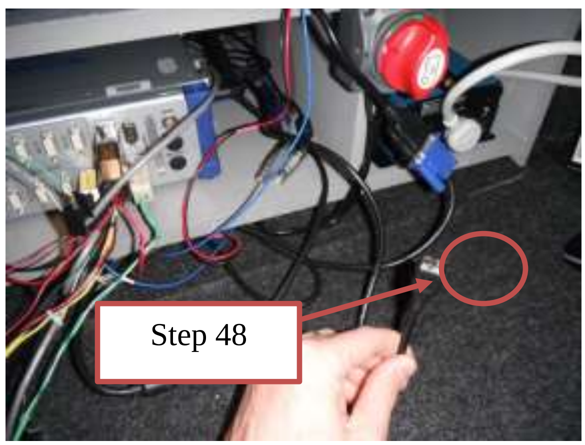
At this point, the Tekscan will be waiting for the external trigger sent from the Dewetron-computer (Dewetron).

Dewetron Pre-data collection setup

46. Find the Dewetron.



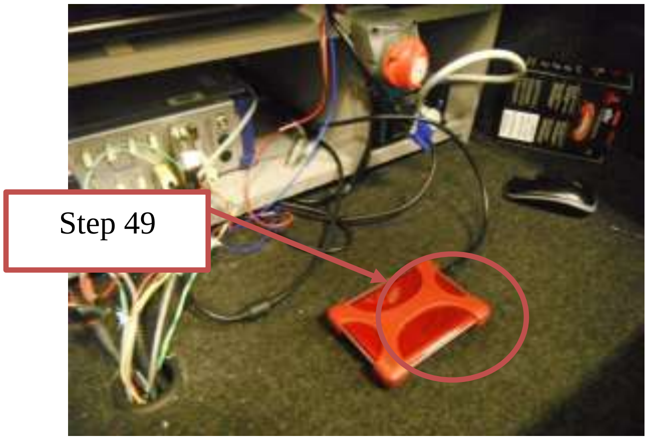
47. Find the USB 2.0A to USB 2.0B cord.



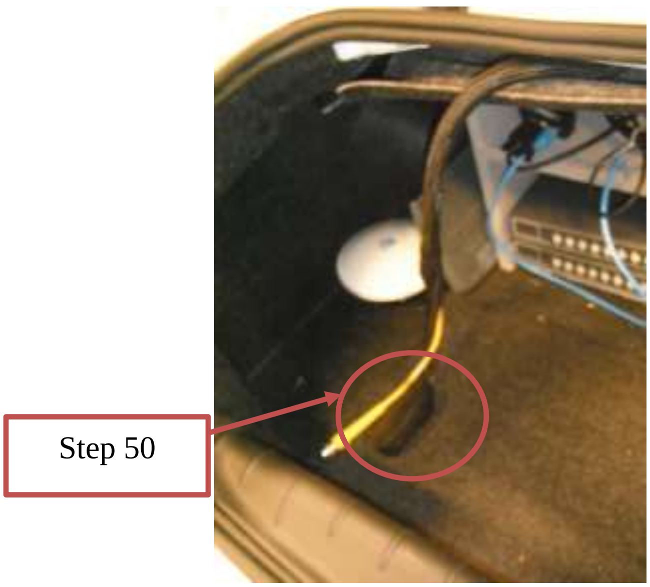
48. Check that the cord is connected to the Dewetron, and an external hard drive.

If the Dewetron is booted without an external hard drive attached, the file location will default to the **internal drive, and data may be lost due to file sizes. If this is done, please refer to the section: **
"Casual Repairs
The following sections outline possible, common errors that may occur during repeated data collectionsessions.
How to restore the file location of the recorded data"

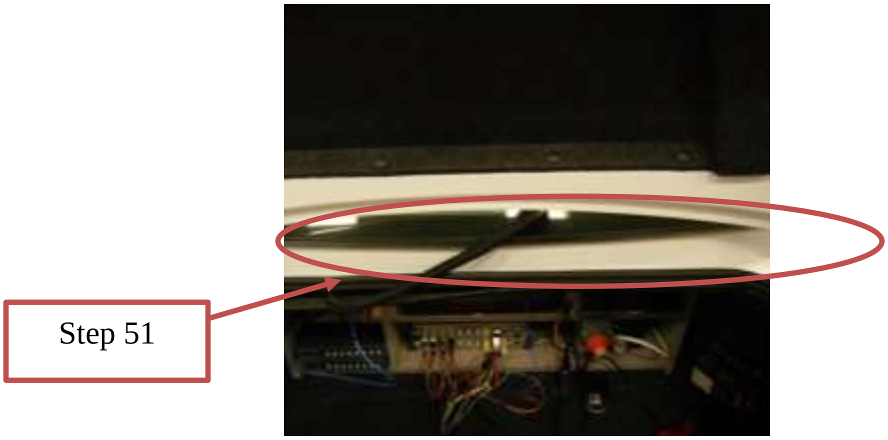
49. If the Dewetron or the external hard drive is not connected, then connect them at this time.



50. Locate the RTK base and yellow satellite cable (GPS Cables)inside the trunk space.

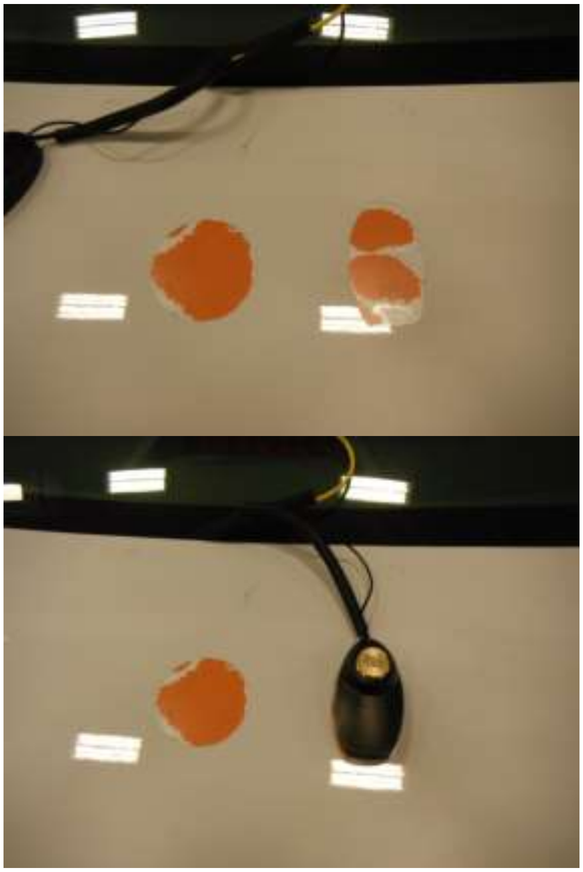


51. Route GPS cables through the gap created by the open deck lid and the rear window.

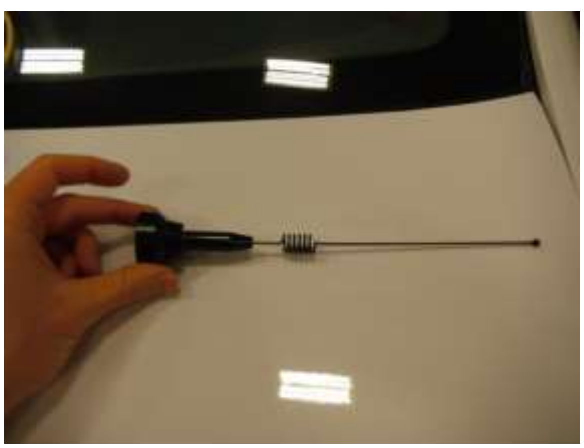


52. Locate the RTK antenna's magnetic base attached at the end of the GPS cables.

53. Place the RTK antenna's magnetic base on the matching stick on the outside top of the deck lid.



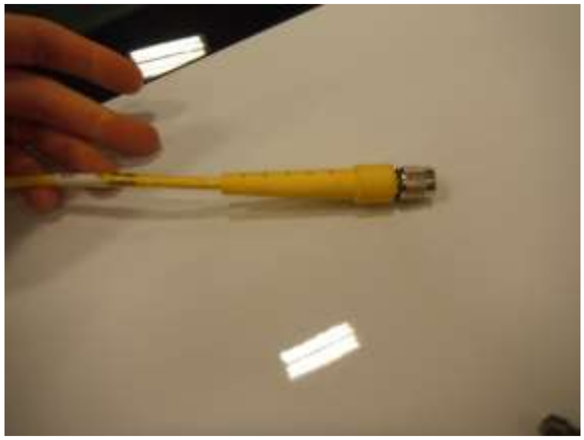
54. Locate the RTK antenna inside the trunk space.



55. Thread the RTK antenna onto the magnetic base.

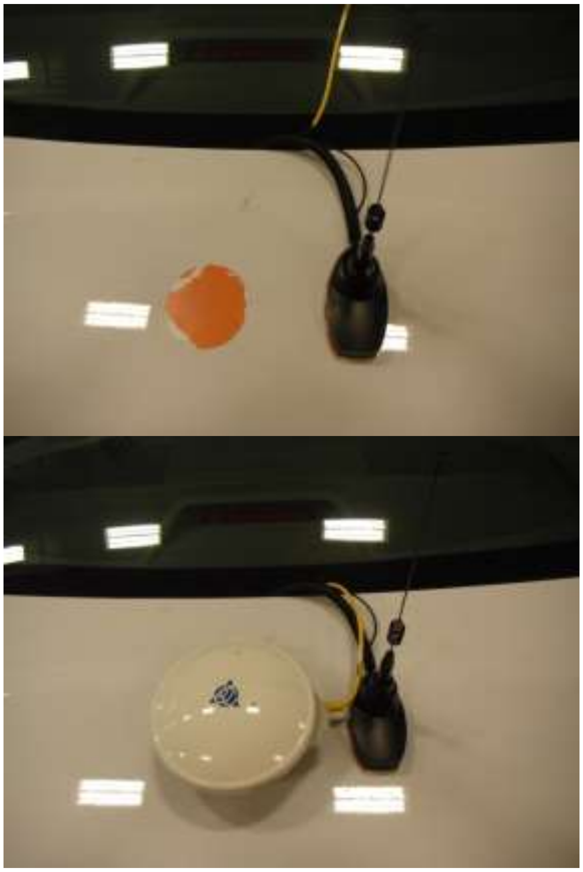
56. Locate the satellite receiver inside the trunk space.

57. Locate the loose, yellow GPS cable.



58. Thread the loose, yellow GPS cable on the receiver.

59. Place the satellite receiver’s magnetic base on the matching sticker on the outside top of the deck lid.



60. Orient the satellite receiver so that the yellow cable is directed to the right.

61. Close the deck lid.

Data Collection

These steps are to be done when data collection is about to begin and after the steps from the previous section “Prior to Data Collection” have been completed.

How to Start the Car

1. Locate the driver seat.
2. Sit in the driver seat.
3. Find the brake pedal.
4. Press and hold the brake pedal.
5. Find the ignition switch and the vehicle key (key).

6. Place the key in the ignition switch.

7. Turn the key three “clicks” in the clockwise direction to the *start* position until the vehicle is running.

8. Release the key so that it naturally returns to the *ON* position,

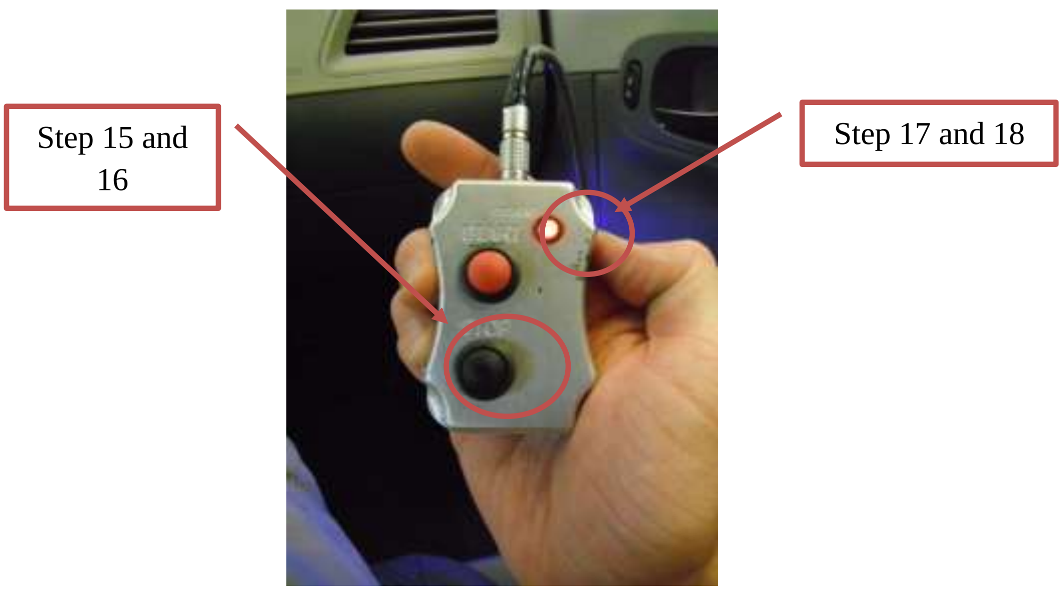
How to Begin Recording Data

9. Wait for Windows to load in the Dewetron.
10. Wait for the DEWEsoft to load.
11. Locate the external DEWEsoft control box in the passenger seat area.
12. Pick-up the external DEWEsoft control box.

13. Locate the blue satellite indicator LED.

14. Wait for the satellite indicator LED to illuminate blue.

15. While still holding the DEWEsoft external control box, locate the red start button.
16. Press the red start button firmly and hold for two seconds.
17. Locate the recording red LED.
18. Check to see if the LED has illuminated red. (If the red LED does not light, repeat step 14-16.)



19. Set the DEWEsoft external control box to the side.
20. Begin testing.

How to Turn Off the System

1. After testing is complete, locate the DEWEsoft external control box.
2. Locate the black stop button.

3. Press the black stop button.
4. Locate the recording red LED.
5. Wait for red LED to turn off.

6. Set the DEWEsoft external control box to the side.
7. Locate the ignition key.

8. Turn the key two "clicks" in the counter clockwise direction to the "off" position.
9. Remove the key from the ignition switch.

10. Find the button to open the trunk.

11. Press the button to open the trunk.
12. Find the location of the trunk.
13. Walk to the trunk.

14. Lift the deck lid to the fully open position.

15. Locate the Dell laptop in the top center of the equipment rack.

16. In the Tekscan F-Socket Research software press the *Stop* button in the main toolbar.

17. Select the *File* drop down menu.

18. Select *Save Movie*.

19. Select *Save All* in the Add Movie to Database Dialog box.

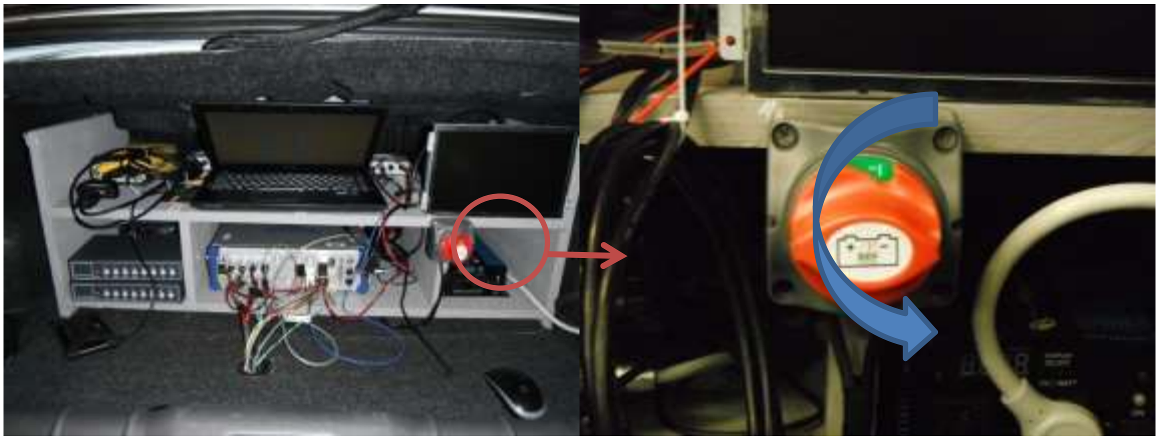
20. Select the *File* drop down menu.

21. Select *Exit.*

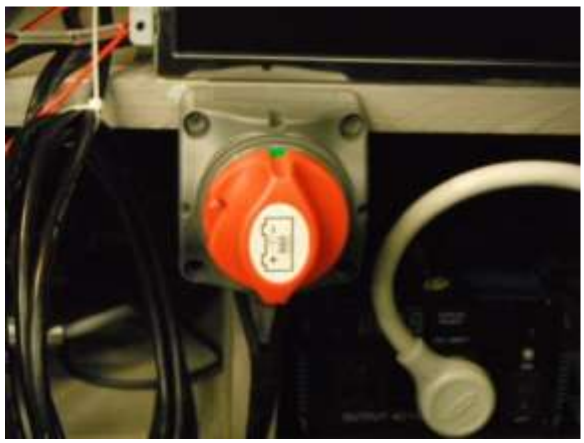
22. Press the Windows *Start* button.

23. Press the *Shut down* button.

24. Find the switch mounted on the face of the equipment rack.



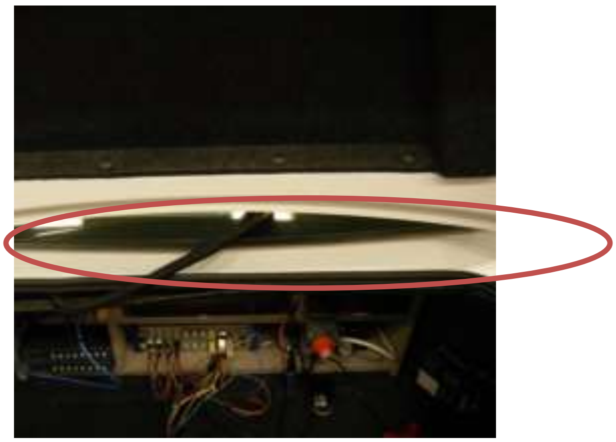
25. Turn the switch one-quarter turn in the counter clockwise direction to the OFF position. In other words, turn the “grip” of the switch so that the “grip” has turned from the horizontal position and ends in the vertical position.



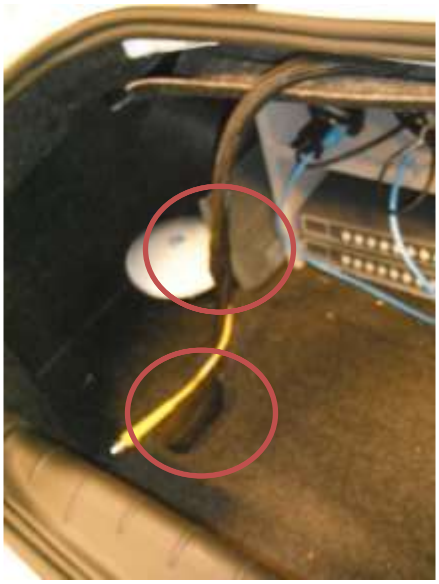
26. Unthread the RTK antenna from the magnetic base and place it in the trunk space.

27. Unthread the yellow GPS cable on the receiver.

28. Route GPS cables through the gap created by the open deck lid and the rear window.



29. Place GPS cables and the satellite receiver inside the trunk space.



30. Close the deck lid.

Casual Repairs

The following sections outline possible, common errors that may occur during repeated data collectionsessions.

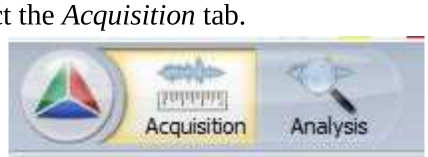
How to restore the file location of the recorded data

The file location has been saved in the project settings to save automatically to an external hard drive; however, if the Dewetron is started without the external hard drive connected, the Dewetron will return to the default setting and save to the internal hard drive. The following steps show how to repair the project setting so that the data files are saved to the desired location.

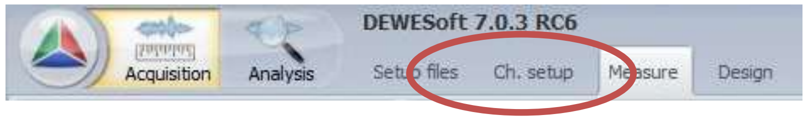
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



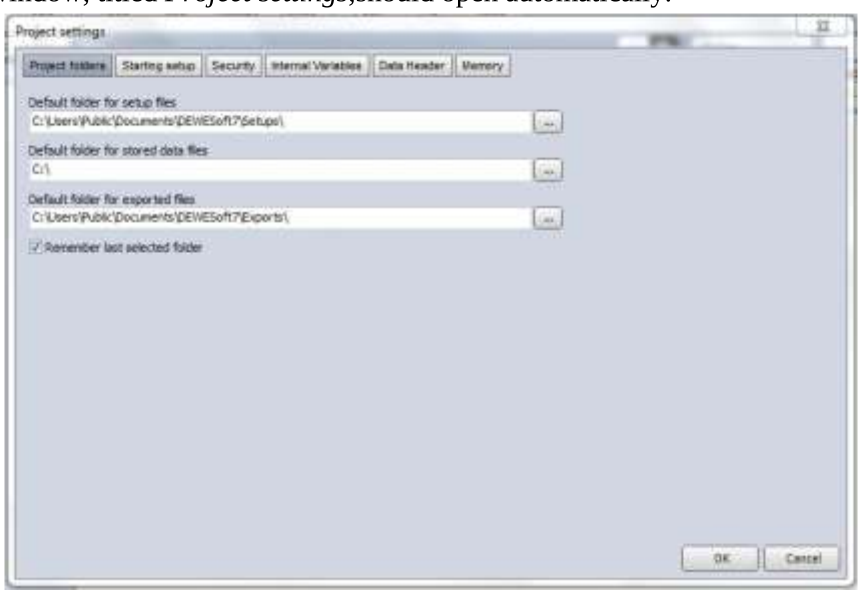
6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.



7. Select the *Settings* button in the top right hand corner of the screen.

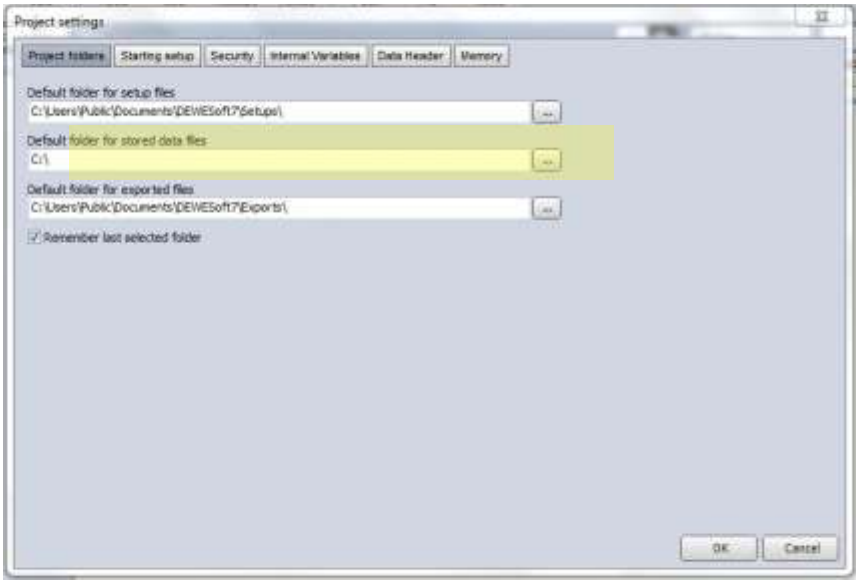
8. From the drop down menu, select *Project setup*.

9. A new window, titled *Project settings*,should open automatically.

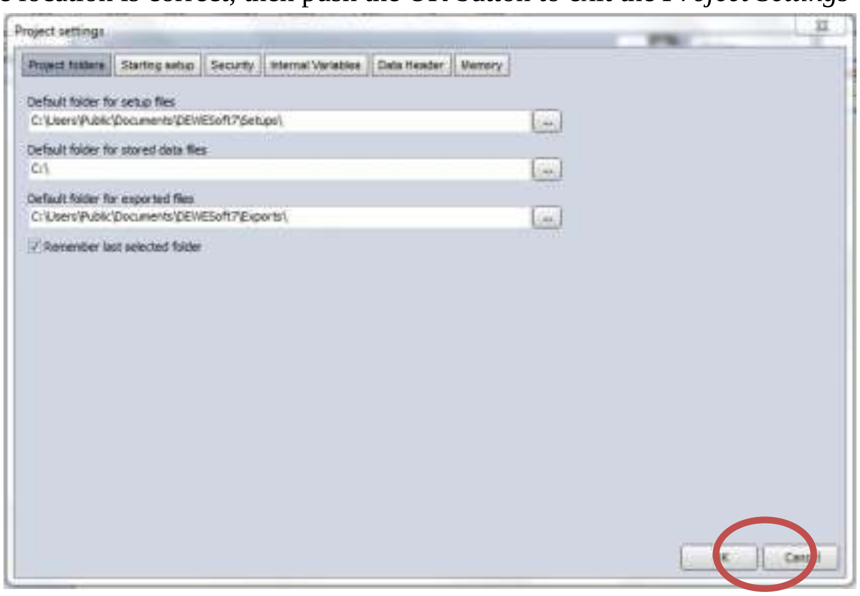


10. Select the *Project folders* tab.

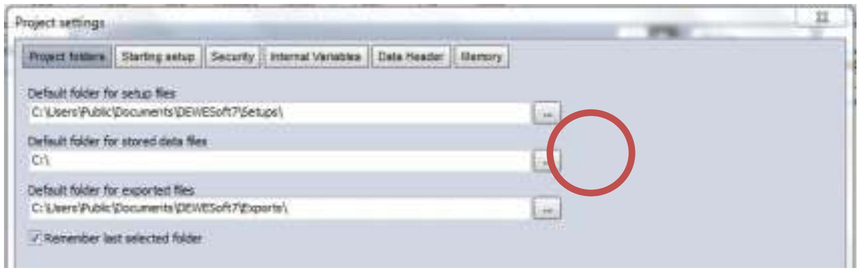
11. The middle line item in this window is the location where the data files will be stored.



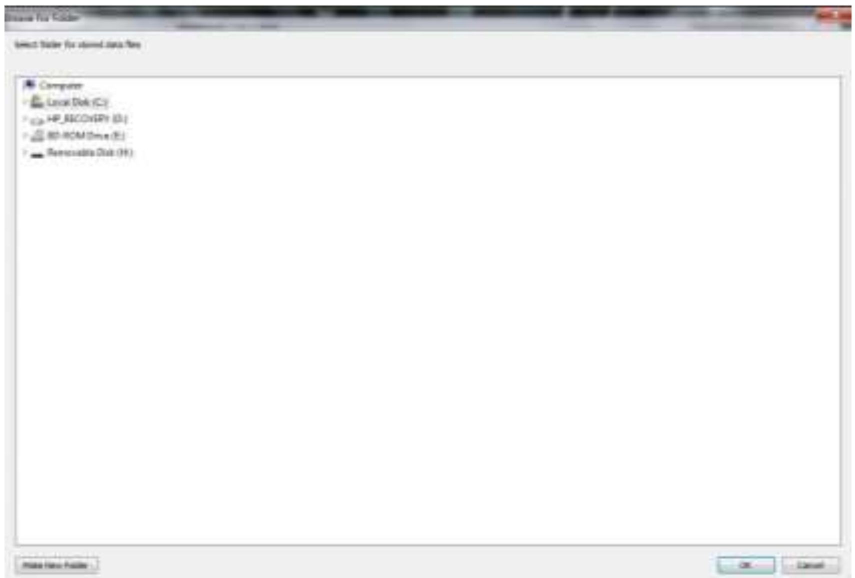
12. If the file location is correct, then push the *OK* button to exit the *Project Settings* window.



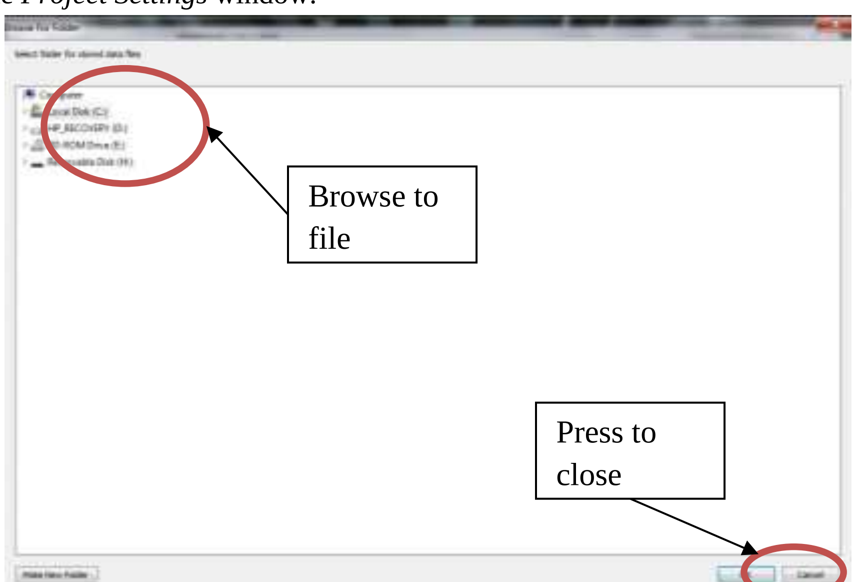
13. If the file location is **not** correct then select the "…" button to the right of the middle line item.



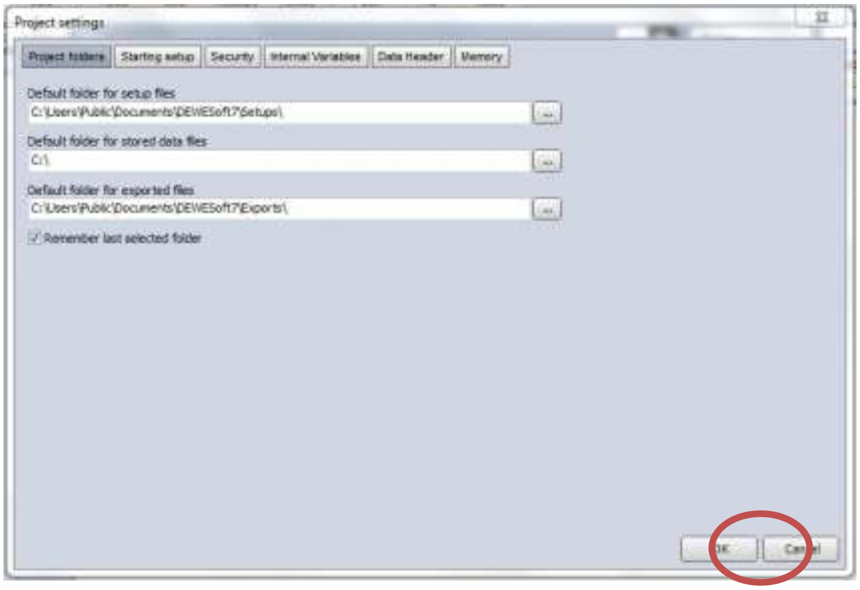
14. A new window titled "*Browse for Folder"* will open.



15. Browse to the desired file location for the files to be stored and press the *OK* button to return the *Project Settings* window.



16. If the file location is correct, then push the *OK* button to exit the *Project Settings* window.



17. If the file location is **not** correct, then repeat steps 11-14.

How to switch between Projects

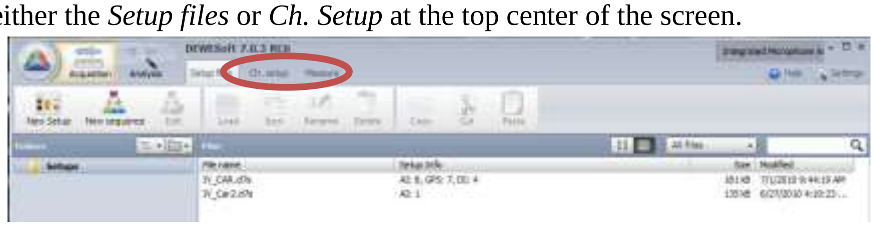
If the Dewetron is being used in multiple studies, it may be necessary to switch between *Projects*. This is accomplished through the *Settings* and is described below.

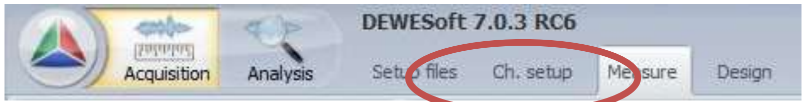
1. Turn on the system.
2. Locate the screen connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

4. The system should load similar to below.

5. In the top left corner select the *Acquisition* tab.

6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.

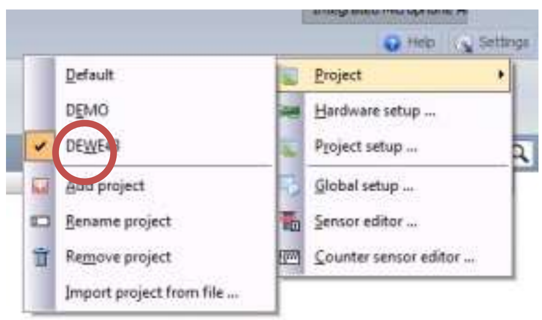




7. Select the *Settings* button in the top right hand corner of the screen.

8. From the drop down menu, select Project.

9. The active Project file will have a check mark.



10. If the Project setup is not correct, then select the desired setup; otherwise, click in the area outside of the drop down menu.

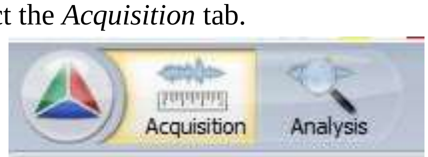
How to change the setup file

Setup files are the files that contain the information about how the sensors are configured and which ones are being used. There may be a need to have multiple configurations, and therefore, a need to switch between them. The following steps describe how to switch between the different setup files.

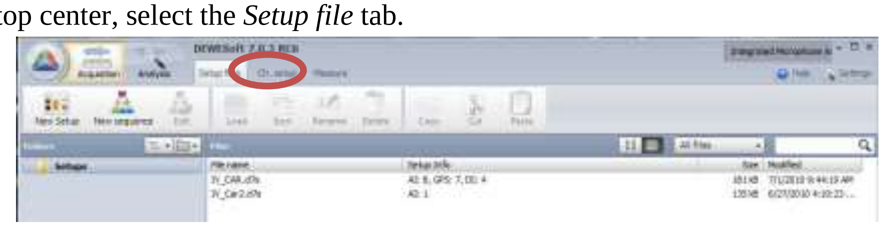
1. Turn on the system.
2. Locate the screen connected to the Dewetron; if one is not connected. then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

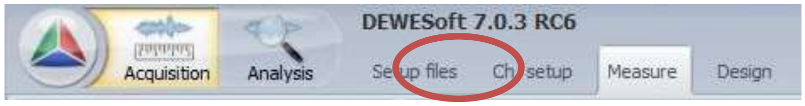
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



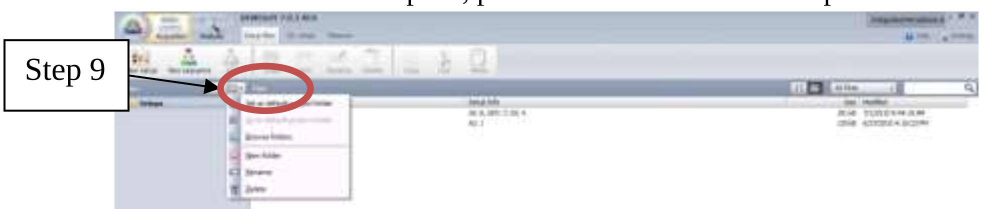
6. In the top center, select the *Setup file* tab.



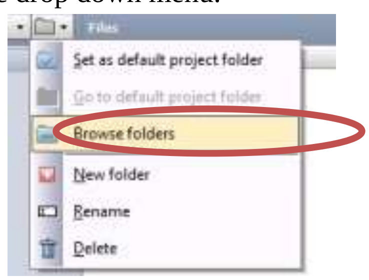


7. In the center pane, a list of setup files should be listed.

8. Select the desired setup file.
9. If no files are listed in the center pane, press the folder icon for a drop down menu.

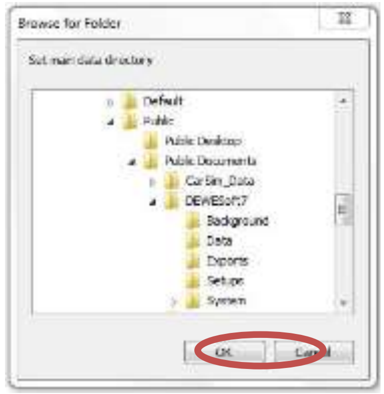


10. Select *Browse folders* from the drop down menu.



11. A new window titled *Browse for Folder* should open.

12. Locate the appropriate folder location and press the *OK* button to return.



13. In the center pane, a list of setup files should be listed.

14. Select the desired setup file.
15. If no files appear, repeat steps 7-11.

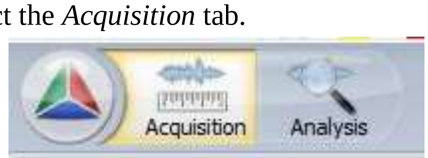
How to change the start-up setup file

A setup file can be saved with a project so that when the project is loaded, the desired setup file will be loaded as well. Follow the steps below to set a setup file with a project file.

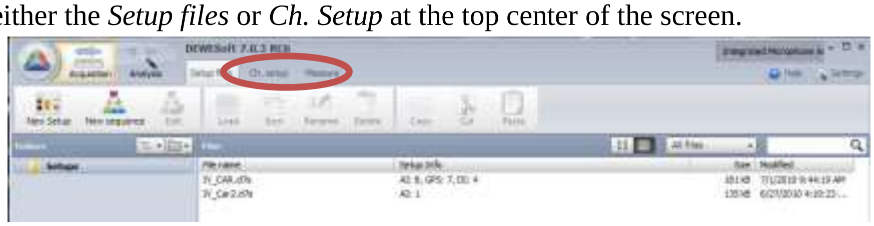
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

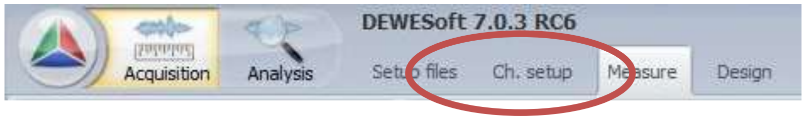
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.

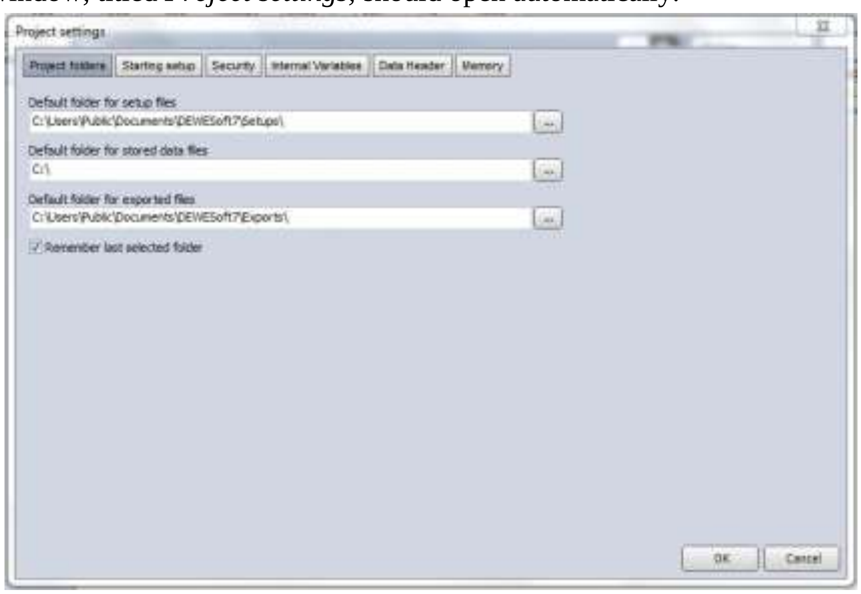




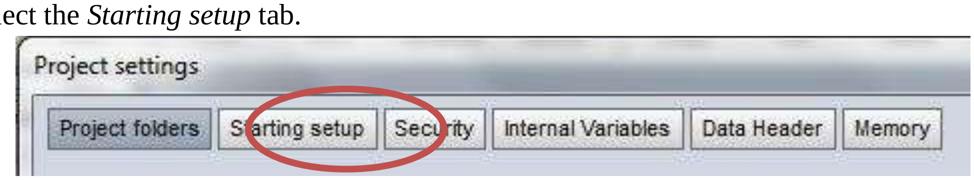
7. Select the *Settings* button in the top right hand corner of the screen.

8. From the drop down menu, select *Project setup*.

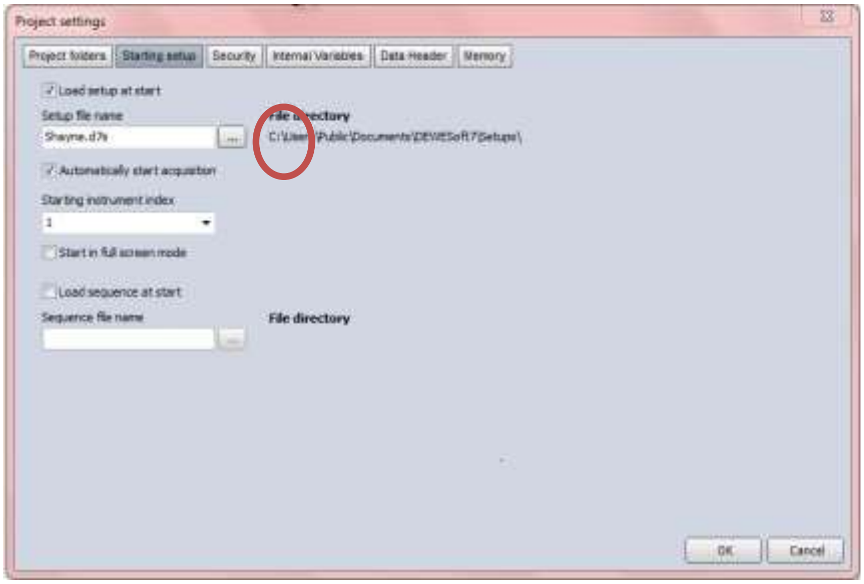
9. A new window, titled *Project settings*, should open automatically.



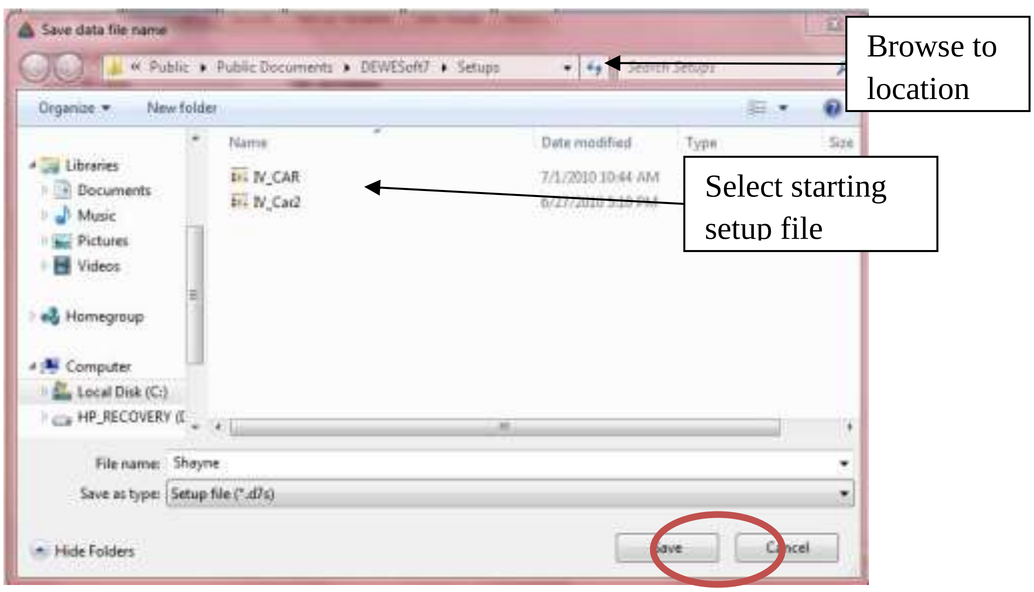
10. Select the *Starting setup* tab.



11. Click the "…" button next to the dialog box titled *Setup file name*.



12. Browse to the desired file location.



13. Select the desired setup file.
14. Press *Save* to return to the *Project settings* window.
15. Press *OK* to exit the *Project settings* window.

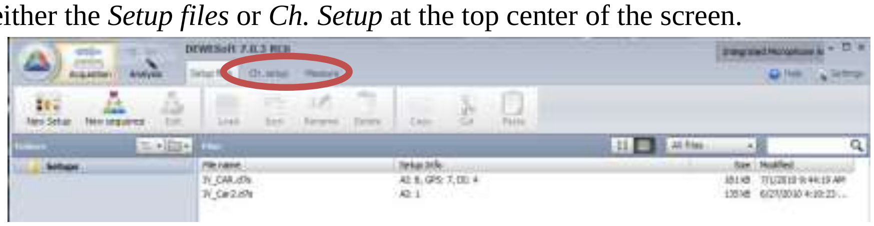
How to create a new project

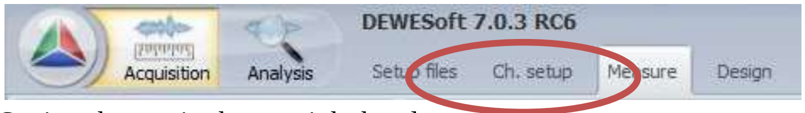
1. Turn on the system.
2. Locate the screen connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.

6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.

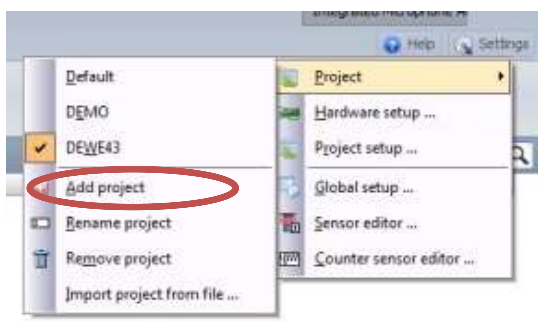




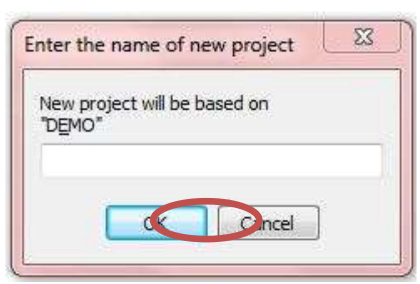
7. Select the *Settings* button in the top right hand corner of the screen.

8. From the drop down menu, select Project.

9. From the drop down menu, select *Add project.*



10. Enter the <*name*> of the new project.



11. Press *OK* to create the new project and exit.

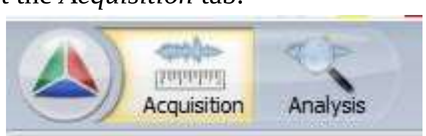
How to change the automatic naming of the data files

Each data file needs to have a unique name. To change the automatic naming format, follow the instructions below.

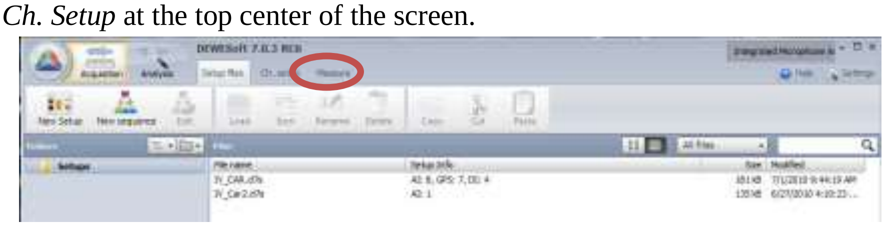
1. Turn on the system.
2. Locate the screen connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

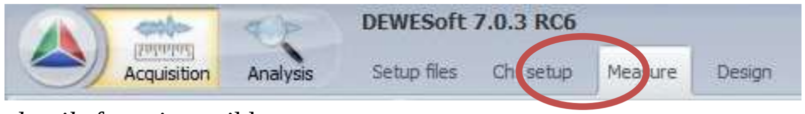
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.

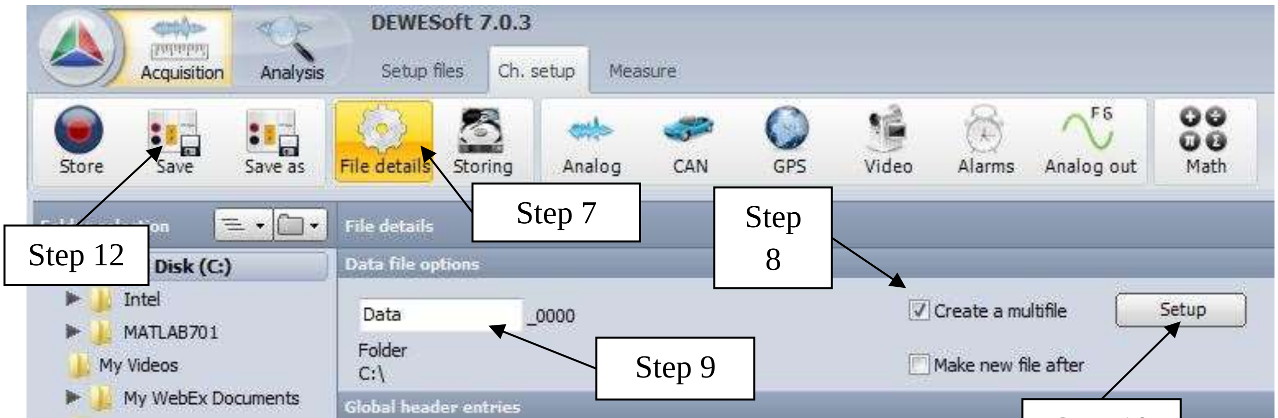


6. Select *Ch. Setup* at the top center of the screen.

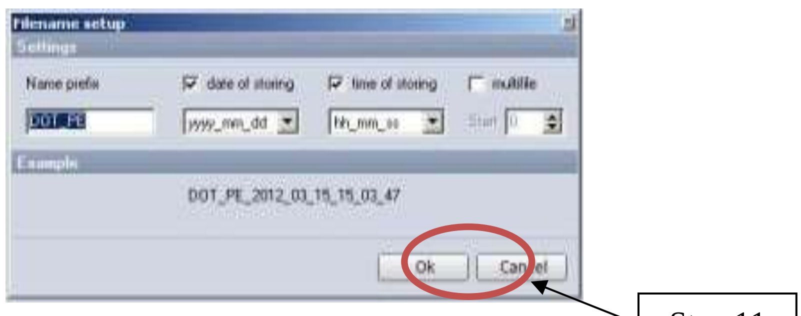




7. Select *File details* from icon ribbon.



8. In the center pane, check the box *Create a multifile.*
9. In the dialog box title the file name prefix.
10. Select the *Setup* button to open *Filename setup* window.



11. Add the desired suffix options, and press *OK* to return to the *Ch. Setup.*
12. Press *Save* from the icon ribbon to save changes.

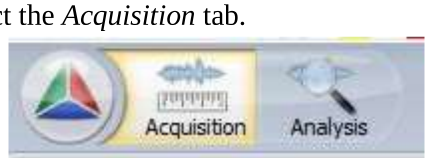
How to enter the DEWEsoft registration information

DEWESoft can be downloaded multiple times and installed on as many computers as necessary, all using the same license key. The trial version that is free to download off the internet can be upgraded by simply entering the provided license.

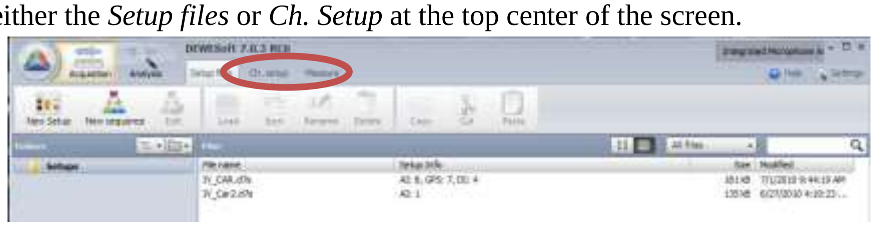
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

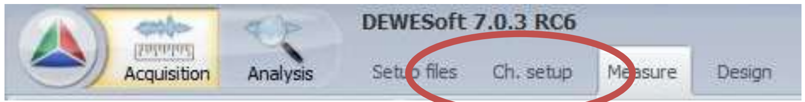
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



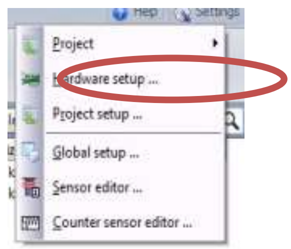
6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.



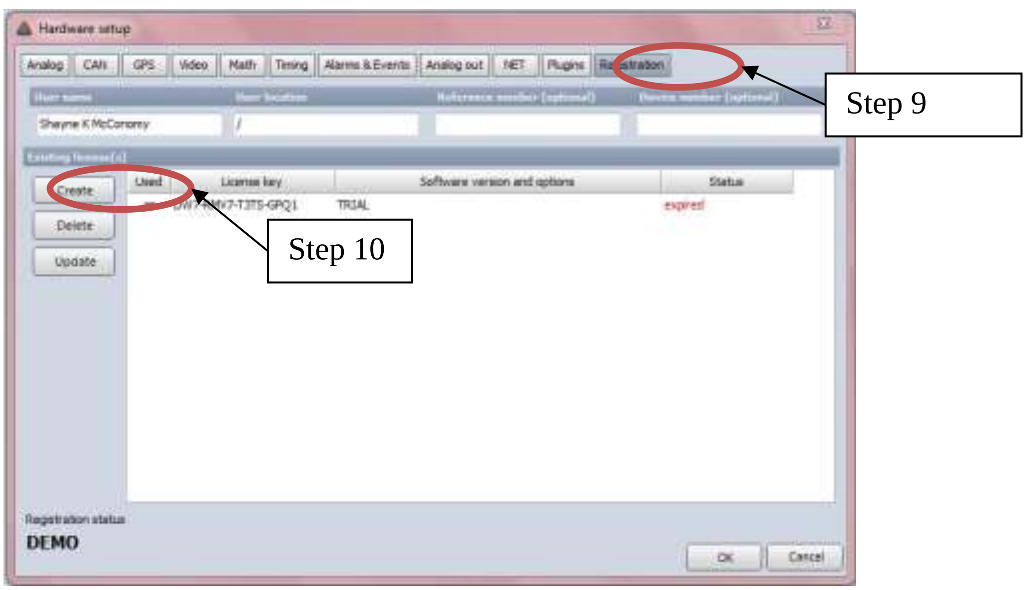


7. Select the *Settings* button in the top right hand corner of the screen.

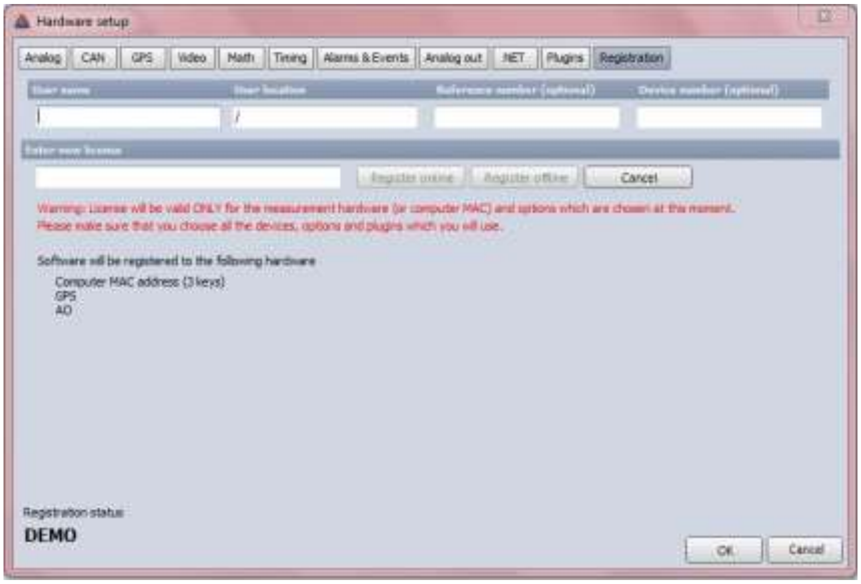
8. From the drop down menu, select *Hardware setup*.



9. In the *Hardware setup* window, select the *Registration* tab.



10. In the lower section of the window under *Existing license(s)*, press the *Create* button.
11. Enter **DW7-UXAR-F3DF-4WL6.**



12. Press the *Register online* button.
13. Press *OK* to exit.

How to access the GPS interface

To change the NEMA files, the setup must be done with in the Ag 432. A crossover cable, a computer, and a monitor will also be needed. There is a blue crossover cable in the cable bag inside the Avalon.

1. Turn on the system.
2. Find the button to open the trunk.
3. Press the button to open the trunk.
4. Find the location of the trunk.
5. Walk to the trunk.
6. Lift the deck lid to a fully open position.
7. Find the Ag-432 GPS unit.

8. There is a 37 pin adapter on the back side of the AG-432.

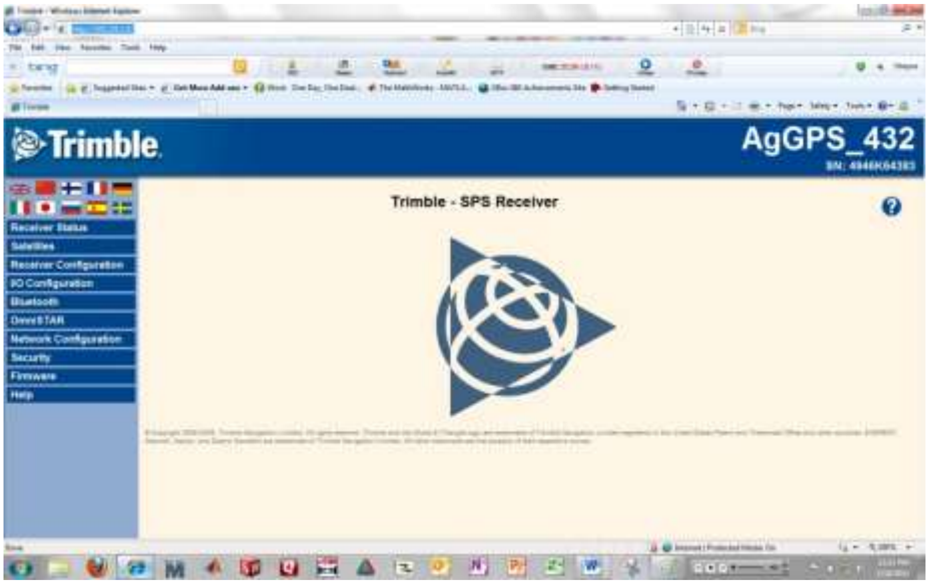
9. On the adapter there is an Ethernet plug which the crossover cable will fit into.
10. The other end of the crossover cable should plug into the computer's Ethernet plug.
11. On the computer open Internet Explorer.
12. There is down arrow on the right side of the face of the Ag-432. Press the down arrow until the I.P. address is displayed (Typically 169.254.1.0).

13. Type the Ag-432's I.P. address into the address bar in Internet Explorer on the computer.
14. The Ag-432 will then prompt for a user name and password.

15. User Name: **admin**

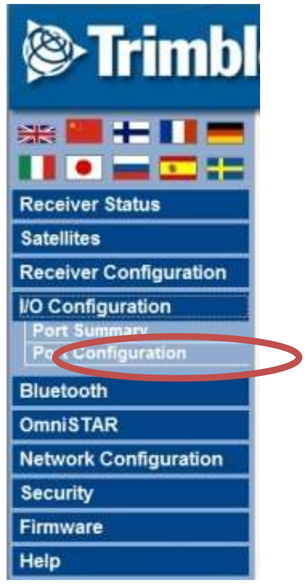
16. Password: **Clemson**

17. You should see the below configuration page.

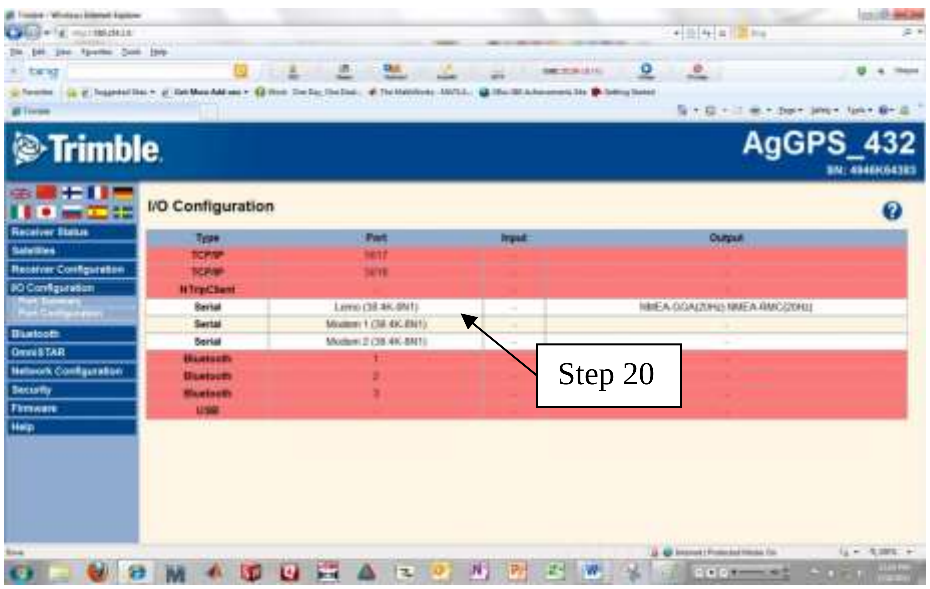


18. In the left side bar, select the I/O Configuration.

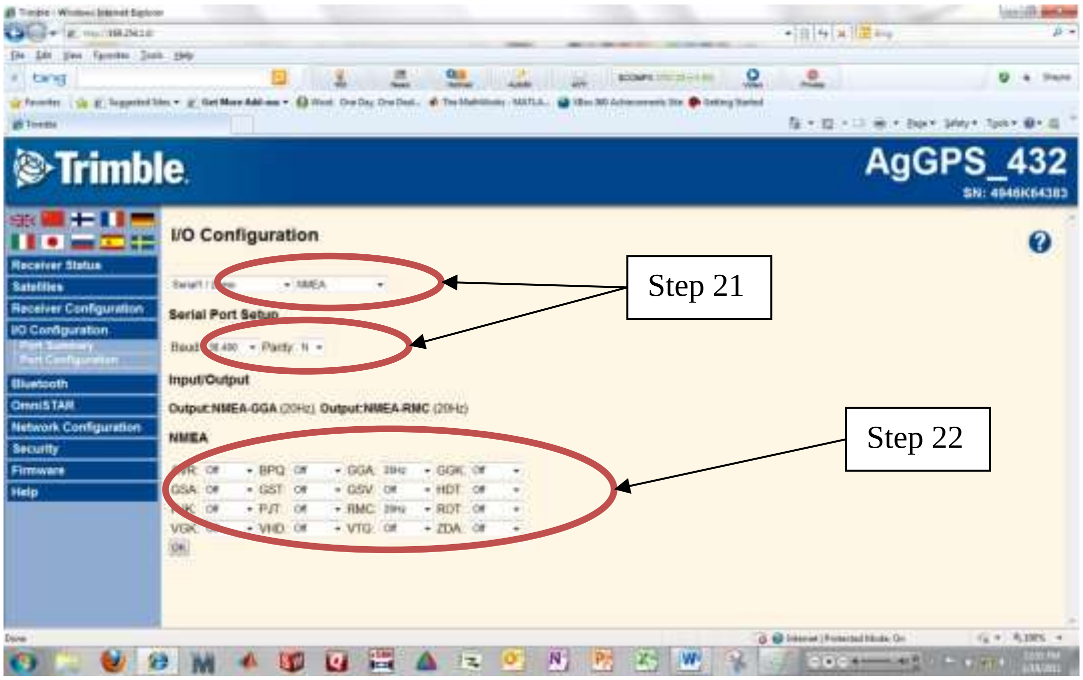
19. In the left side bar, select Port Configuration.



20. Under I/O Configuration, select the serial1/Lemo connections and NMEA data.



21. Under the Serial Port Setup, set the Baud to 38,400 with no parity.
22. Under the NMEA, turn on the desired outputs and frequencies. GGA RMC and VTG at 20 Hz are used in this case.


Trimble
AgGPS_432
I/O Configuration
Receiver Status
Satellites
Receiver Configuration
I/O Configuration
Bluetooth
OmniSTAR
Network Configuration
Security
Firmware
Help
Serial Port Setup
Input/Output
Output:NMEA-GGA (20Hz) Output:NMEA-RMC (20Hz)
NMEA
Step 21
Step 22

DEWEsoft Setup information

The following sections chronicle the various setup screens of the DEWEsoft system. Each setup is documented illustrating how the final screen should appear. If there was no change to the screen, that information will be noted below the screenshot.

Global Setup

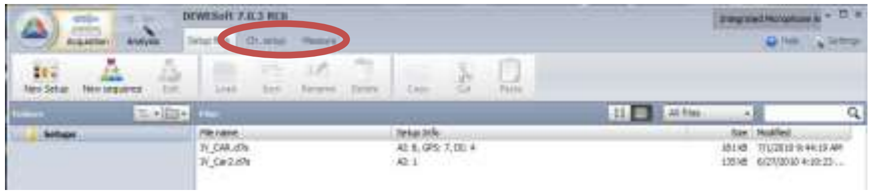
No Changes were made from the factory settings for Global Setup; however, below is a description on how to access the Global Setup menu and screen shots of the factory setting used.

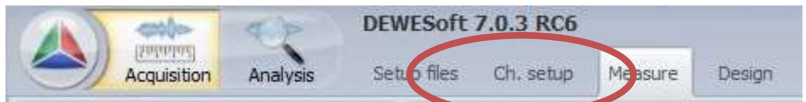
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

4. The system should load similar to below.

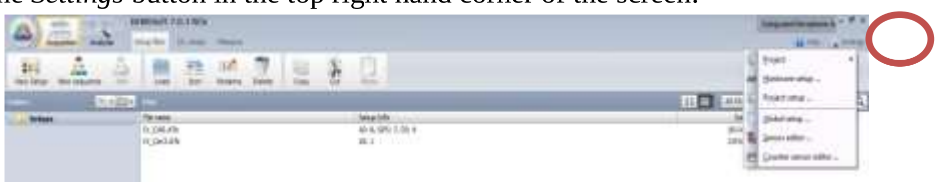
5. In the top left corner , select the *Acquisition* tab.

6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.

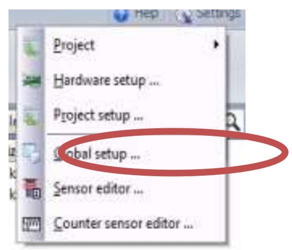




7. Select the *Settings* button in the top right hand corner of the screen.



8. From the drop down menu, select *Global setup*.



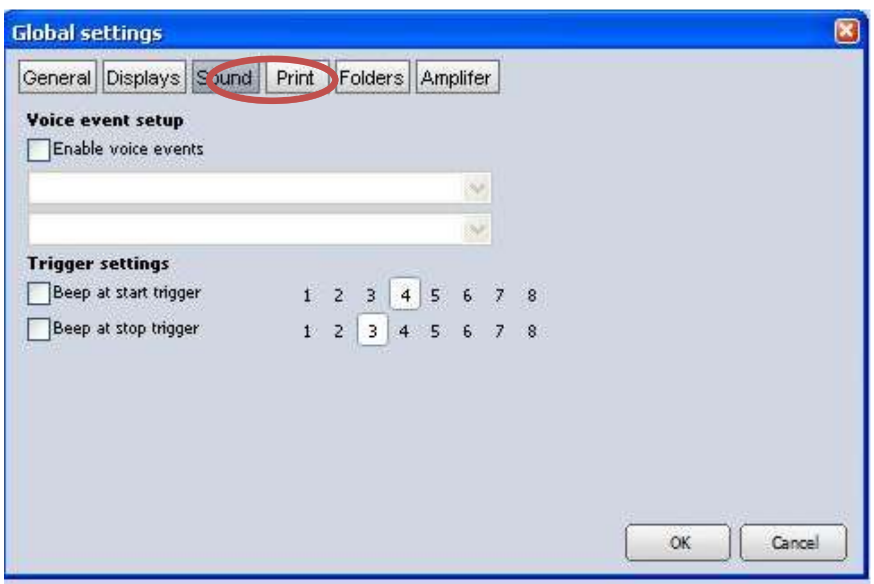
General

No Change

Displays

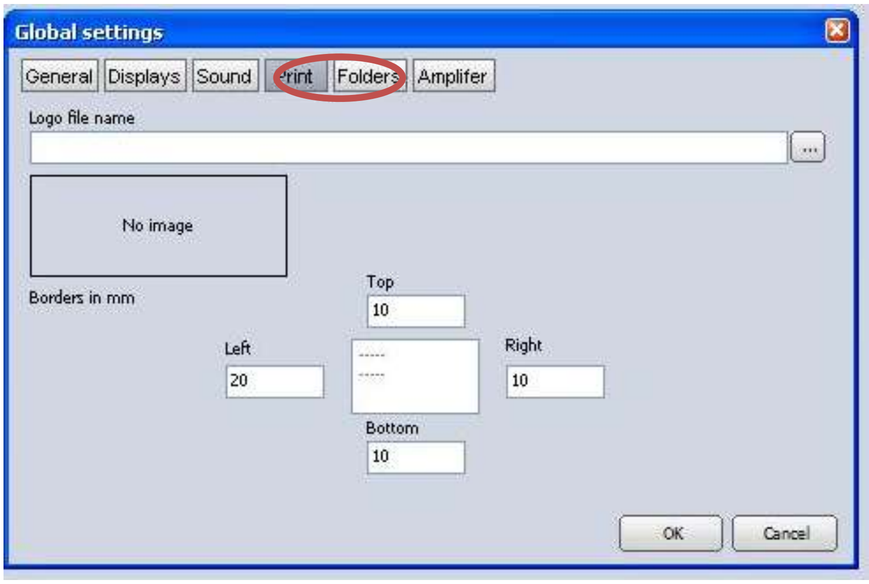
No Change

Sound



No Change

Print



No Change

Folders

No Change

Amplifier

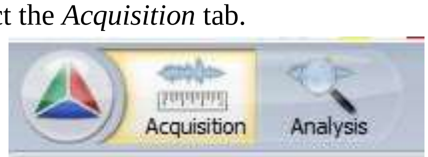
No Change

Hardware Setup

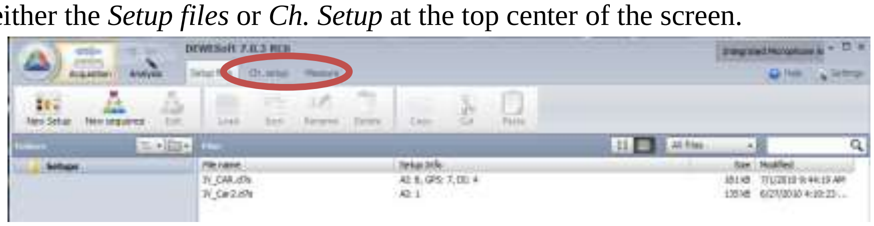
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

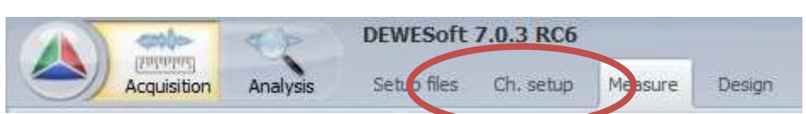
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



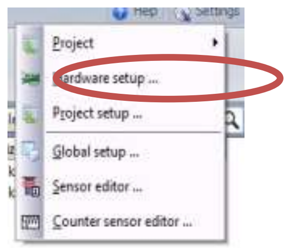
6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.





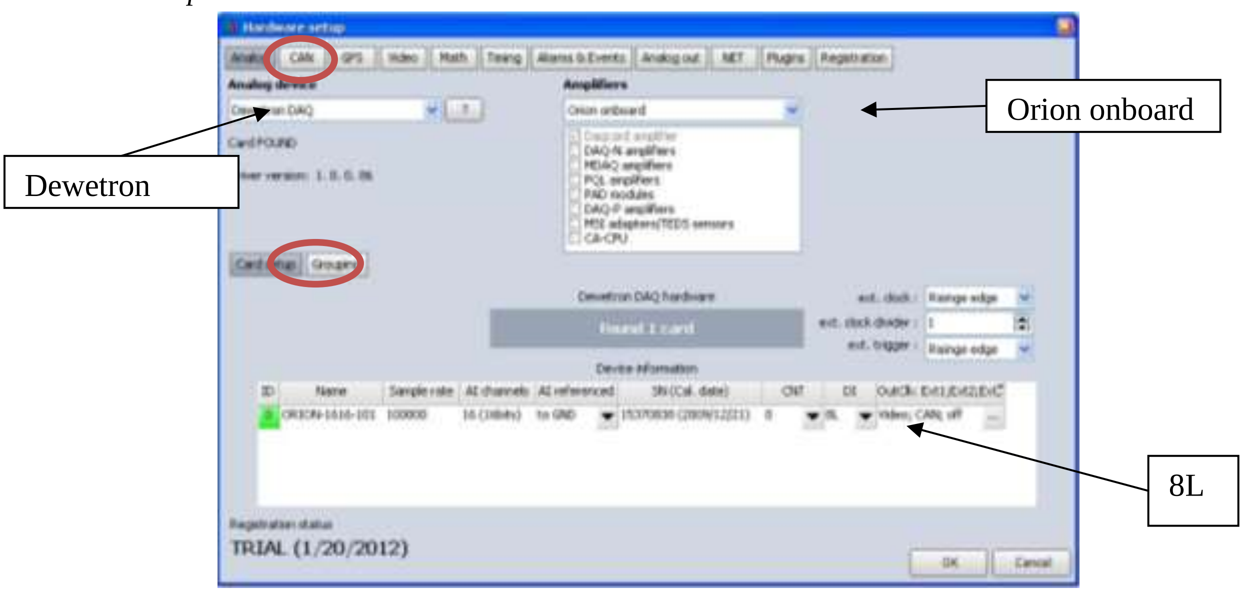
7. Select the *Settings* button in the top right hand corner of the screen.

8. From the drop down menu ,select *Hardware setup.*



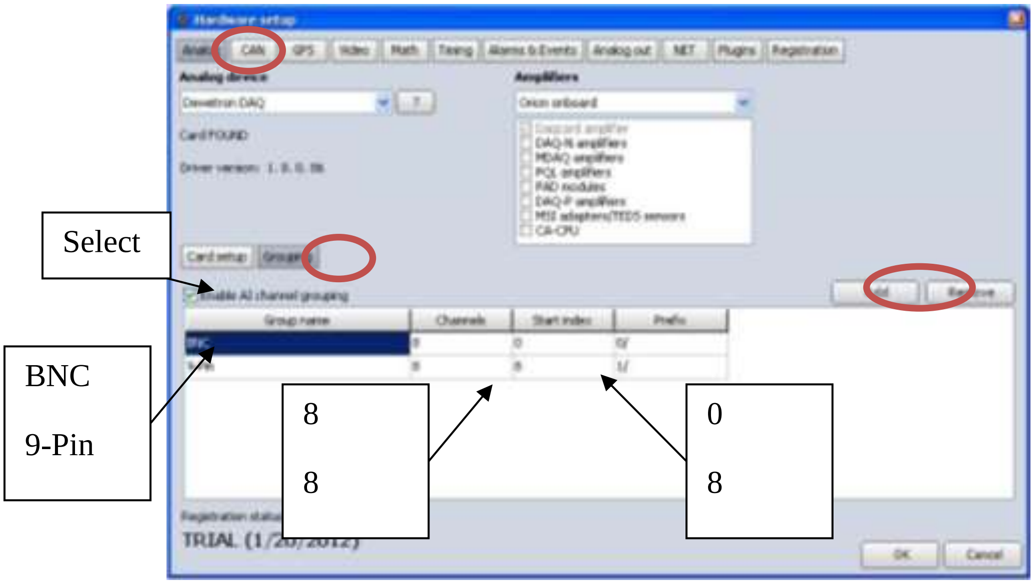
Analog

Card setup



1. Analog Device: *Dewetron DAQ*
2. Amplifiers: *Orion onboard*
3. Device information, DI: *8L*

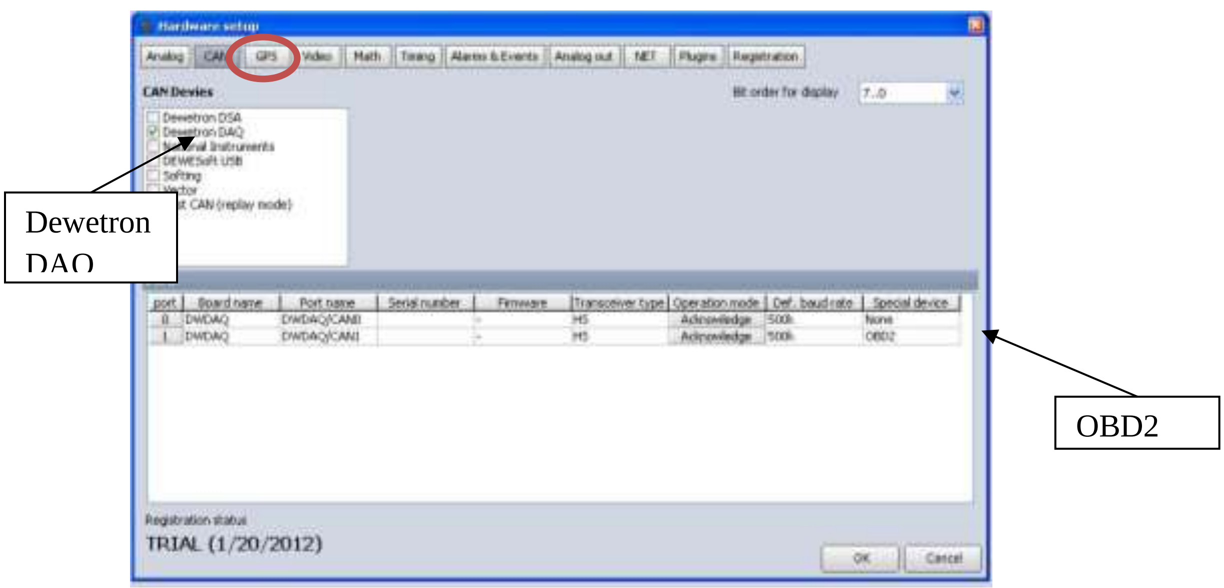
Grouping



1. Enable AI Channel Grouping: <u>*<check>*</u>

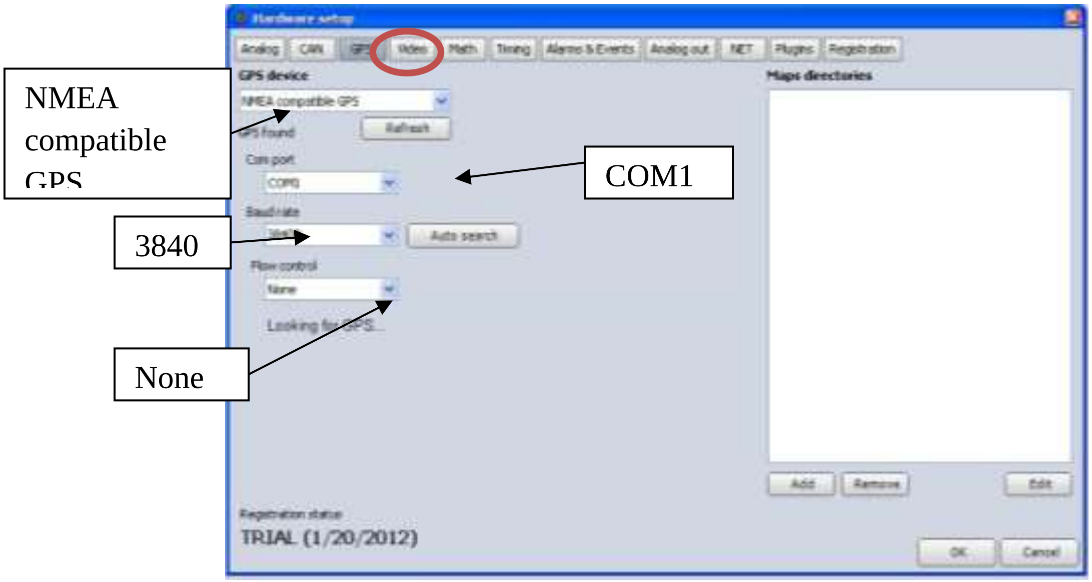
Group Name	Channels	Startindex	Prefix
BNC	8	0	0\
9-Pin	8	8	1\

CAN



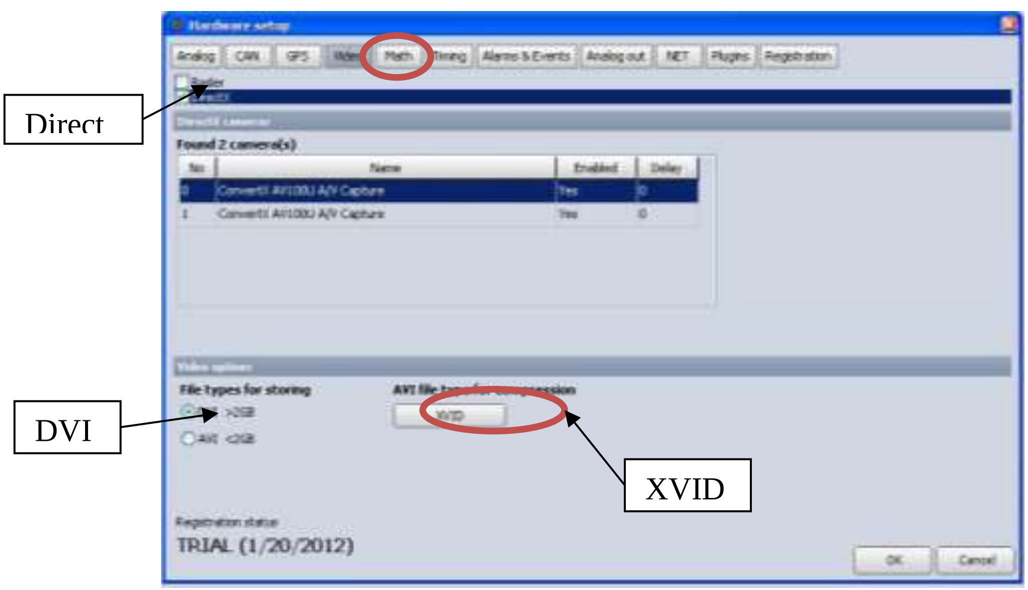
1. CAN Device: <u>Dewetron DAQ</u>
2. Special device: <u>OBD2</u>

GPS



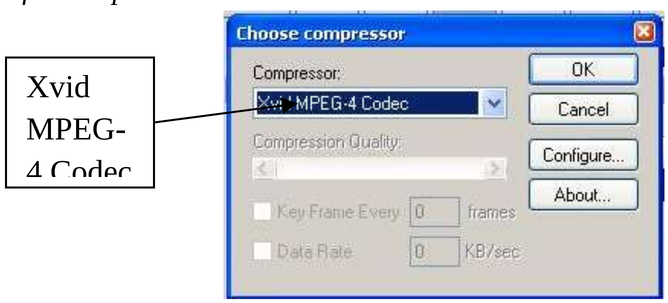
1. GPS device: NMEA compatible GPS
2. Com port: Com1
3. Baud rate: 38400
4. Flow control: None

Video



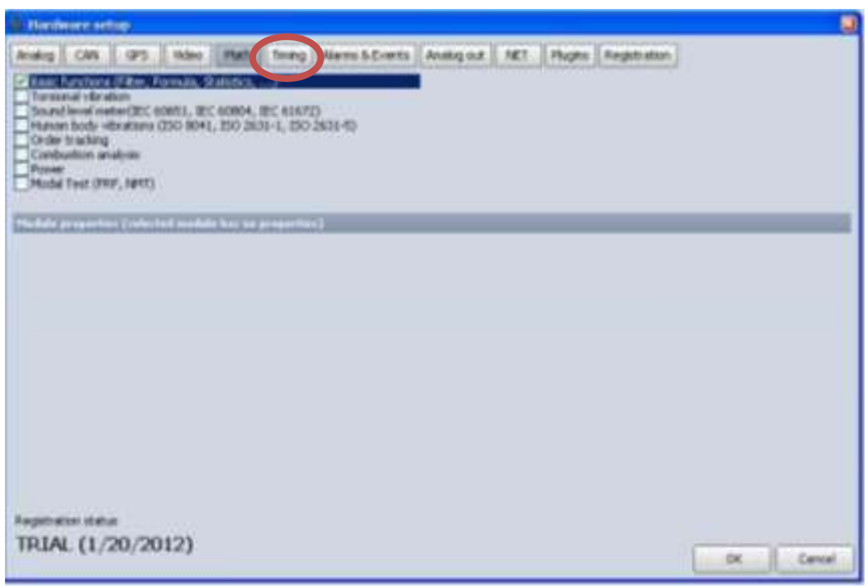
1. DirectX
2. File types for storing: DVI > 2GB
3. AVI file type for compression: XVID

AVI file type for compression



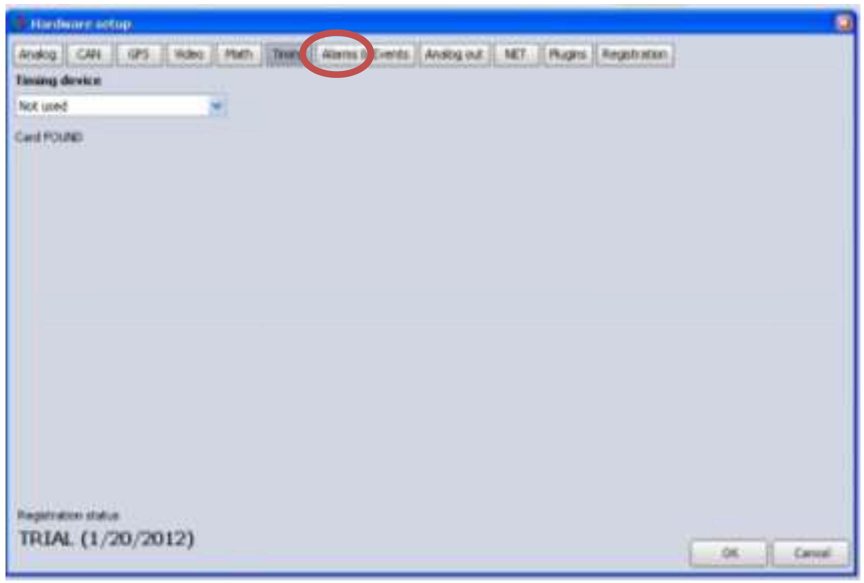
1. Compressor: Xvid MPEG 0 4 Codec

Math



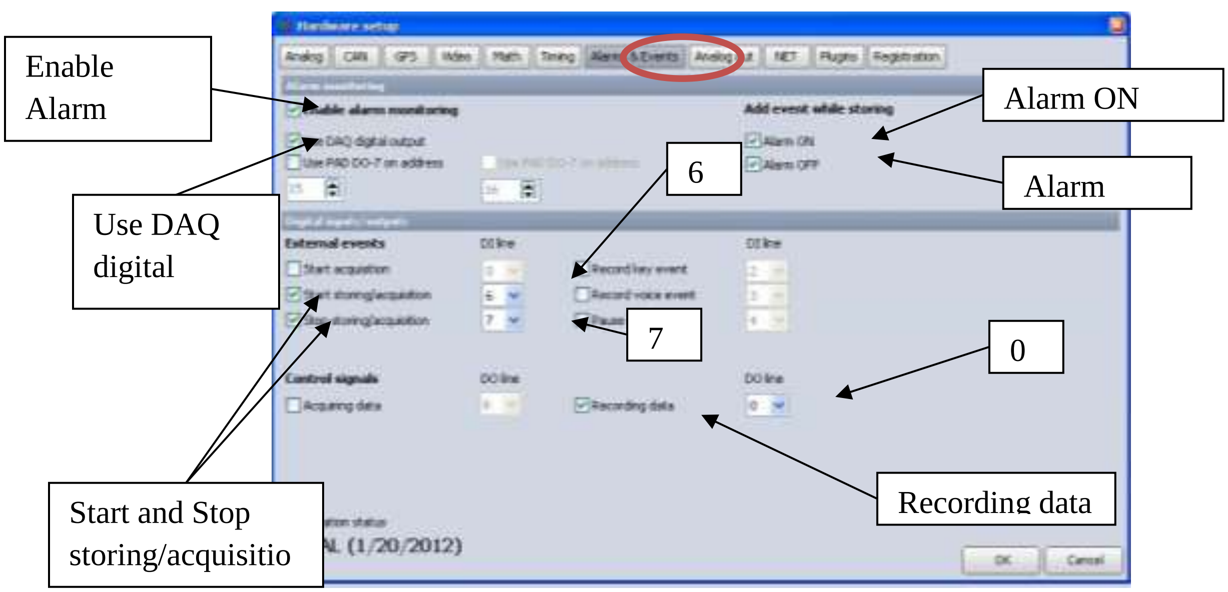
Factory settings are used for the *Math* tab.

Timing



Factory settings are used for the *Timing* tab.

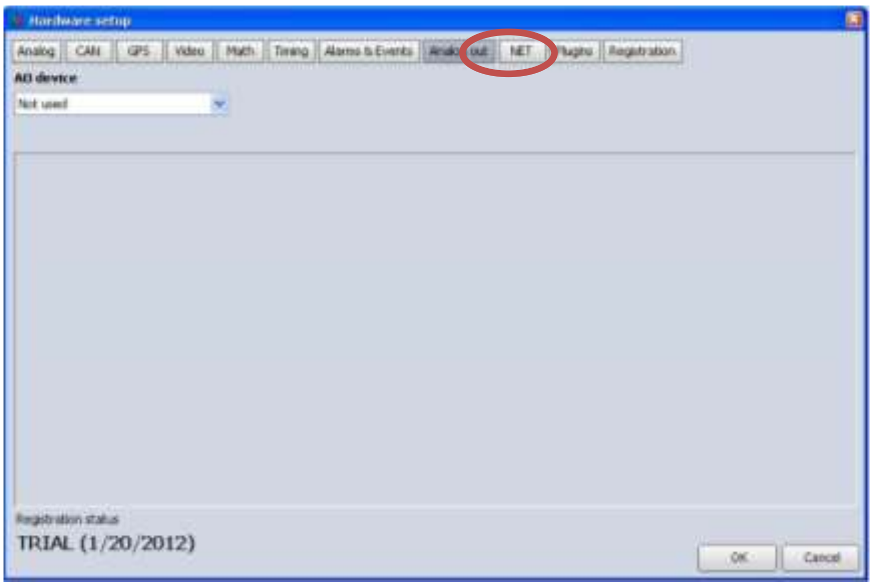
Alarms & Events



1. Enable the use of Alarms: <u>*<check>*</u>
2. Enable the use of digital outputs: <u>*<check>*</u>
3. Add event while storing
    a. Alarm ON: <u>*<check>*</u>
    b. Alarm OFF: <u>*<check>*</u>
4. External Events

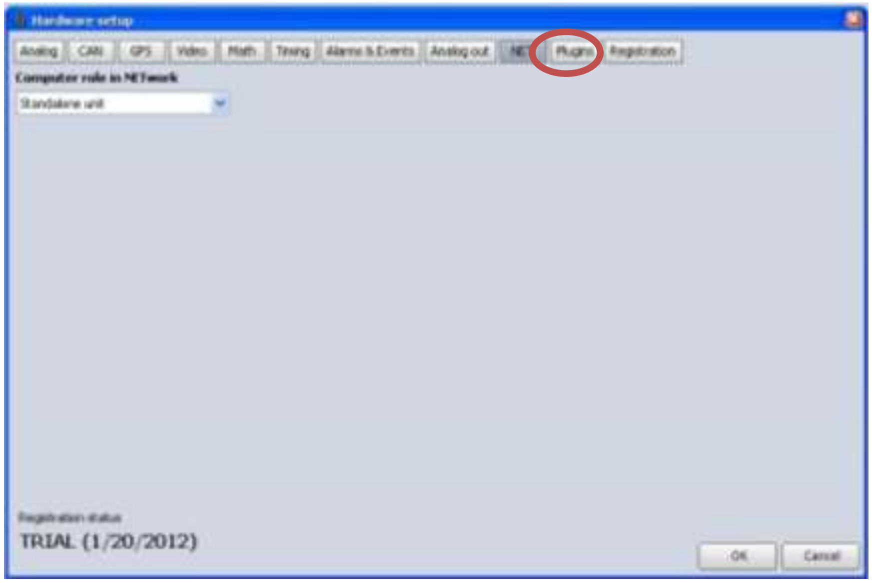
    a. Start storing/acquisition: *<check>*
    b. Stop storing/acquisition: *<check>*
5. DI Line
    a. 6
    b. 7
6. Recording data: *<check>*
7. DO line: *0*

Analog out



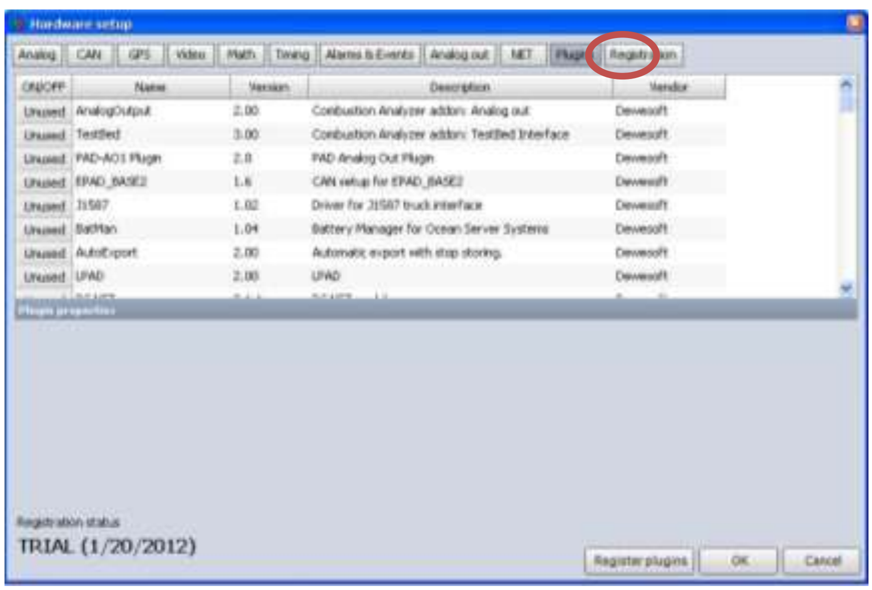
Factory settings are used for the *Analog out* tab.

NET



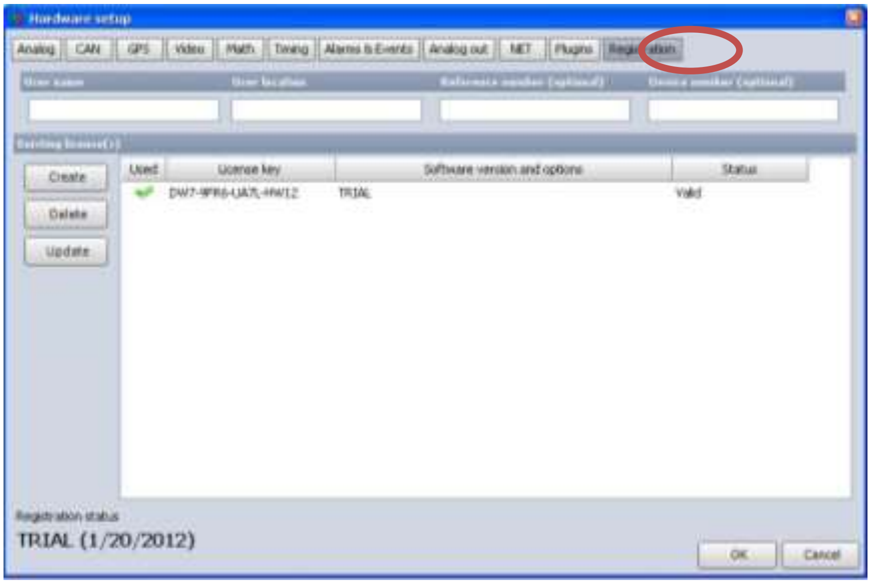
Factory settings are used for the *NET* tab.

Plugins



Factory settings are used for the *Plugins* tab.

Registration



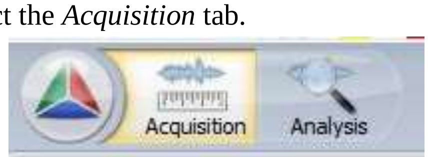
See the section above, "How to enter the DEWEsoft registration information".

Project setup

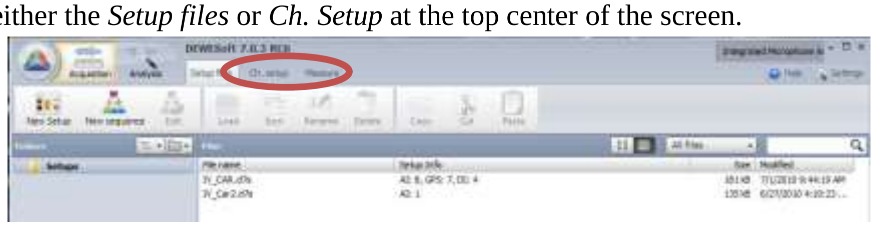
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

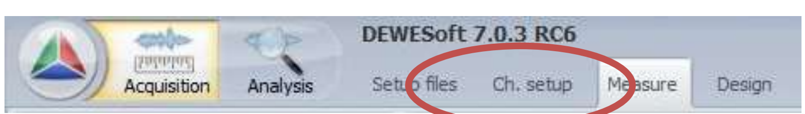
4. The system should load similar to below.

5. In the top left corner, select the *Acquisition* tab.



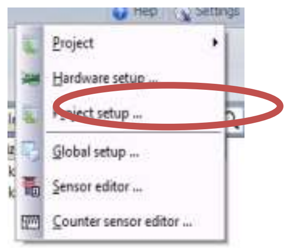
6. Select either the *Setup files* or *Ch. Setup* at the top center of the screen.





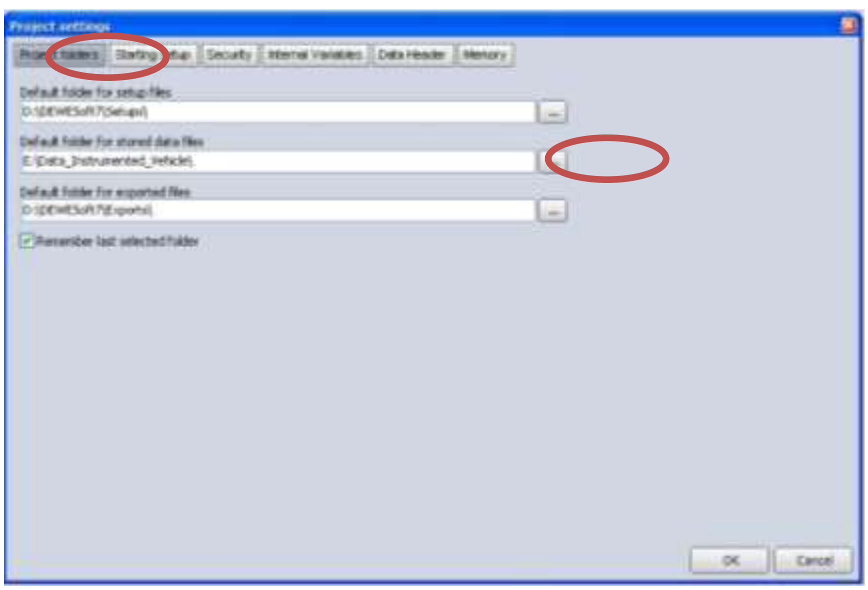
7. Select the *Settings* button in the top right hand corner of the screen.

8. From the drop down menu, select *Project setup.*



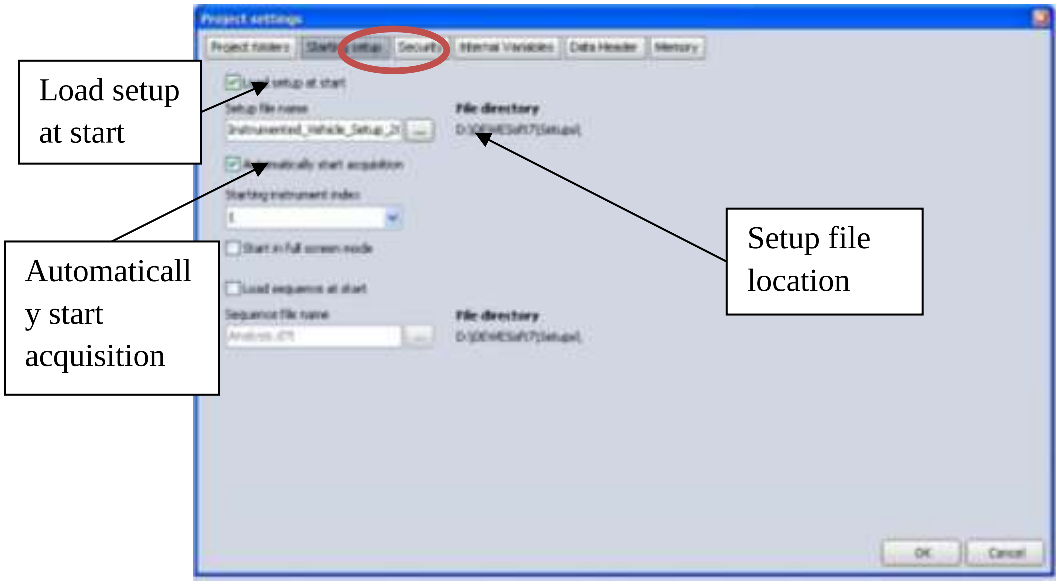
Project folders

The setup file and exported file location remains factory default; however, the data file location is changed to an external hard drive. This is necessary in order to capture the video data. If no video data are being captured, the factory settings could probably be used. See the section "How to restore the file location of the recorded data" for more details.



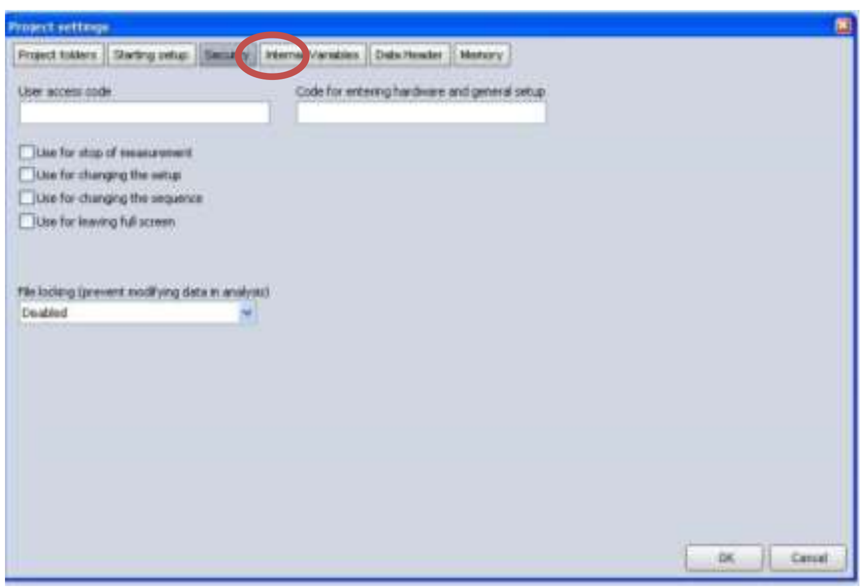
Starting setup

The Dewetron and DEWEsoft are setup so that there is minimal user interface. Therefore, in the *Starting setup* setting the *automatically start acquisition* box is checked as well as the *load setup at start* is checked.



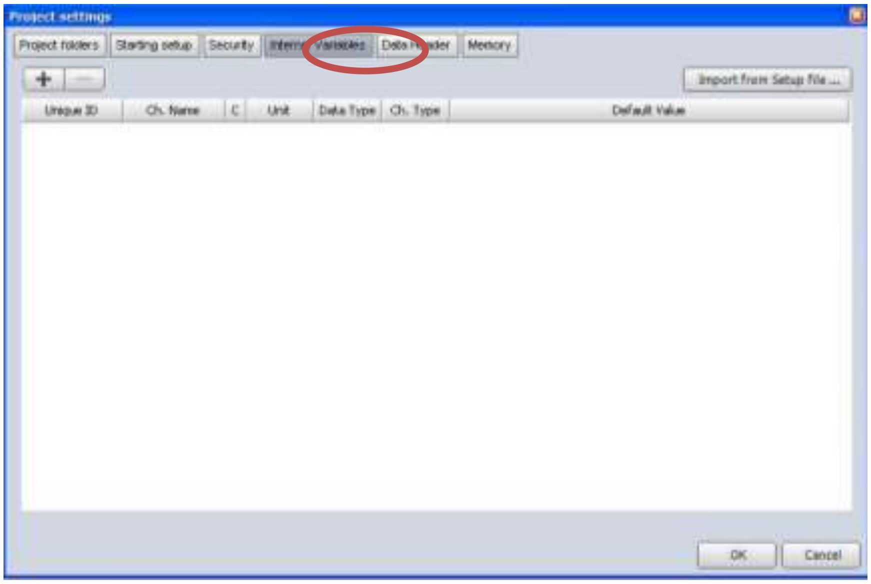
1. Load setup at start: *<checked>*
2. Setup file name: *<file name>*
3. Automatically start acquisition: *<checked>*

Security



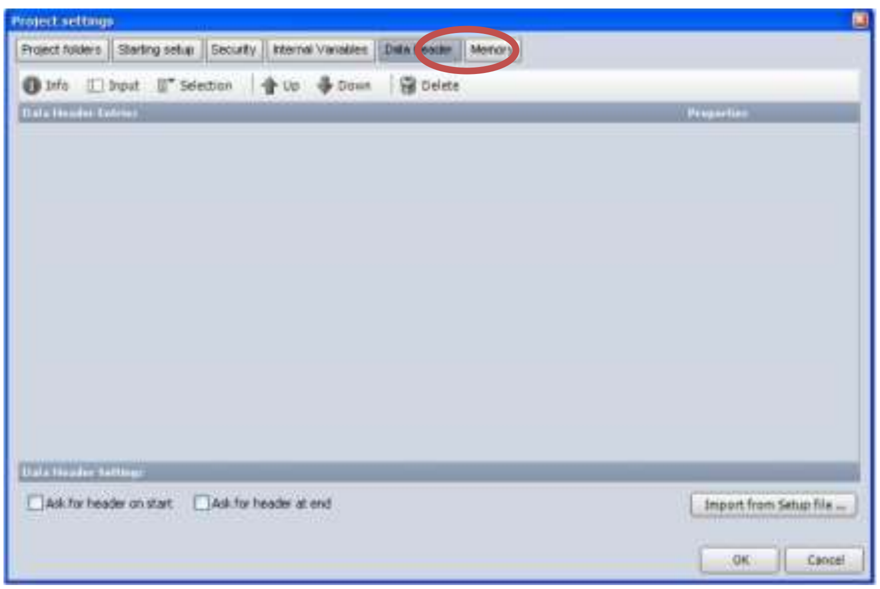
Factory settings are used for the *Security* tab.

Internal Variables



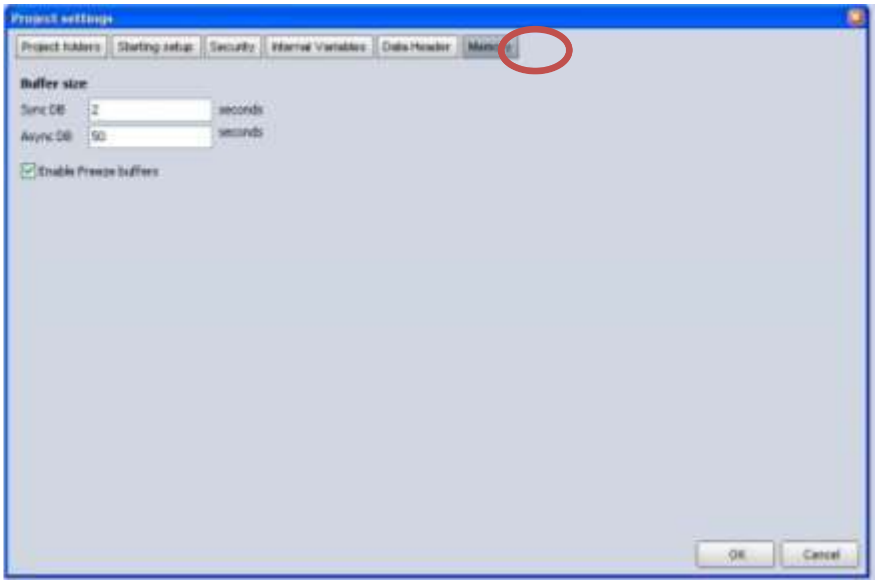
Factory settings are used for *Internal Variables* tab.

Data Header



Factory settings are used for *Data Header* tab.

Memory



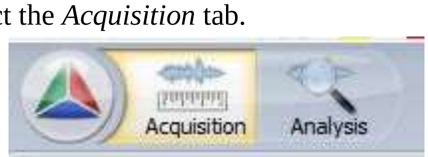
Factory settings are used for *Memory* tab.

Channel setup

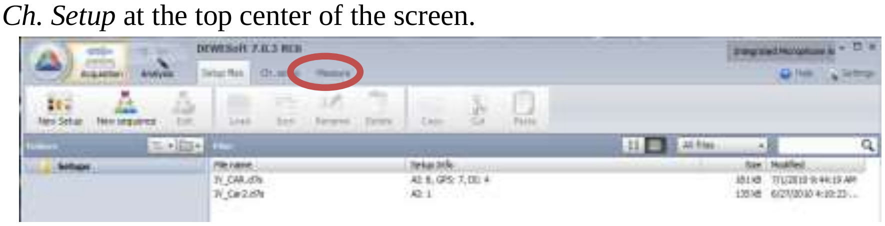
1. Turn on the system.
2. Locate the monitor and mouse connected to the Dewetron; if one is not connected, then connect one at this time.
3. The DEWESoft software should have started automatically; if it did not, click the icon on the desktop.

4. The system should load similar to below.

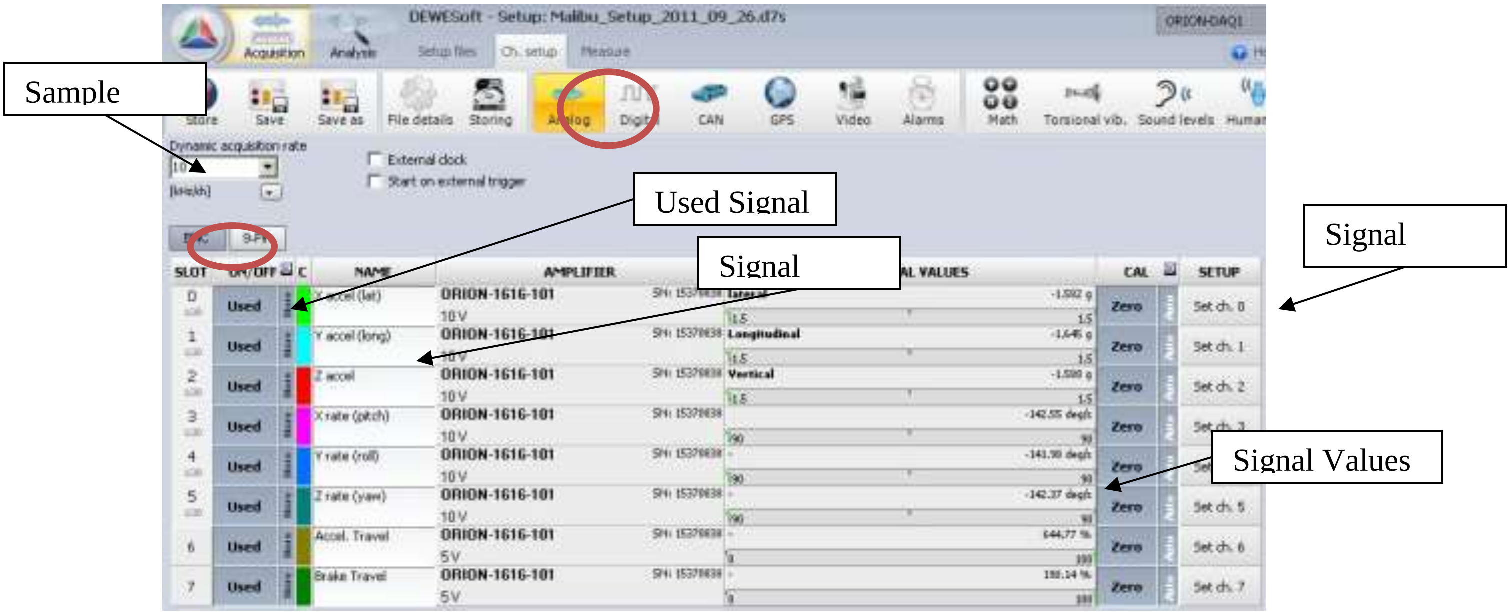
5. In the top left corner, select the *Acquisition* tab.



6. Select *Ch. Setup* at the top center of the screen.



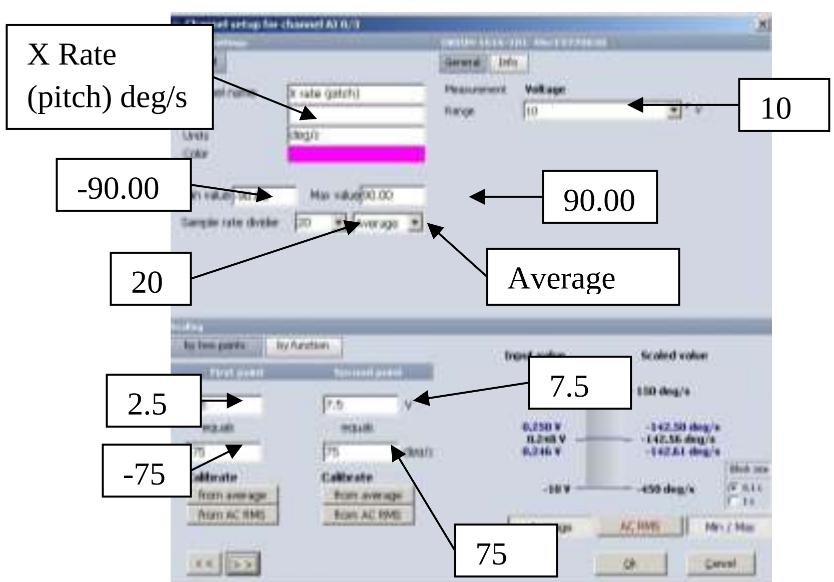
BNC Analog



Press the signal setup button to access the specifics of the signal and to calibrate the sensor.

Inertia Sensor

X rate



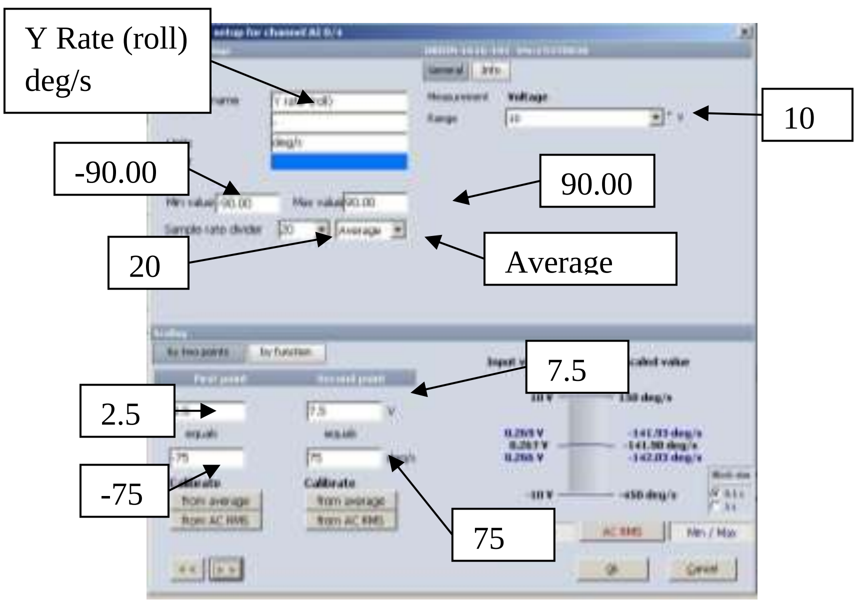
Channel Settings

1. Channel Name: X Rate (pitch)
2. Units: deg/s
3. Voltage: 10 V
4. Min Value : -90
5. Max Value: 90
6. Sample rate divider: 20 average

Scaling

First Point	Second Point
2.5	7.5
-75	75

Y rate



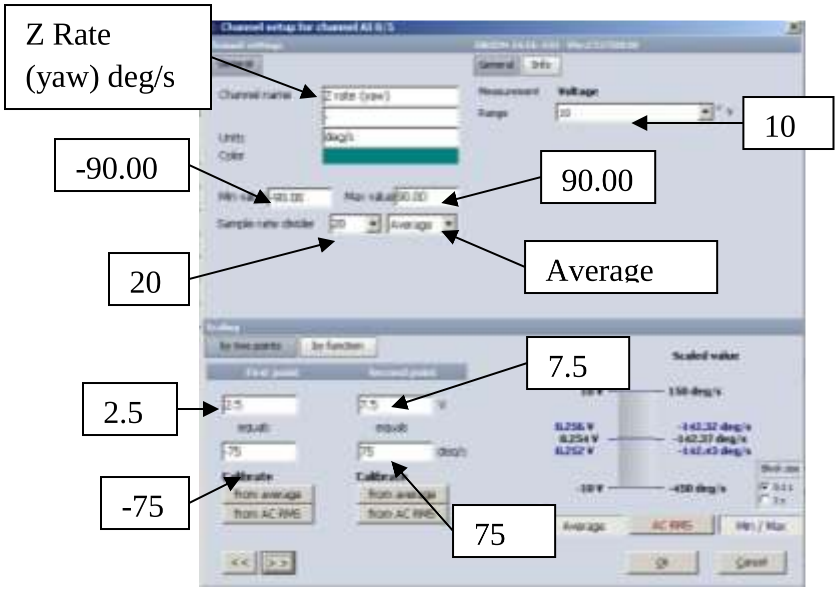
Channel Settings

7. Channel Name: Y Rate (roll)
8. Units: deg/s
9. Voltage: 10 V
10. Min Value : -90
11. Max Value: 90
12. Sample rate divider: 20 average

Scaling

First Point	Second Point
2.5	7.5
-75	75

Z Rate



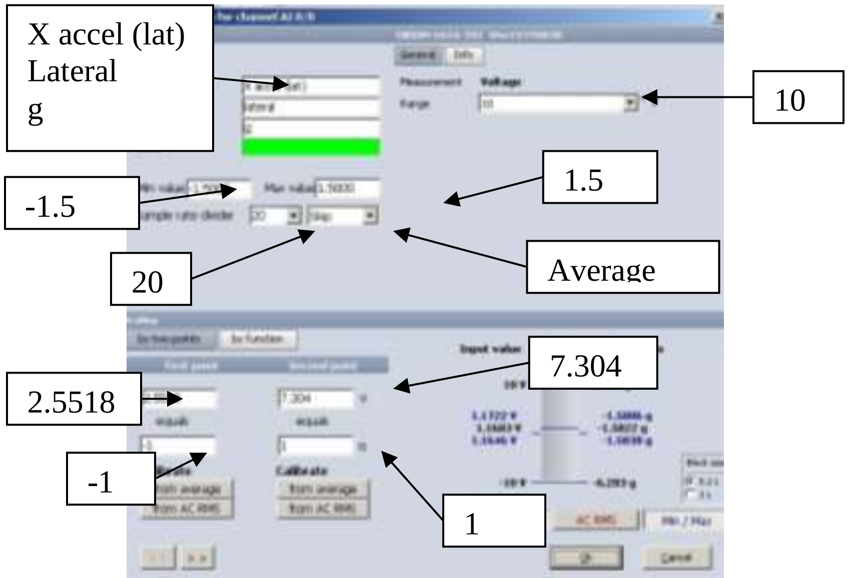
Channel Settings

13. Channel Name: Z Rate (yaw)
14. Units: deg/s
15. Voltage: 10 V
16. Min Value : -90
17. Max Value: 90
18. Sample rate divider: 20 average

Scaling

First Point	Second Point
2.5	7.5
-75	75

X acceleration



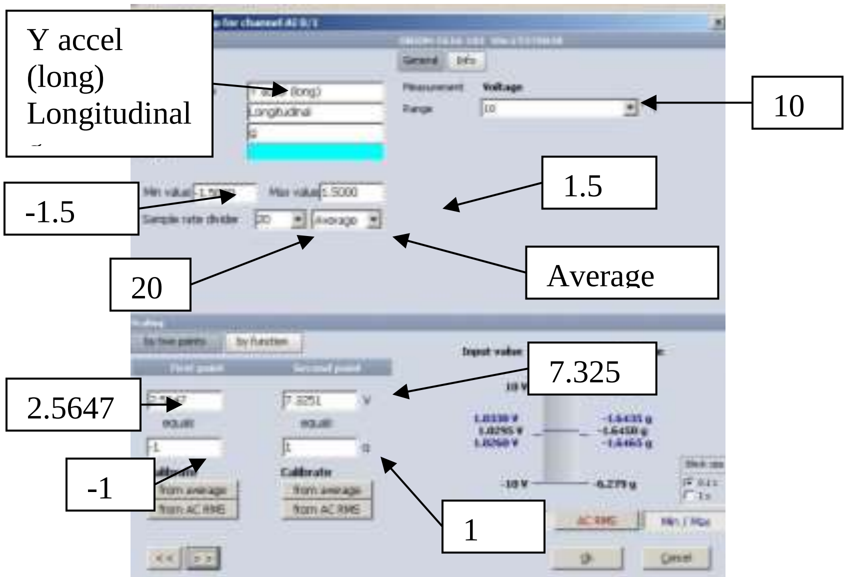
Channel Settings

1. Channel Name: X accel (lat)
2. Units: g
3. Voltage: 10 V
4. Min Value : -90
5. Max Value: 90
6. Sample rate divider: 20 average

Scaling

First Point	Second Point
2.5518	7.304
-1	1

Y acceleration



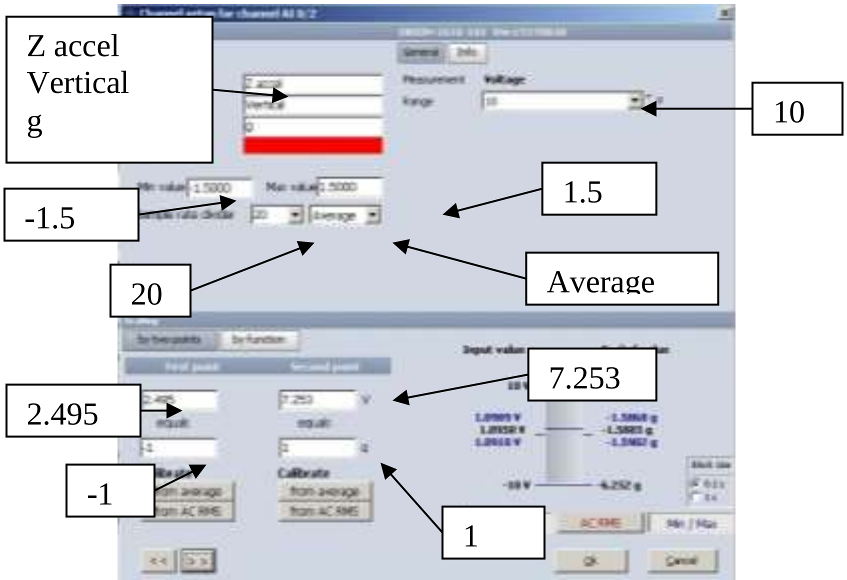
Channel Settings

1. Channel Name: Y accel (long)
2. Units: g
3. Voltage: 10 V
4. Min Value : -1.5
5. Max Value: 1.5
6. Sample rate divider: 20 average

Scaling

First Point	Second Point
2.5647	7.3251
-1	1

Z acceleration



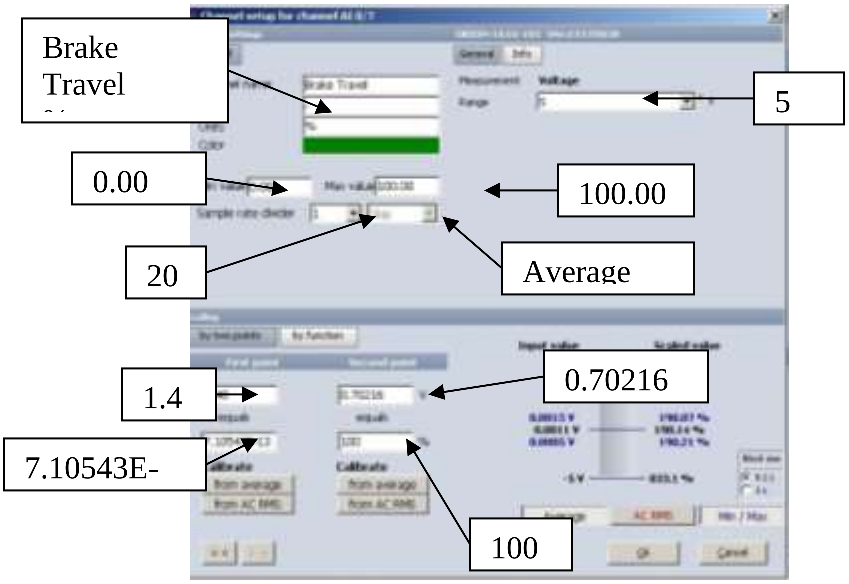
Channel Settings

1. Channel Name: Z accel
2. Units: g
3. Voltage: 10 V
4. Min Value : -1.5
5. Max Value: 1.5
6. Sample rate divider: 20 average

Scaling

First Point	**Second Point**
2.495	7.253
-1	1

Brake Pedal Travel:



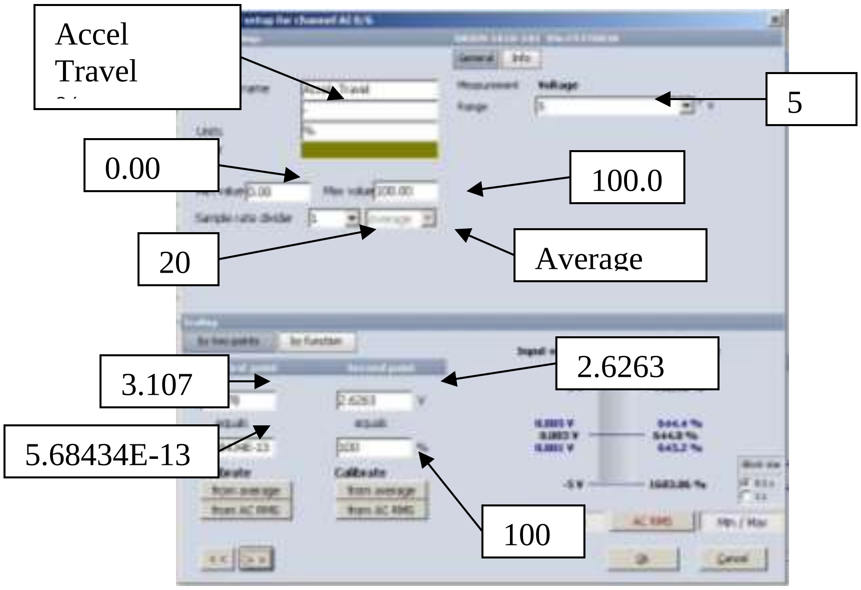
Channel Settings

1. Channel Name: Brake Travel
2. Units: %
3. Voltage: 5 V
4. Min Value : 0.00
5. Max Value: 100.00
6. Sample rate divider: 20 average

Scaling

First Point	Second Point
1.48	0.70216
7.10543E-13	100

Accelerator Pedal Travel



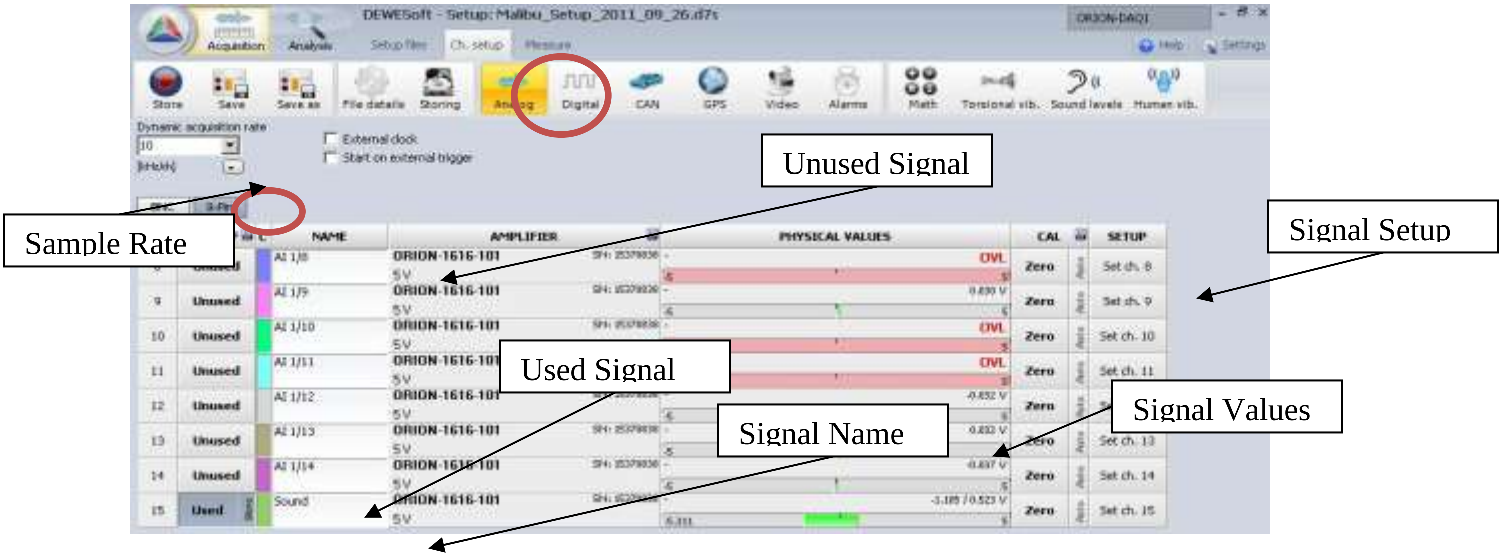
Channel Settings

1. Channel Name: <u>Accel Travel</u>
2. Units: <u>%</u>
3. Voltage: <u>5 V</u>
4. Min Value : <u>0.00</u>
5. Max Value: <u>100.00</u>
6. Sample rate divider: <u>20 average</u>

Scaling

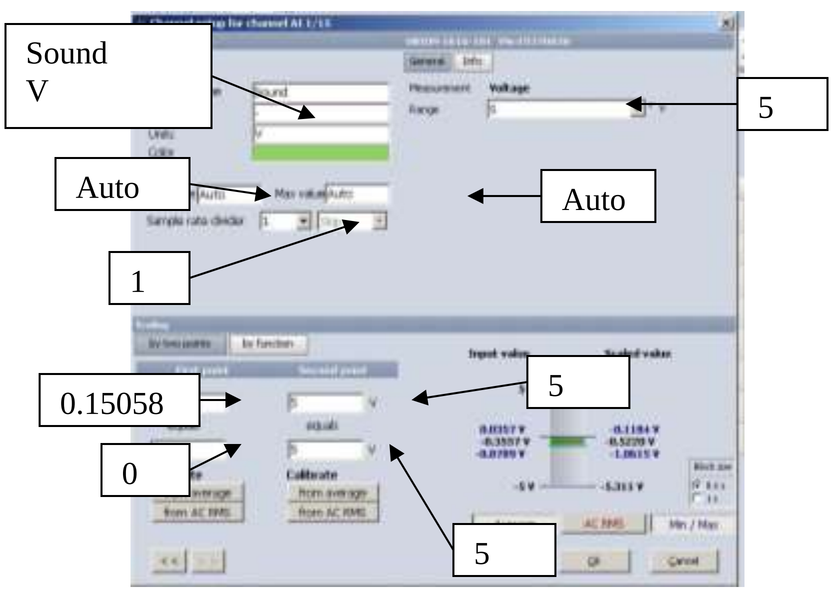
First Point	Second Point
3.1078	2.6263
5.68434E-13	100

9-Pin Analog



Press the signal setup button to access the specifics of the signal and to calibrate the sensor.

Microphone



Channel Settings

1. Channel Name: <u>Sound</u>
2. Units: <u>V</u>
3. Voltage: <u>10 V</u>
4. Min Value : <u>Auto</u>

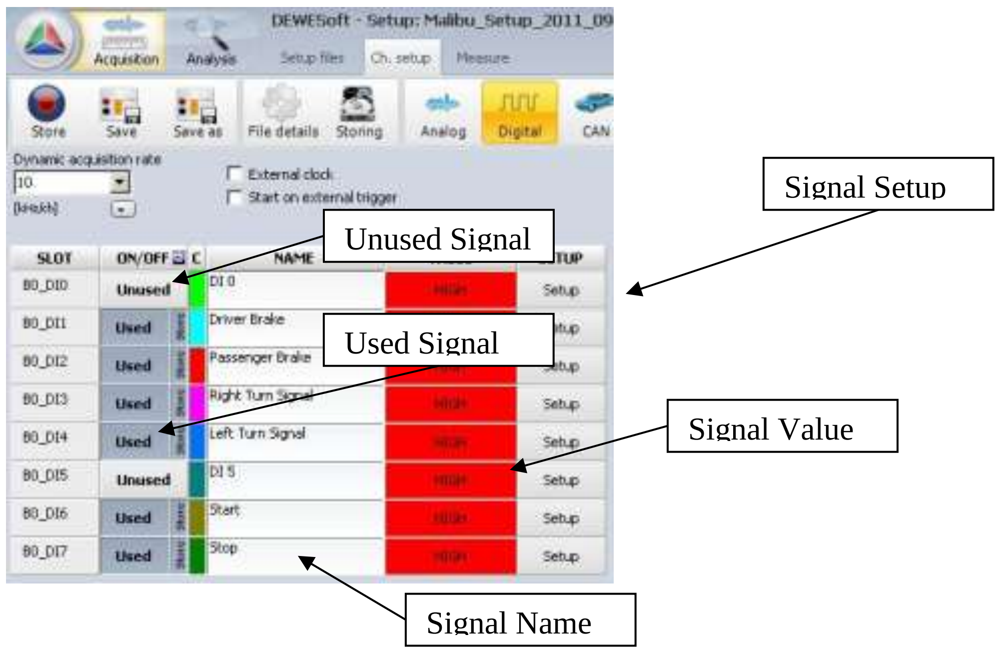
5. Max Value: Auto
6. Sample rate divider: 1

Scaling

First Point	Second Point
0.15058	5
0	5

Digital Input

This tab is not activated unless it is turned on under the Analog Hardware Setup *(see above)*

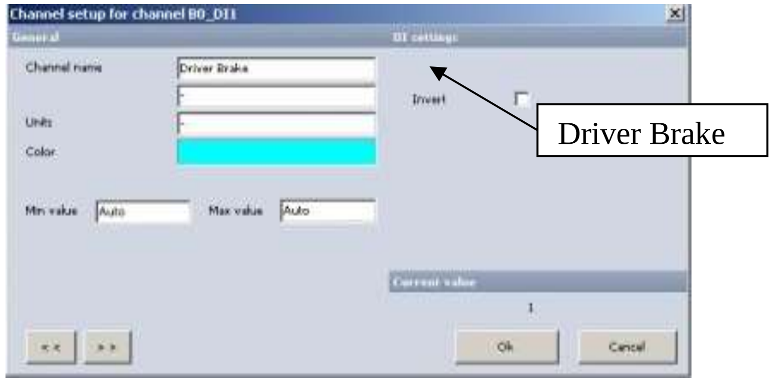


Press the signal setup button to access the specifics of the signal and to calibrate the sensor.

Digital Input Setup Dialog Box

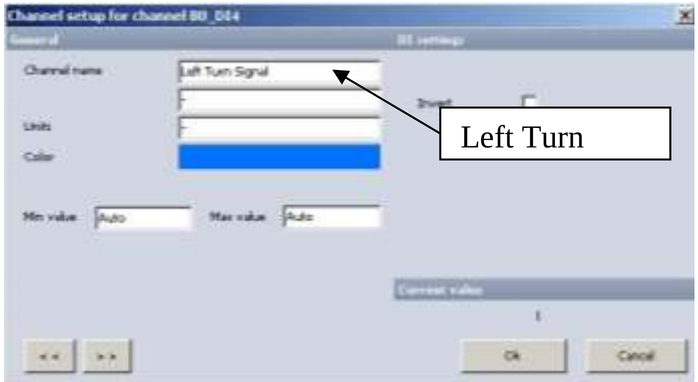
This is where the name, description, units are changed as needed.

Driver Brake



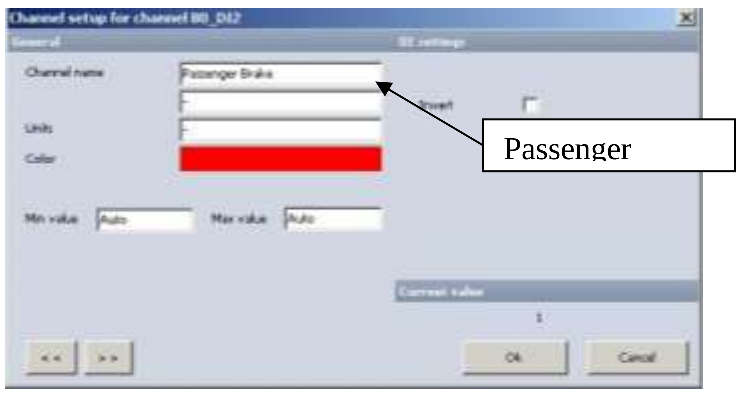
1. Channel name: Driver Brake

Left Turn Signal



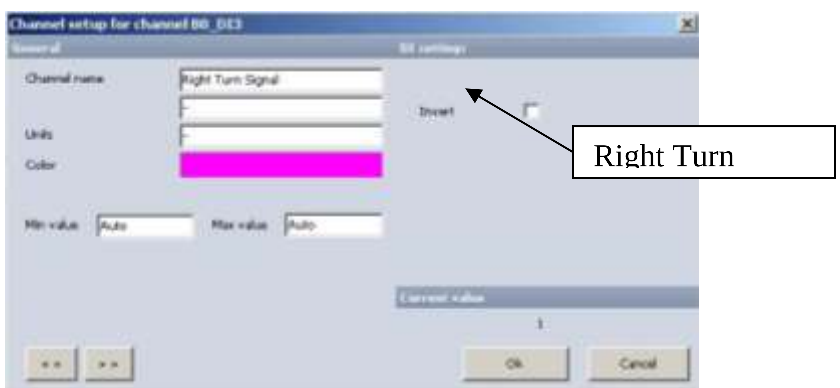
1. Channel name: <u>Left Turn Signal</u>

Passenger Brake



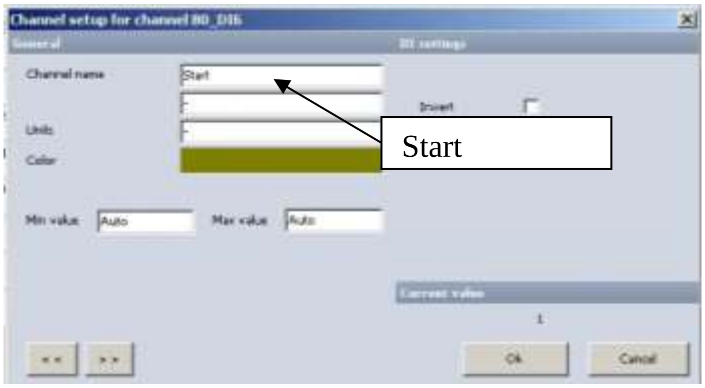
1. Channel name: <u>Passenger Brake</u>

Right Turn Signal



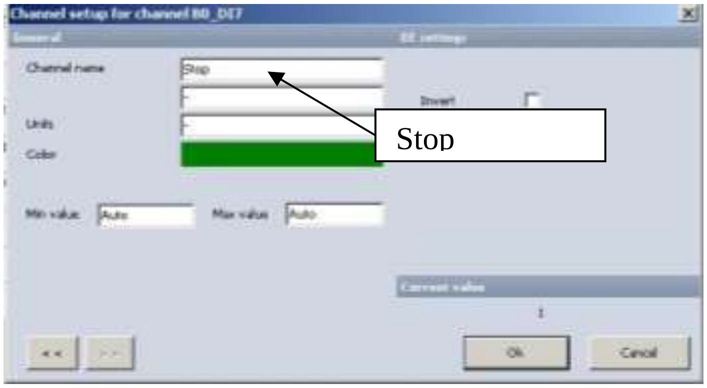
1. Channel name: <u>Right Turn Signal</u>

Start



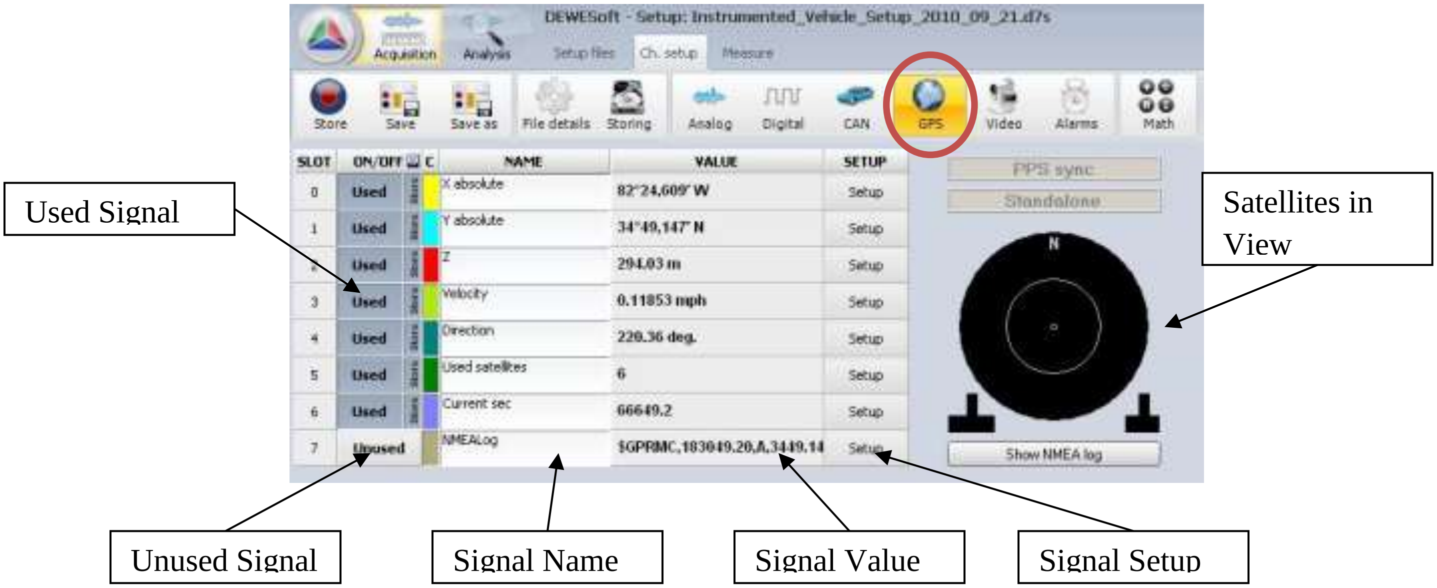
1. Channel name: Start

Stop



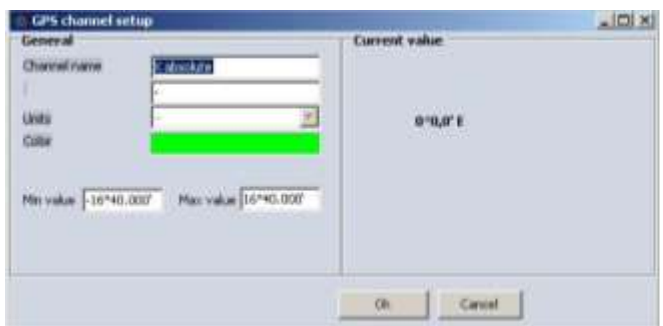
1. Channel name: Stop

GPS



Press the signal setup button to access the specifics of the signal and to calibrate the sensor.

X absolute

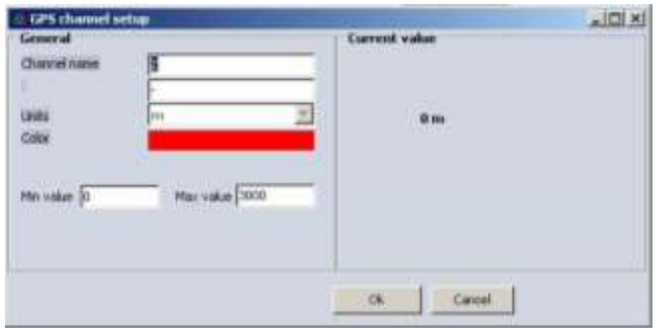


No change

Y absolute

No change

Z



No change

Velocity

No change

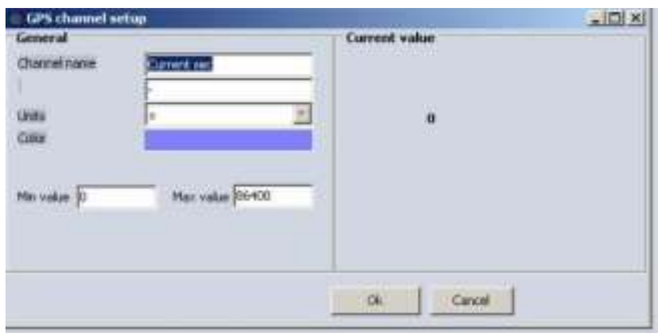
Direction

No change

Used Satellies

No change

Current sec

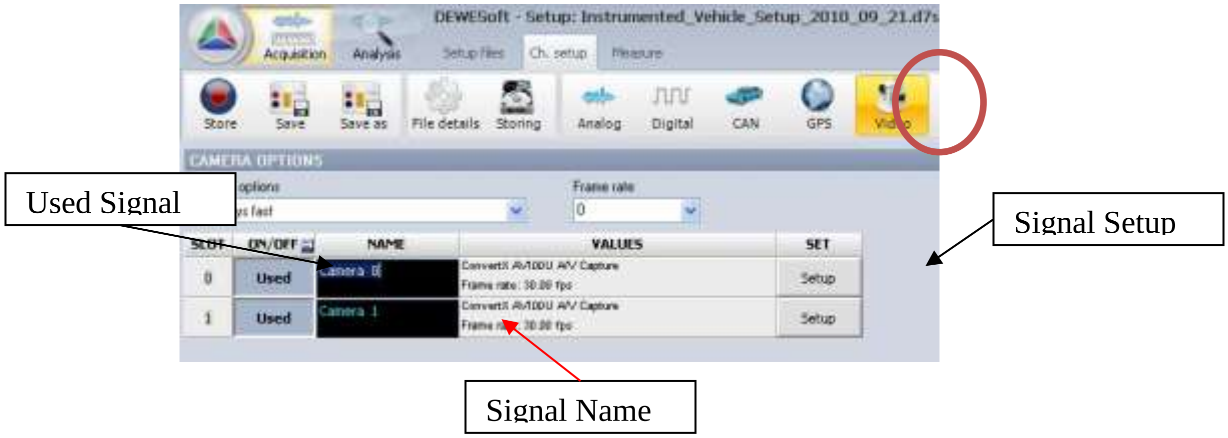


No change

NMEA log

No change

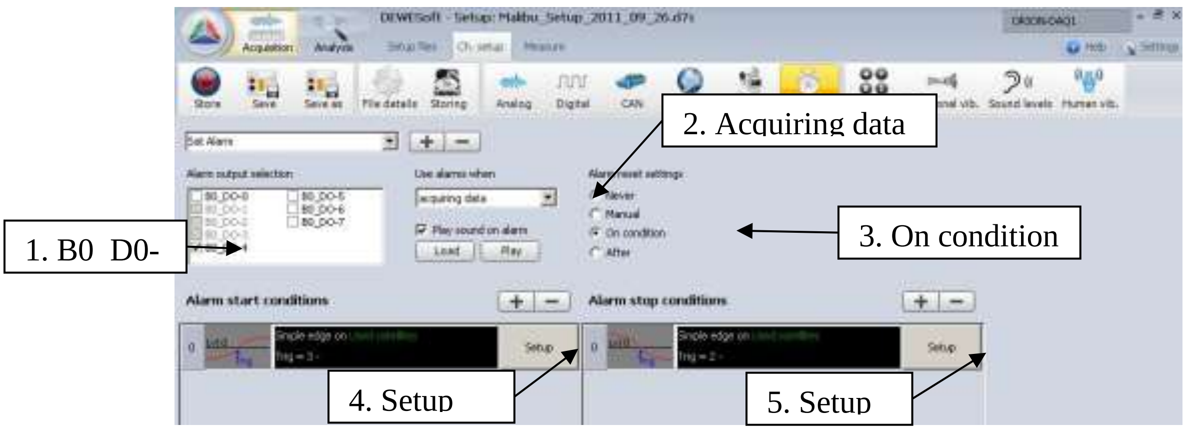
Video



Video data requires a lot of memory, and therefore, the resolution and frame rate have been reduced to the lowest acceptable values; if more memory is obtained, then these values could be increased for more clarity.

Alarms

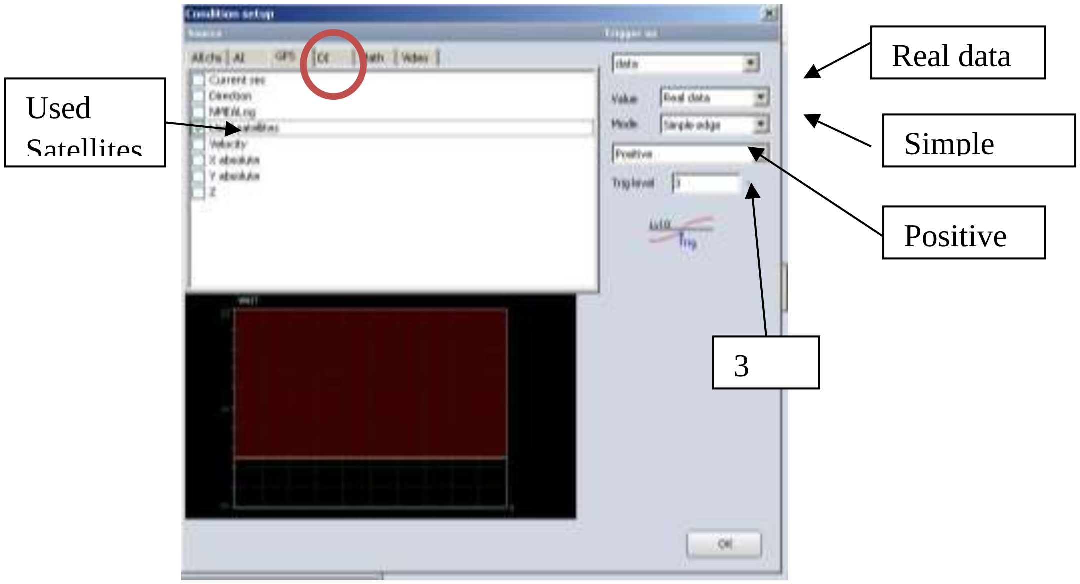
Satellite Alarm



In order to get the blue satellite LED to work, an alarm had to be created in DEWEsoft that turns on when the number of “used satellites” are three or more, and turned off when the number of “used satellites” are less than three.

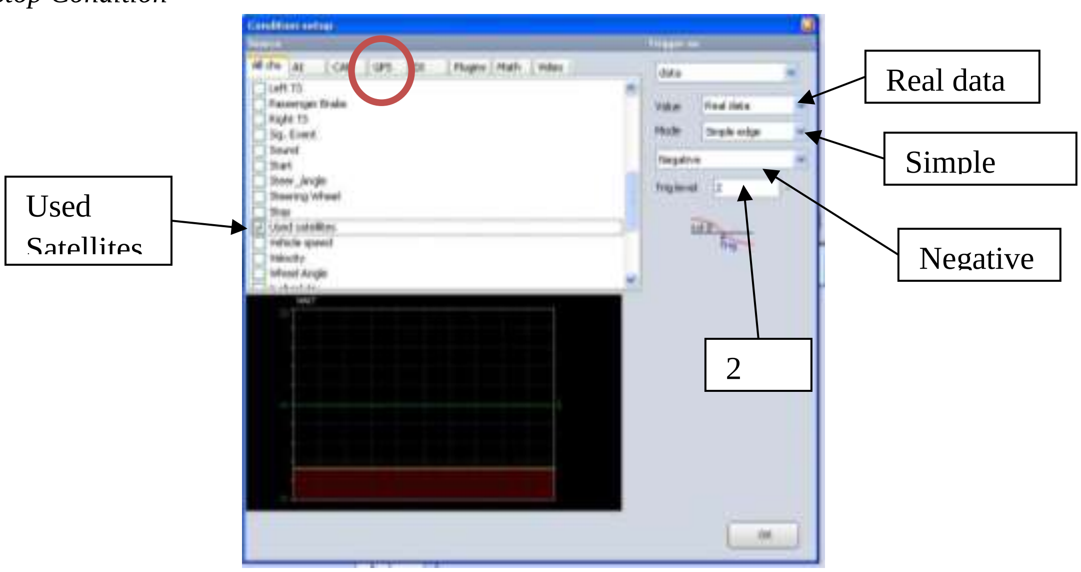
1. Alarm output selection: B0_D0-4
2. Use alarms when: acquiring data
3. Alarm rest settings: On condition
4. Alarm Start Conditions Setup
5. Alarm Stop Conditions Setup

Alarm Start Condition



1. Source: Used satellites
2. Value: Real data
3. Mode: Simple edge
4. Positive
5. Trig level: 3

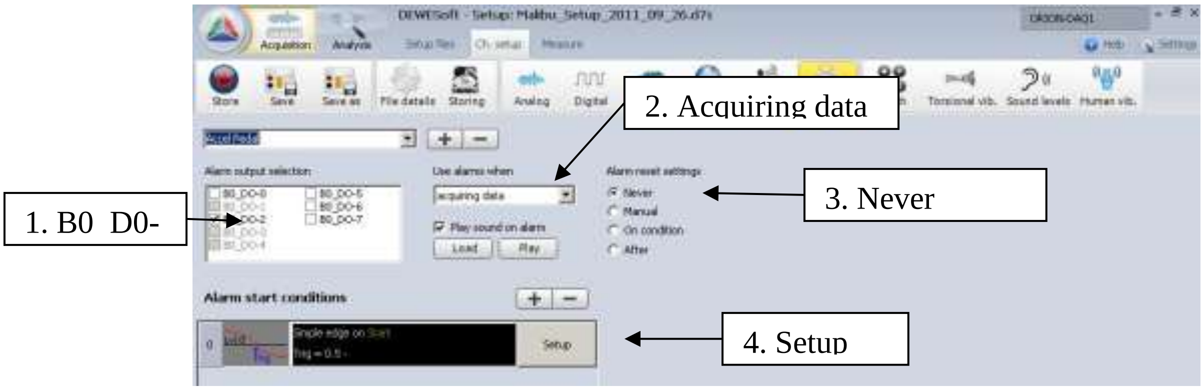
Alarm Stop Condition



1. Source: Used satellites
2. Value: Real data
3. Mode: Simple edge

4. Negative
5. Trig level: 2

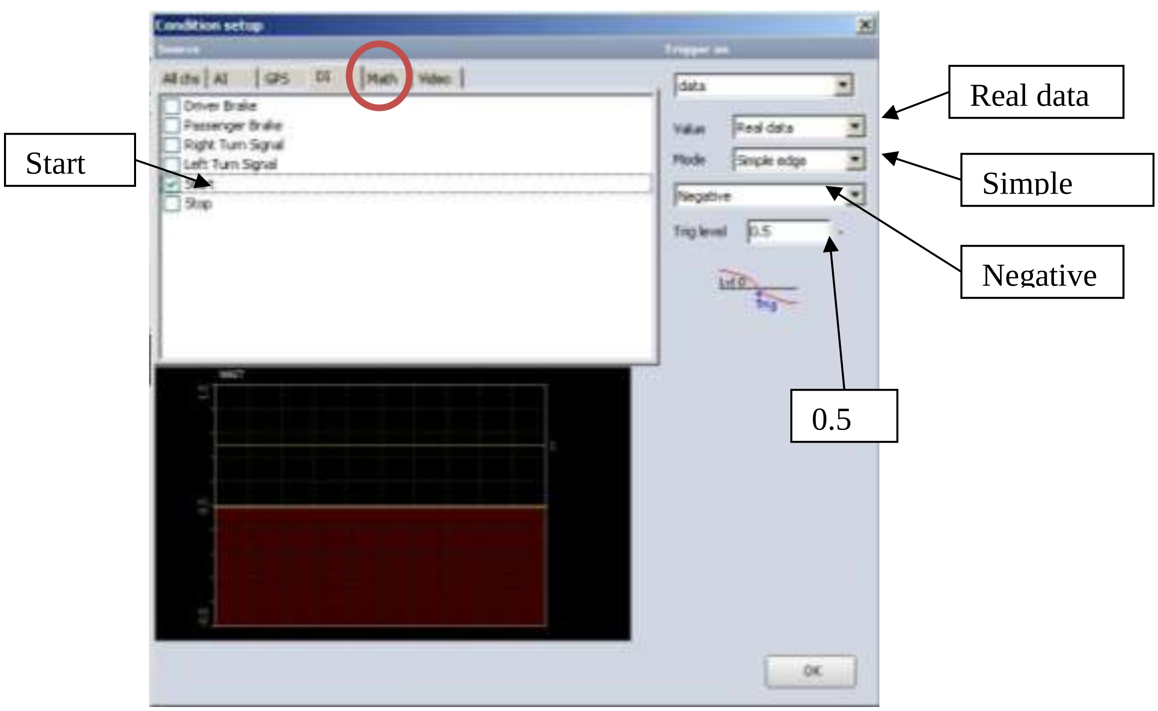
Accelerator pedal



The potentiometer attached to the accelerator pedal is powered by the TTL output of the DEWEtron. This output is activated when acquiring data and after the start button has been pushed.

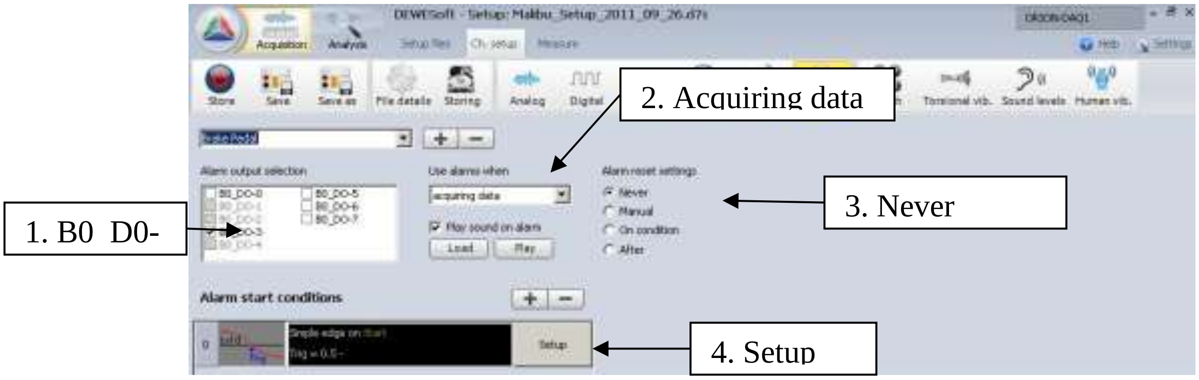
1. Alarm output selection: B0_D0-2
2. Use Alarms when: acquiring data
3. Alarm rest settings: On condition
4. Alarm Start Conditions Setup

Alarm Start Condition



1. Source: Start
2. Value: Real data
3. Mode: Simple edge
4. Negative
5. Trig level: 0.5

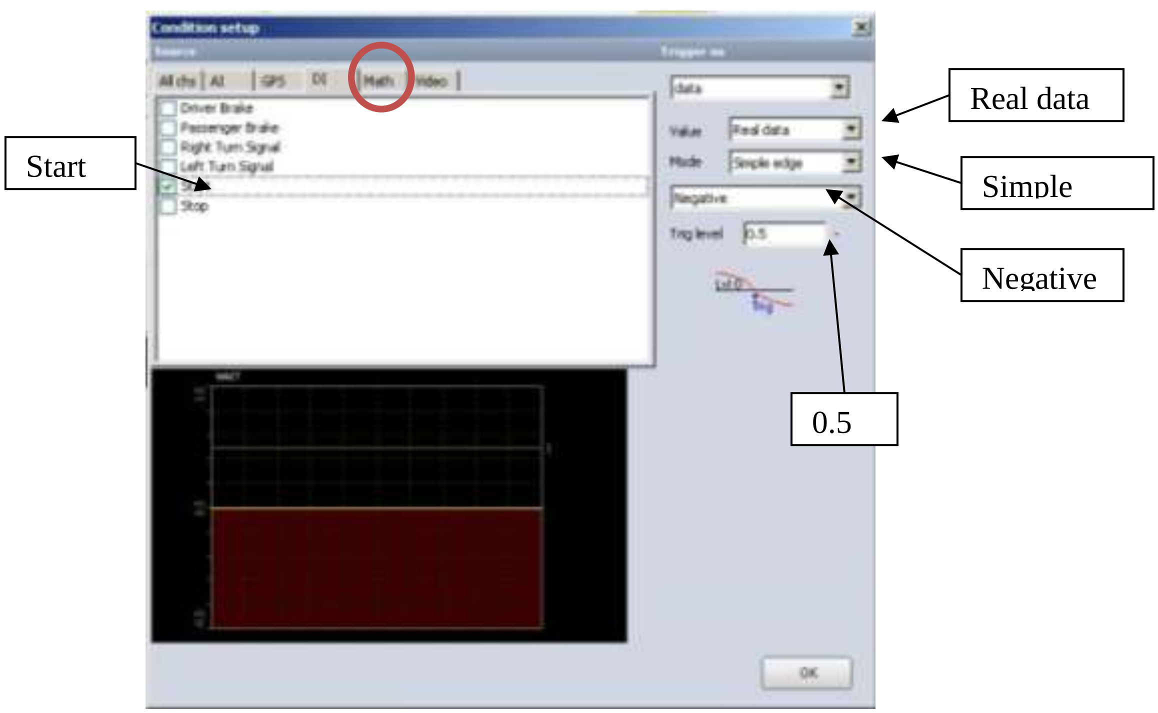
Brake Pedal



The potentiometer attached to the brake pedal is powered by the TTL output of the DEWEtron. This output is activated when acquiring data and after the start button has been pushed.

1. Alarm output selection: B0_D0-3
2. Use Alarms when: acquiring data
3. Alarm rest settings: On condition
4. Alarm Start Conditions Setup

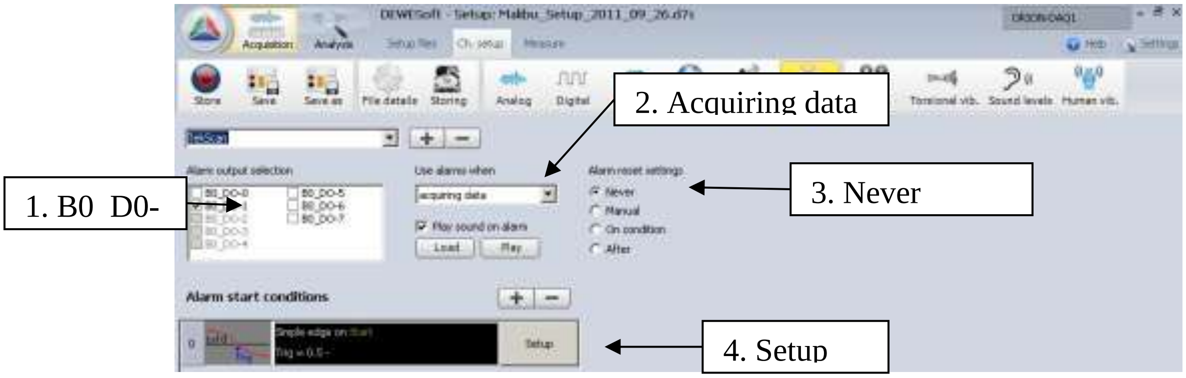
Alarm Start Condition



1. Source: Start
2. Value: Real data

3. Mode: Simple edge
4. Negative
5. Trig level: 0.5

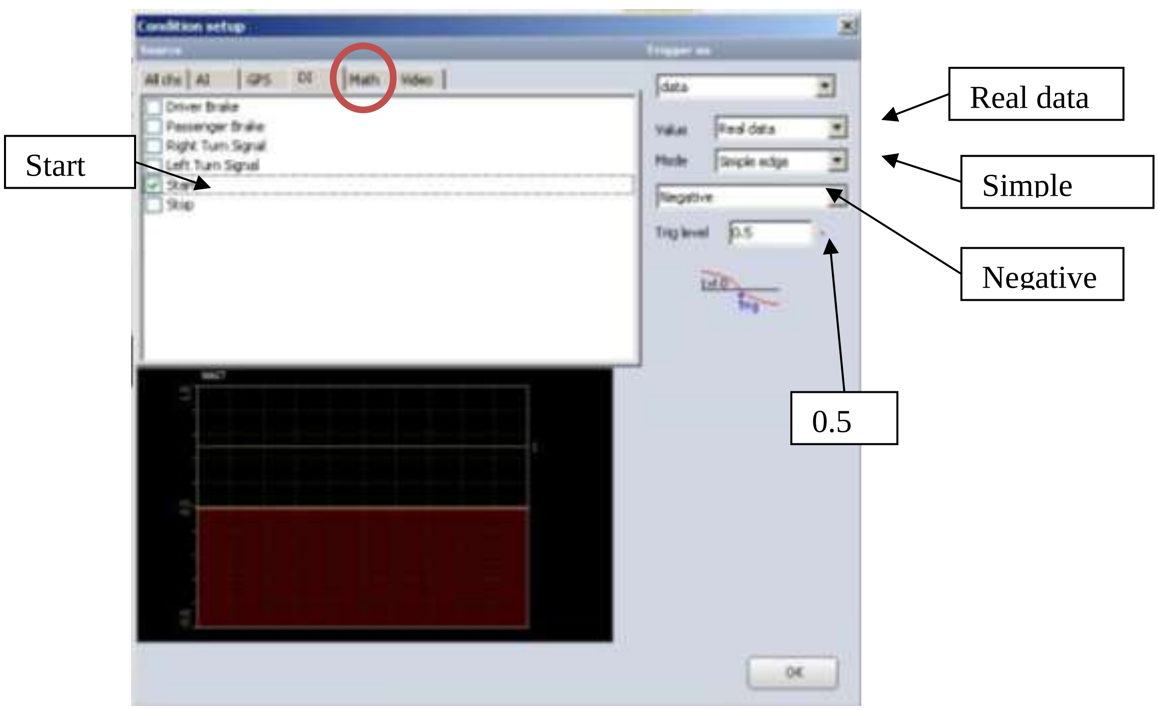
Tek Scan Trigger



The Tekscan trigger is powered by the TTL output of the DEWEtron. This output is activated when acquiring data and after the start button has been pushed.

1. Alarm output selection: B0_D0-1
2. Use Alarms when: acquiring data
3. Alarm rest settings: On condition
4. Alarm Start Conditions Setup

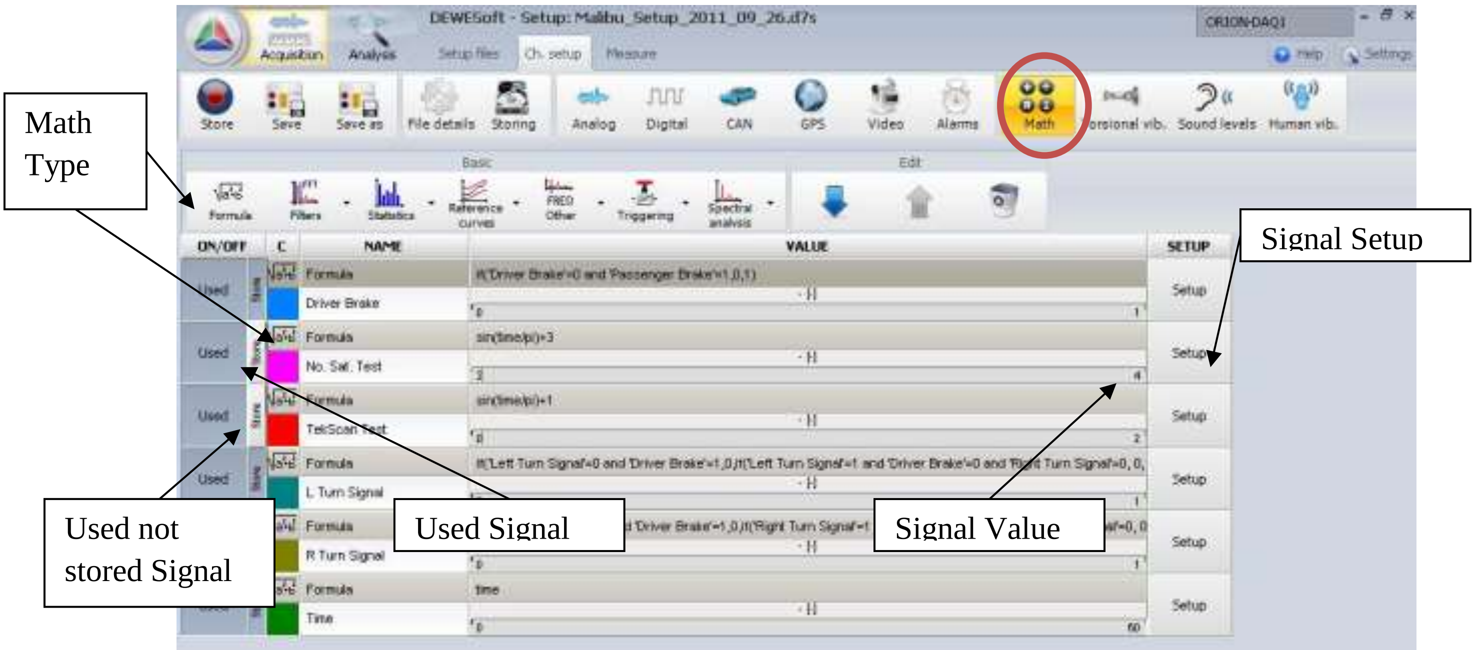
Alarm Start Condition



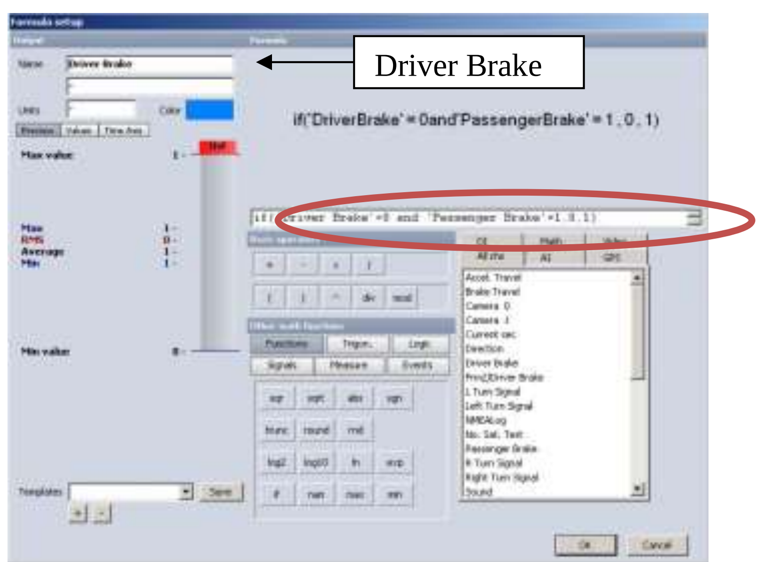
1. Source: Start
2. Value: Real data
3. Mode: Simple edge

4. Negative
5. Trig level: 0.5

Math



Driver Brake

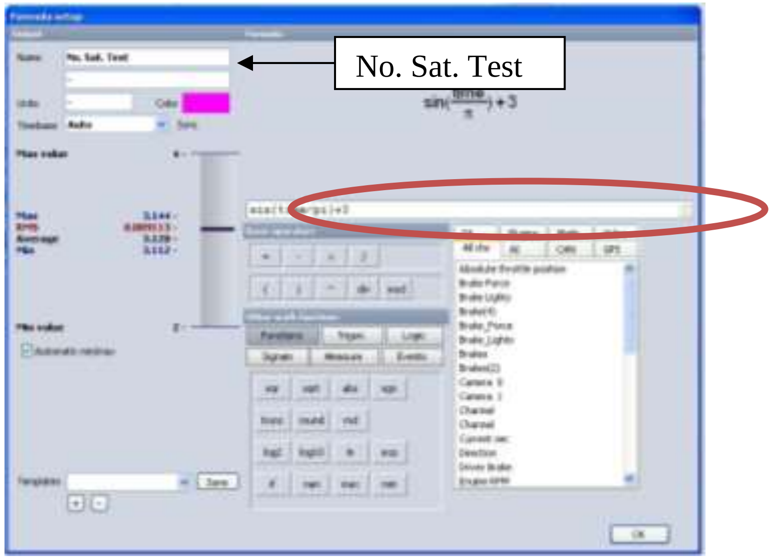


The below logic is used to assess whether the driver brake or passenger brake has been used based on the digital input sensors.

Equation 1

$$if\ (Driver\ Brake = 0\ and\ Passenger\ Brake = 1, 0, 1)$$

Number of Satellites Test

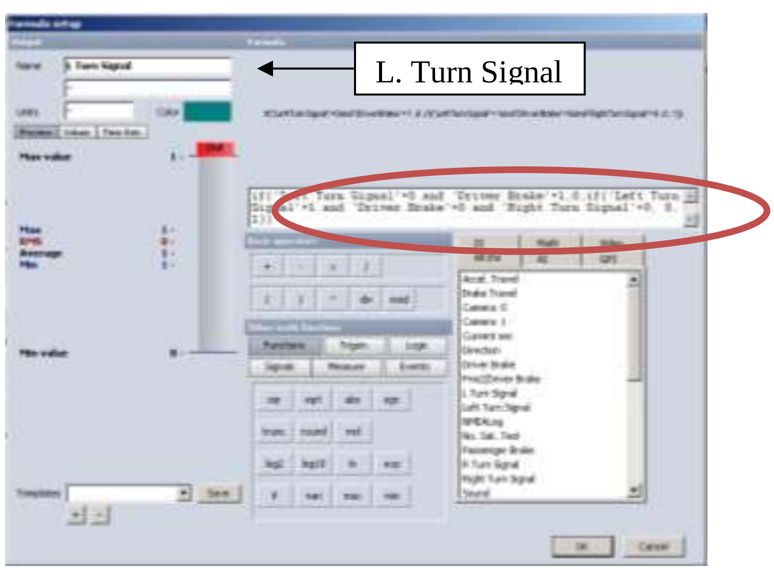


The function seen below is used when the GPS is unavailable and the Satellite Alarm LED needs to be tested.

Equation 2

$$\sin\frac{time}{\pi} + 3$$

Left Turn Signal

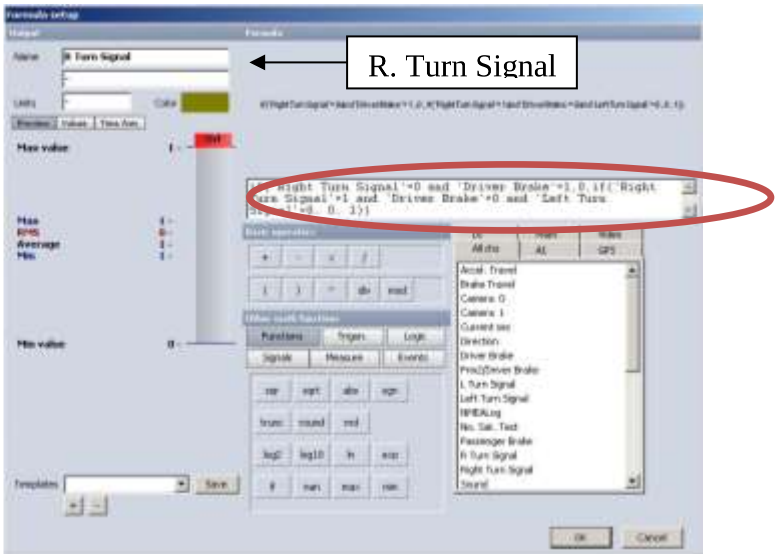


The equation that follows is used to decipher all the scenarios for the two filament light bulb for turn signal, brake light, tail light, and all combinations.

Equation 3

$$if(Left\ Turn\ Signal = 0\ and\ Driver\ Brake = 1, 0,$$
$$if(Left\ Turn\ Signal = 1\ and\ Driver\ Brake = 0\ and\ Right\ Turn\ Signal = 0, 0,1))$$

Right Turn Signal

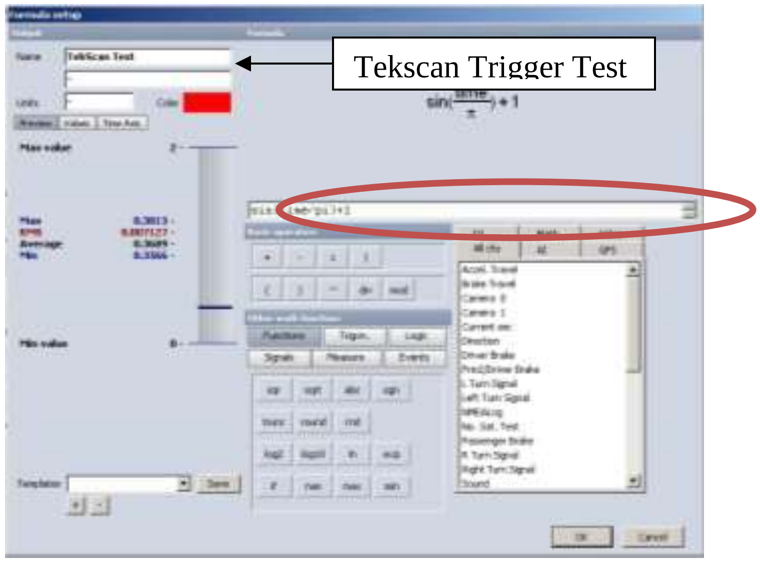


The equation that follows is used to decipher all the scenarios for the two filament light bulb for turn signal, brake light, tail light, and all combinations.

Equation 4

$$if(Right\ Turn\ Signal = 0\ and\ Driver\ Brake = 1, 0$$
$$if(Right\ Turn\ Signal = 1\ and\ Driver\ Brake = 0\ and\ Left\ Turn\ Signal = 0, 0,1))$$

Tekscan Trigger Test

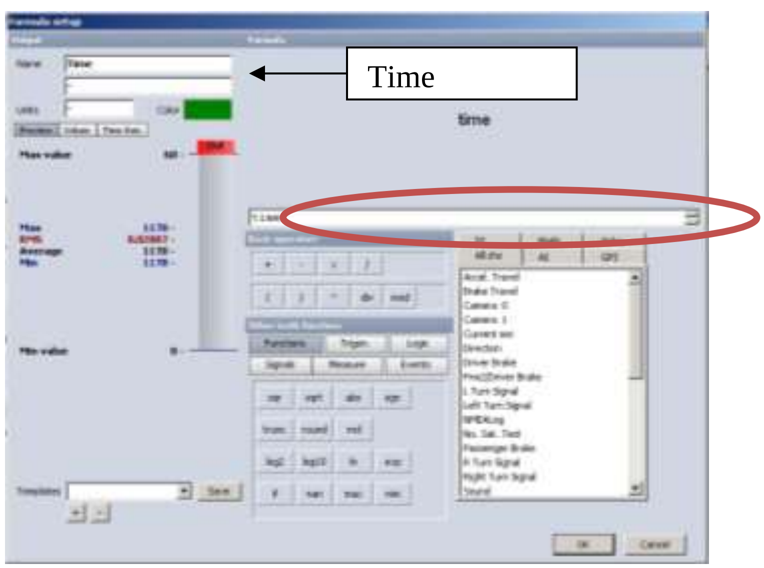


The following equation is used as a test signal for the Tekscan trigger.

Equation 5

$$\sin\frac{time}{\pi} + 1$$

Time



The following equation is used so that the time can outputted as a signal to Excel for data processing.

Equation 6

$$time$$

Equipment

Item	Vendor	Make	Model
Cabinet	CU-ICAR	CU-ICAR	custom
Data acquisition	Dewetron	Dewetron	DEWE-211
Data acquisition dc/dc converter	Dewetron	Dewetron	DEWE-DCDC-24-300-ISO
GPS	Spectra I.S.	Trimble	Ag-432
Differential correction	Spectra I.S.	Intuicom	FIP1-101RTK-VAG
Microphone	PCB Piezotronics	PCB Piezotronics	130D20
Inertial sensor	Systron Donner	Systron Donner	Motion Pak II
3.6 mm wide angle color bullet camera	Accu-Tech	Weldex	WDB 5407 SS
Digital color quad processor	CCTV Camera Pros	VM	Q401A
Digital video converter	Amazon	Star Tech	SVID2USB2
Power inverter	Grainger	Power Bright	PW1100-12
Brake application indicator light	CU-ICAR	CU-ICAR	custom
Passenger brake application sensor	CU-ICAR	CU-ICAR	custom
Turn signal application sensor	CU-ICAR	CU-ICAR	custom
Brake application sensor	CU-ICAR	CU-ICAR	custom
Power box	CU-ICAR	CU-ICAR	custom
Brake force sensor	TekScan	TeckScan	F-Socket Mat, Insert
Pedal camera illumination led	CU-ICAR	CU-ICAR	custom
Number of Satellites LED	CU-ICAR	CU-ICAR	custom
Remote start/stop	Dewetron	Dewetron	RACK-SPEC
Tekscan trigger	CU-ICAR	CU-ICAR	custom

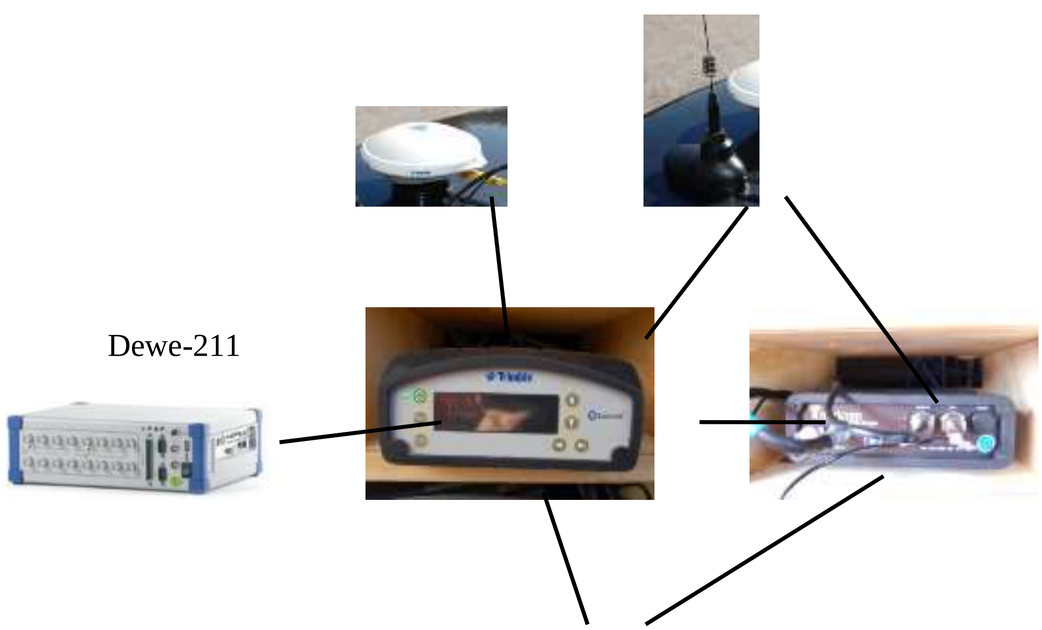
Camera Layout

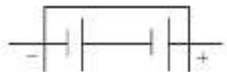
Sensor Layout

Dewetron

Dell

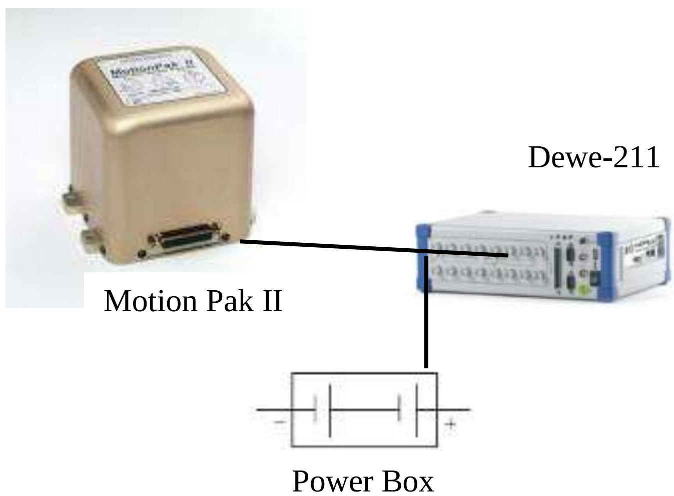
GPS




Power Box

Microphone

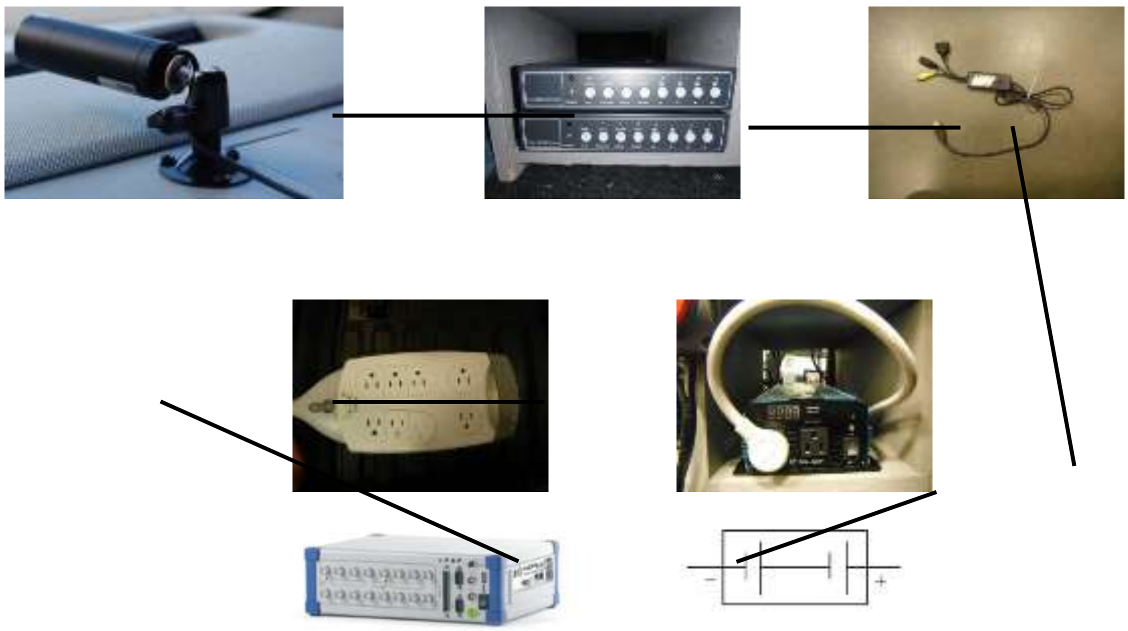
Inertial Sensor



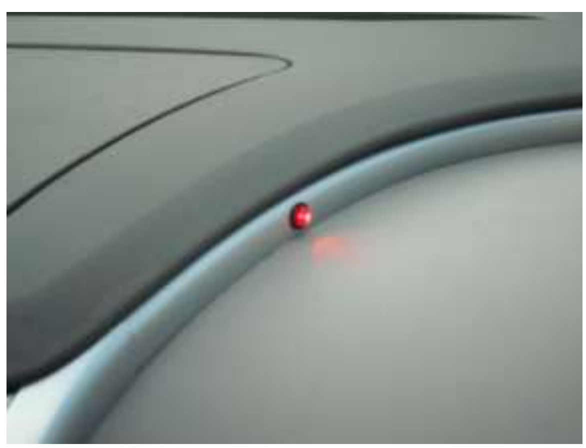
Motion Pak II Pin Out

Pin	Wire Code	Description
1	Red	+12 V
3	Black	Pwr. Ground
6	White/Brown	Common Signal – Low
18	Green/White	X-rate out
19	Orange/White	y- rate out
20	Blue/White	Z – rate out
22	White/Orange	Y – accel out
24	White/Green	X –accel out
25	White/Blue	Z – accel out

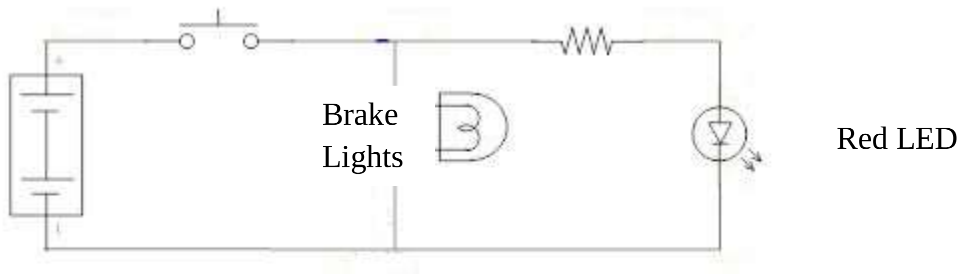
Video



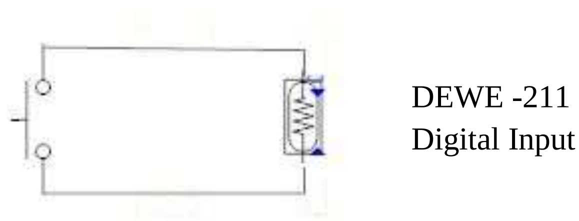
Brake Application Indicator Light



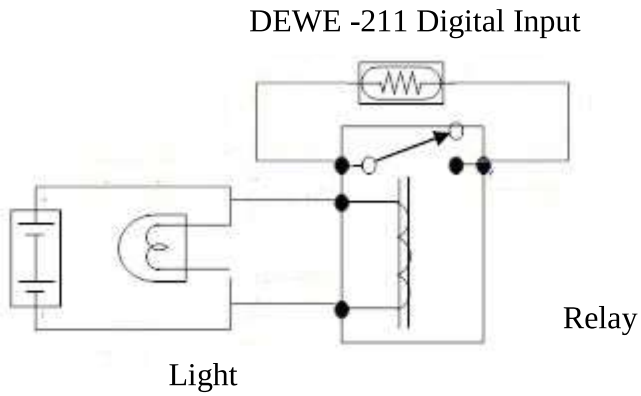
Brake Pedal R=510Ω



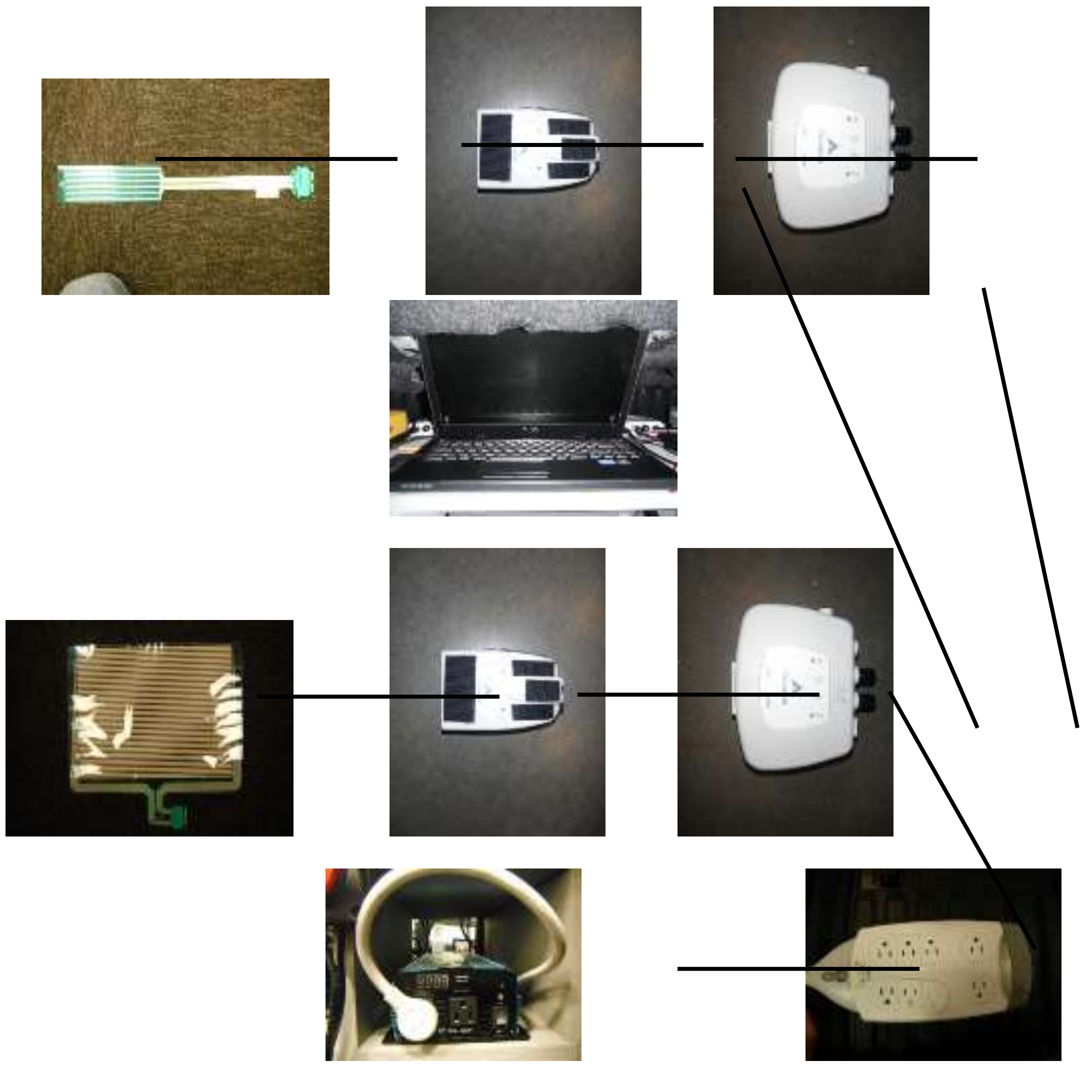
Passenger Brake Application Sensor



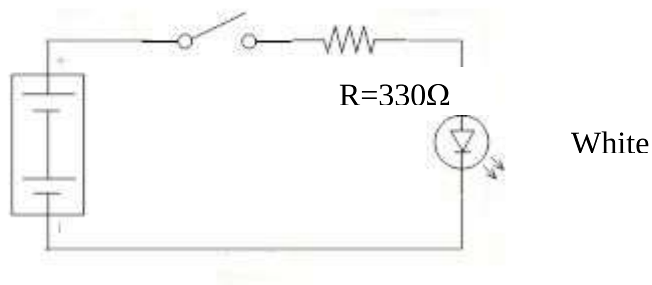
Turn Signal and Brake Application Sensor


DEWE -211 Digital Input
Relay
Light

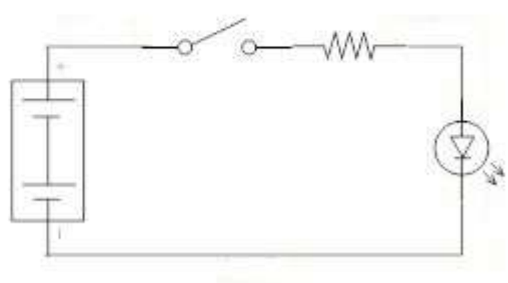
Tekscan



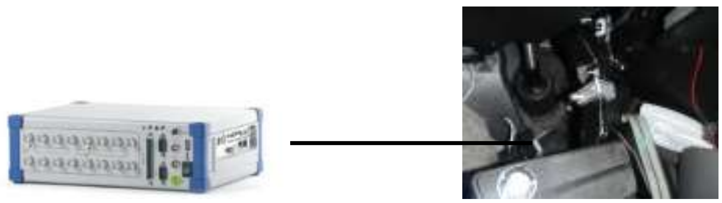
Pedal Camera Illumination LED



Number of Satellites LED

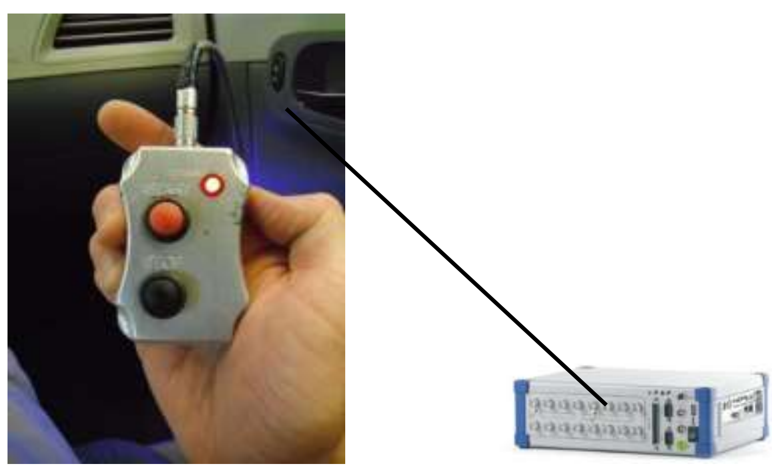


Brake Position Sensor



Accelerator Position Sensor

External Control Box



Digital Input/Output 37 Pin Connector

Digital Inputs	
DI0	
DI1	Driver Brake
DI2	Passenger Brake
DI3	Right Turn Signal
DI4	Left Turn Signal
DI5	
DI6	Start
DI7	Stop

Digital Outputs	
DO0	Recording Red LED
DO1	Tekscan Trigger
DO2	Accelerator Position
DO3	Brake Position
DO4	Blue LED
DO5	
DO6	
DO7	

LED Values

LED Color	LED Voltage (V)	LED Current (mA)	Supply Voltage(V)	Resistance (Ω)
Red	2.0	3	12	330
Blue	3.8	30	3	none
White	3.3	30	12	330

Resistance calculated using Ohm's Law:

$$V = I * R$$

Led Resistance

$$R_s = \frac{V - V_{LED}}{I_{LED}}$$

Sources of Equipment

Data Acquisition

Dewetron					
Item Number	**Vendor**	**Description**	**Make**	**Model**	**Qty**
1	Dewetron	Ruggedized data logger	Dewetron	DEWE-211	1
2	Dewetron	Remote on Power Supply	Dewetron	201-REMOTE-0N	1
3	Dewetron	16 Channel base amplifier	Dewetron	MDAQ-BASE-5	1
4	Dewetron	8 Channel strain gage/voltage input	Dewetron	MDAQ-SUB-STG-D	1
5	Dewetron	8 Channel voltage input	Dewetron	MDAQ-SUB-V-200-BNC	1
6	Dewetron	Data acquisition software	Dewetron	DEWESoft-6-PROF	1
7	Dewetron	16 Channel PCI AD card	Dewetron	ORION-1616-101	1
8	Dewetron	64 GB flash disk	Dewetron	HDD-250-SSD-64	1
9	Dewetron	Remote start/stop switch	Dewetron	RACK-SPEC	1
10	Dewetron	3.6 mm wide angle bullet cameras, quad splitter, Plextor digital video output	various	VIDEO-4-BUNDLE-COLOR-12VDC	2
11	Dewetron	IEPE/ICP signal conditioning input for microphone	Isotron	MSI-BR-ACC	1

12	Dewetron	General purpose microphone	Isotron	SEN-MIC-IEPE	1
13	Dewetron	Dc/dc converter	Dewetron	DEWE-DCDC-24-300-ISO	1

Dell

Item Number	Vendor	Description	Make	Model	Qty
1	Dell	Laptop computer	Dell	vostro	1

Video

Camera

Item Number	Vendor	Description	Make	Model	Qty
1	Accutech	3.6 mm wide angle color bullet camera	Weldex	WDB 5407 SS	5
2	Dog Sport Cameras	Various camera mount (3x Cradle, 2x Suction, 2x Roll Cage, 1x Post)	Dog Spot	Various	3
3	Newark	RCA to BNC	AIM/Cambridge	54M7978	5
4	Newark	Coaxial CCTV video/power cable , 25 ft	Defender Security	12M5230	5
5	Radio Shack	Coaxial dc power plug	Radio Shack		4
6	Allied Electronics	4 strand grounded and shielded cable	Belden		12
7	Newark	Dc/dc converter	TDK Lambda	PXE3012S05	2
8	Allied Electronics	Banana plugs	Poma	528-0197, 528-0198	2
9	CCTV Camera Pros	4 channel digital color quad processor	VM	Q401A	2
10	Radio Shack	RCA to RCA cable	Radio Shack		2
11	Amazon	Analog video to digital video	Star Tech	SVID2USB2	2
12	Newark	Mini USB to USB	Molex	25M5758	2
13	Radio Shack	Vehicle adapter plug (cigarette adapter plug)	Enercell	270-028	1

GPS

GPS					
Item Number	**Vendor**	**Description**	**Make**	**Model**	**Qty**
1	Spectra I.S.	Ag432 RTK receiver	Trimble	62432-0	1
2	Spectra I.S.	Cable ag GPS 10 meter	Trimble	29510	1
3	Spectra I.S.	RTK bridge kit	Intuicom	FIP1-101RTK-VAG	1
4	Spectra I.S.	Dual mode high gain antenna	Trimble	FIP4-MRMD-MAX-ANT	1
5	Spectra I.S.	Custom connector	Spectra I.S.	SCS-CONN	1
6	Spectra I.S.	Pwr/programming cable assy	Spectra I.S.	FIP4-RTKPWDATA-AC	1
7	Spectra I.S.	5 pin-lemo cable	Spectra I.S.	F1P4-RTKCAB-UNF	1
8	Spectra I.S.	Dual Band Cell/Pcs Foff mt Ant	Intuicom	FIP-824/1850ANT	1
9	Spectra I.S.	Cable - 1.5m, DB9(F) Y to 0S/7P/M to Po	Spectra I.S.	32345	1
10	Mr. Knickerbocker	Location Sticker for Antenna	Clemson	various	2

Analog

Sound					
Item Number	**Vendor**	**Description**	**Make**	**Model**	**Qty**
1	PCB Piezotronics	ICP Microphone with integral preamplifier and BNC Jack Connector	PCB Piezotronics	130E20	1
2	PCB	Low-noise, Blue, Coaxial Teflon	PCB	003AC	1

	Piezotronics	Cable, 30-ft BNC plug to BNC Plug	Piezotronics	030AC	
3	Dewetron	Isotron adapter	Dewetron	MSI-BR-ACC	1
4	Home Depot	Polyurethane foam	Great Stuff		1

Inertial Sensor

Item Number	**Vendor**	**Description**	**Make**	**Model**	**Qty**
1	Systron Donner	Multi-axis inertial sensing system	Motion Pak II	MP2K-CCC-666-100	1
2	Newark	25 pin dsub female connector	Tyco Electronics	79K3497	1
3	Newark	25 pin dsub case	Harting	93C8007	1
4	Mouser	8 strand grounded and shielded cable	Belden	566-8418-100-10	25
5	Allied Electronics	BNC	Poma	885-4970	6
6	Radio Shack	Vehicle adapter plug (cigarette adapter plug)	Enercell	270-028	1
7	CU-ICAR	Mount	CU-ICAR	custom	1

Brake Pedal Position

Item Number	**Vendor**	**Description**	**Make**	**Model**	**Qty**
1	Radio Shack	Push button switch	Radio Shack		2
3	Super Bright LED	T-1 13000 mcd Green LED	Hp	RL5-G13008	1
4	Mouser	6 strand grounded shielded cable	Belden		25
5	Newark	37 pin dsub female connector	Harting	26M5413	1
6	Newark	37 pin dsub case	Harting	93C8038	1
7		Housing			1

Accelerator Pedal Position

Item Number	Vendor	Description	Make	Model	Qty
1	Radio Shack	Push button switch	Radio Shack		2
3	Super Bright LED	T-1 13000 mcd Green LED	Hp	RL5-G13008	1
4	Mouser	6 strand grounded shielded cable	Belden		25
5	Newark	37 pin dsub female connector	Harting	26M5413	1
6	Newark	37 pin dsub case	Harting	93C8038	1
7		Housing			1

Digital Input

Passenger Brake Application Sensor

Item Number	Vendor	Description	Make	Model	Qty
1	Radio Shack	Micro switch	Radio Shack	275-017	1
2	Mouser	2 strand grounded and shielded cable	Belden		20
2	CU-ICAR	Mount	CU-ICAR	custom	1

Turn Signal Application Sensor

Item Number	Vendor	Description	Make	Model	Qty
1	Radio Shack	Relay	Radio Shack		2
2	Radio Shack	Resistor	Radio Shack		1
3	Radio Shack	Amplifier	Radio Shack	LM741CN	2
4	Super Bright LED	T-1 10000 mcd yellow LED	HP	RL5-Y10008	2
5	Radio Shack	T-1 led holder	Radio Shack	279-079	2

6	Radio Shack	Circuit board	Radio Shack	276-170	1
7	Radio Shack	Circuit box	Radio Shack		1
8	Mouser	2 strand grounded and shielded cable	Belden		12
9	Radio Shack	Wire taps	3M	6134	4

Remote Start

Item Number	Vendor	Description	Make	Model	Qty
1	Dewetron	Remote start unit	Dewetron	SW-Start-Stop	1

Brake Application Sensor

Item Number	Vendor	Description	Make	Model	Qty
1	Radio Shack	Relay	Radio Shack		2
2	Radio Shack	Resistor	Radio Shack		1
3	Radio Shack	Amplifier	Radio Shack	LM741CN	2
4	Super Bright LED	T-1 12000mcd red LED	HP	RL5-R12008	2
5	Radio Shack	T-1 led holder	Radio Shack	279-079	2
6	Radio Shack	Circuit board	Radio Shack	276-170	1
7	Radio Shack	Circuit box	Radio Shack		1
8	Mouser	2 strand grounded and shielded cable	Belden		12
9	Radio Shack	Wire taps	3M	6134	4

Digital Output

Sat LED

Item	Vendor	Description	Make	Model	Qt

Number					y
1	Super Bright LED	T-1 12000mcd Red LED	HP	RL5-R12008	1
2	Radio Shack	T-1 LED holder	Radio Shack	276-080	1
3	Mouser	2 strand grounded and shielded cable	Belden		8
4	Radio Shack	Resistors	Radio Shack		1
5	Radio Shack	Wire taps	3M	6134	2

Tekscan Trigger

Item Number	Vendor	Description	Make	Model	Qty
1	Radio Shack	Transistor	Radio Shack	2N4401	1
2	Radio Shack	100 ohm resistor	Radio Shack		1
3	Radio Shack	Circuit board	Radio Shack	276-130	1
4	Radio Shack	Project housing	Radio Shack		1
5	Radio Shack	PC board terminal	Radio Shack	276-1388	1
6	Allied Electronics	BNC connector			

LED

Brake Application Indicator LED

Item Number	Vendor	Description	Make	Model	Qty
1	Super Bright LED	T-1 12000mcd red LED	HP	RL5-R12008	1
2	Radio Shack	T-1 LED holder	Radio Shack	276-080	1
3	Mouser	2 strand grounded and shielded cable	Belden		8
4	Radio Shack	Resistors	Radio Shack		1
5	Radio Shack	Wire taps	3M	6134	2

Pedal Camera Illumination LED

Item Number	Vendor	Description	Make	Model	Qty
1	Super Bright LED	T-1 10000 mcd white LED	HP	RL5-W10015	1
2	Radio Shack	T-1 LED holder	Radio Shack	279-079	2
3	Mouser	2 strand grounded and shielded cable	Belden		12
4	Radio Shack	Wire taps	3M	6134	4

Miscellaneous

Item Number	Vendor	Description	Make	Model	Qty
	ACE Hardware	Nuts			25
	ACE Hardware	Bolts			25
	ACE Hardware	Washers			50
	Allied Electronics	BNC connectors			10
	Allied Electronics	Banana plugs			10
	Radio Shack	Resistors			3
	Radio Shack	Capacitors			3
	Radio Shack	Diodes			3
	Allied Electronics	Shrink wrap			2
	Bentley Publishing	Automobile service manual			3