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Foot placement during error and pedal applications in naturalistic driving

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ABSTRACT

Data from a naturalistic driving study was used to examine foot placement during routine foot pedal movements and possible pedal misapplications. The study included four weeks of observations from 30 drivers, where pedal responses were recorded and categorized. The foot movements associated with pedal misapplications and errors were the focus of the analyses. A random forest algorithm was used to predict the pedal application types based the video observations, foot placements, drivers' characteristics, drivers' cognitive function levels and anthropometric measurements. A repeated multinomial logit model was then used to estimate the likelihood of the foot placement given various driver characteristics and driving scenarios. The findings showed that prior foot location, the drivers' seat position, and the drive sequence were all associated with incorrect foot placement during an event. The study showed that there is a potential to develop a driver assistance system that can reduce the likelihood of a pedal error.

1. Introduction

Most accelerator and brake pedal applications do not result in a safety critical situation. Occasionally, drivers might confuse the pedals, or press the wrong pedal on their way towards the correct pedal. But in the majority of cases, the drivers are able to correct themselves. Tran et al., 2011 defined pedal errors as those situations when the driver mistakenly presses the wrong pedal or does not press any pedal at all. Although such pedal misapplications are rare, they could have the potential to cause serious damage and injuries once it happens, and safety concerns do exist as to why drivers may misapply the pedal (Pollard and Sussman, 1989; Schmidt, 1989).

Pedal errors and misapplications are not reporting categories in the US crash reporting database. Hence, it is difficult to extract pedal error related crashes from such national databases. Moreover, most of the crash data associated with these events are self-reported, and drivers are not always able to accurately recall when they engaged a pedal press or the context that a pedal error may occur. According to the Institute for Traffic Accident Research and Data Analysis (ITARDA) (2004), there were approximately 6000 to 7000 pedal error related crashes recorded in police reports in Japan in 2004. In the past decade, the US DOT–National Highway Traffic Safety Administration (NHTSA) has received 15,174 complaints related to sudden acceleration (Green, 2010). Researchers examining these crash types have relied largely on the narrative in the police reports (Schmidt et al., 1997, 1999).

Most studies that examine pedal errors have been conducted in the laboratory using driving simulators given the rarity of the events. For example, Rogers and Wierwille (1988) showed that about 0.2% of participants' foot movements in a simulator study resulted in the wrong pedal or both pedals being pressed, and Tomerlin and Vernoy (1990) showed that 1 out of 169 drivers would continue to step on the wrong pedal. Most studies on pedal errors have focused on driver's pedal response time (Lee et al., 2002; Muttart, 2005), but few have examined the foot placements as it transitions between pedals or from the floor to the pedal using real world scenarios. There are many studies on the response time to a safety critical situation (e.g, braking response time). However, quantifying the foot movements and placements during this responses using real world data can be challenging.

Differences have been shown in drivers' foot placements on pedals between normal and emergency braking situations. Kitazawa and Matsuura (2004) placed markers on drivers' shoes, accelerator pedal and brake pedal to record drivers foot placements in a lab-

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based experiment. There were only three young men examined for this study. But there were descriptive differences between normal and emergency braking with respect to the drivers' foot trajectories, foot movement velocity, and their brake pedal stroke. Additional data may have provided greater evidence regarding the relationship between drivers' foot placements versus the pedal application types.

An error in response execution could lead to unexpected rapid acceleration and failure to slow down. Pedal errors contain different types of errors and researchers use different types of pedal error classifications. Rogers and Wierwille (1988) defined three types of pedal errors from a simulator study: serious error (wrong pedal or both pedals pressed), catch errors, and scuff errors. Tran et al. (2011) focused on misses and misapplications in their study, while Schmidt and Young (2010) focused on slips and wrong pedals. Young et al., 2011 examined slips and misses, and Wu et al. (2015) looked at both correct and incorrect pedal applications.

The driving context that the pedal error(s) occur is important. For example, driver's seating position might change while the vehicle is turning, therefore the foot movements might not appear appropriate. Drivers can become startled or placed in panic mode when a sudden event occurs and real world driving scenarios may provide insights on the context associated with these sudden events. Sudden events require drivers to cognitively perceive and process a situation quickly to take immediate action (Belanger et al., 2010). The role of cognition is also important during pre-crash events for assessing drivers' pedal operations. Freund et al. (2008) noted that cognitive decline might be a contributing factor to pedal misapplication. Further, cognitive impaired groups (such as autism spectrum disorders (ASD), attention deficit hyperactivity disorder (ADHD)) often have difficulties distinguishing the gas and brake pedals (Lococo et al., 2012). Thus, it is of interest to consider the cognitive function in on-road studies. Instrumented vehicles used in naturalistic driving studies make it possible to collect information on real world driver behavior (Dingus et al., 2006; Hickman et al., 2010). Such systems are usually equipped with sensors and cameras so that the researchers can review complex circumstances and situations after the study is complete.

The goal of this study is to examine the factors that might cause pedal errors. Different types of pedal application were quantified using data from a naturalistic driving study, and then related to the foot placements prior to and during pedal applications. The two research questions addressed in this paper are:

1. How do pedal application types related with foot placement on the pedal?
2. Do drivers' foot placements during the error(s) related to previous foot locations and do foot positions differ in terms of context?

2. Methods

2.1. Participants

Drivers with a valid driver's license and proof of vehicle insurance were invited to participant in this study. They were also required to drive, on average, one round trip per day (e.g., to the store and back). Participants' vehicles had to have an automatic transmission, be free of special equipment (pedal extensions, hand brakes, or throttle or spinner wheel knobs) and have a model year of 1996 or newer. This model year (1996) was the first year that vehicles were equipped with an on-board diagnostic port (OBD), where data could be downloaded for this current study. The vehicle's electronic configuration was reviewed to ensure compatibility with our data collection systems.

There were 36 drivers who participated in this study and a total of 30 drivers completed the study. Two drivers could not complete the study because of system and vehicle incompatibility issues. Four drivers used their left foot while driving, which is unconventional in the US and was therefore, excluded from the analysis. The mean age among those that completed the study is 57.99 years old and they were drawn from two age groups: young (age 25–35 yrs. old, n = 10, mean age = 28.73 yrs. old) and older (over age of 65 yrs. old, n = 20, mean age = 70.18). This included 16 females and 14 males.

2.2. Apparatus

A naturalistic driving event-triggered video recorder was used for this study. The system included a palm-sized device that integrated two video cameras (forward and interior view), two foot-well cameras, a three-axis accelerometer, GPS, two infrared illuminators (to light the vehicle's interior and foot well at night), and a wireless transmitter.

This device was mounted on the windshield behind the rearview mirror, and captured audio and video inside the vehicle, and video only outside the vehicle. The cameras were placed in approximately the same locations in each vehicle in such a way as to not interfere with driving while capturing the accelerator and brake pedals and the heel of the driver (see Fig. 1).

2.3. Procedure

After arriving at the testing facility (National Advanced Driving Simulator, University of Iowa) and completion of an IRB consent form, the data collection system was installed in the participant's vehicle and took approximately 3–4 h. During this time, the participants completed a series of questionnaires, cognitive function test and anthropometric measurement.

Measurements and photographs were taken of the participant vehicle's brake and accelerator pedals, as well as the distance between the pedals. The pedals were also marked with several white lines (for example, right 1/3 line) to help researchers identify the foot placements from the videos. A sticker label was placed on the lower corners of the windows of the passenger doors to notify occupants that there was video recording inside the vehicle. GPS, accelerometer and OBD data were collected continuously. There were video recordings at the start and end of each drive, at crashes, and at accelerometer thresholds of 0.5 g and greater:

- Startup sequence

The system booted up within 3–6 s after the driver's side door was opened and recorded for one min or until the vehicle's speed reached 20 mph.

- Parking sequence

The system recorded the last 1 min of the drive going back from vehicle ignition was turned off.

- Longitudinal trigger threshold

The force level required to trigger the system with a positive or negative acceleration. Longitudinal triggers were often caused by hard braking events. The threshold setting used for this study was ±0.5 g.

- Lateral trigger threshold