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Detection of driver engagement in secondary tasks from observed naturalistic driving behavior

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ABSTRACT

Distracted driving has long been acknowledged as one of the leading causes of death or injury in roadway crashes. The focus of past research has been mainly on the impact of different causes of distraction on driving behavior. However, only a few studies attempted to address how some driving behavior attributes could be linked to the cause of distraction. In essence, this study takes advantage of the rich SHRP 2 Naturalistic Driving Study (NDS) database to develop a model for detecting the likelihood of a driver's involvement in secondary tasks from distinctive attributes of driving behavior. Five performance attributes, namely speed, longitudinal acceleration, lateral acceleration, yaw rate, and throttle position were used to describe the driving behavior. A model was developed for each of three selected secondary tasks: calling, texting, and passenger interaction. The models were developed using a supervised feed-forward Artificial Neural Network (ANN) architecture to account for the effect of inherent nonlinearity in the relationships between driving behavior and secondary tasks. The results show that the developed ANN models were able to detect the drivers' involvement in calling, texting, and passenger interaction with an overall accuracy of 99.5%, 98.1%, and 99.8%, respectively. These results show that the selected driving performance attributes were effective in detecting the associated secondary tasks with driving behavior. The results are very promising and the developed models could potentially be applied in crash investigations to resolve legal disputes in traffic accidents.

1. Introduction

Distracted driving is defined as the action of driving a motor vehicle while being engaged in a secondary task. Distracted driving is considered one of the main causes of roadway crashes. The 2011 Fatality Analysis Reporting System (FARS) results show that at least 10% of the fatal crashes and 17% of the crashes with injuries involved distracted driving (Lavoie et al., 2016). Drivers may get distracted while driving when they are involved in secondary tasks such as texting, interaction with a passenger, talking on a handheld cell phone, eating, and adjusting the radio among others. Dingus et al. reported that drivers tend to be engaged with at least one secondary activity during 51.93% of the time while driving; this raises the crash risk to at least 2 times higher than it is during normal driving (Dingus et al., 2016).

There has been extensive research work to understand how driving distractions might impact driver behavior and safety using driving simulators since 1934 (Caird and Horrey, 2011). Driving simulators can mimic the actual driving conditions without physically placing participants in real hazard. With different degrees, these studies (Horrey et al., 2008; Caird et al., 2008; Harbluk et al., 2007) showed that the driving behavior was significantly influenced when drivers got involved in secondary tasks or got distracted by any means. While driving simulators are able to study driver behavior, they do not accurately replicate realistic driving environments where interaction between drivers take place, except for very few attempts where the interaction between more than one driving simulators was studied [3]. This problem was overcome in the recently completed Naturalistic Driving Study (NDS) by the Second Strategic Highway Research Program (SHRP 2). NDS is a data collection project in which 3100 drivers of ages ranging between 16 and 80 volunteered to have sensors and video cameras installed in their cars for continuous monitoring and collection of naturalistic driving behavior data during regular commutes of the participants (Transportation Research Board of the National Academies of Science, 2017). Additionally, the NDS included collecting data on the socioeconomic characteristics of drivers, secondary tasks drivers were engaged in while driving, and crash and near-crash events. The NDS was conducted in six different states including Florida, Indiana, North Carolina, New York, Pennsylvania, and Washington. This data

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collection effort accumulated more than 33 million miles traveled and 3800 vehicle-years of driving into a database that exceeds 4 petabytes.

Several researchers used the NDS data to confirm the findings of previous studies that distractions and involvement in secondary tasks have a significant impact on driving behavior and safety. However, to the authors' knowledge, few studies attempted to detect the involvement of drivers in secondary tasks explicitly from observing their driving behavior. One of the few attempts was made by Jenkins et al. (Jenkins et al., 2016) who applied Multiple Logistic Regression (MLR) examine the relationship between secondary tasks and driving behavior. The study showed that the conventional linear statistical techniques are inadequate for such a comprehensive type of modeling. The main challenge stems from the fact that relationships involving driver behavior tend to be more complex and highly nonlinear. Thus, this study applies an Artificial Intelligence technique to detect the drivers' involvement in secondary tasks from explicit observations of their associated driving behavior. To achieve this goal, this study develops an Artificial Neural Network (ANN) model using the detailed driving records of the NDS data in order to capture potential association between driving behavior and engagement in secondary tasks.

2. Background

Distracted driving has captured the attention of many researchers and transportation officials due to its significant impact on traffic safety. The literature in distracted driving can be divided into three main categories: studies focused on the impact of distracted driving on driving behavior; studies focused on identifying the performance attributes mostly impacted by distracted driving; and studies focused on the secondary tasks that cause significant changes to driving behavior.

Based on several studies, causes of distracted driving are likely to increase the reaction time of drivers and their response time to potential hazards (Horrey et al., 2008; Caird et al., 2008; Harbluk et al., 2007). This is in addition to increasing the headway between vehicles unnecessarily and reducing the operational efficiency of traffic networks (Victor and Johansson, 2005). When analyzing the impact of specific secondary tasks, studies have shown that: (1) talking on a handheld cellphone impairs the drivers' ability to maintain their speed and position on the road (Narad et al., 2013; Stavrinos et al., 2013); (2) texting increases braking reaction times to hazards and increases lane-position variability with no change in speed (Kircher et al., 2014; Hosking et al., 2009). Victor et al. (Victor et al., 2015) used the NDS data in a comparative study between the risks involved with several secondary tasks. The authors analyzed the impact of driver glance behavior due to in-vehicle electronics, vehicle equipment use, non-visual activities, passenger related activities, external distractions, and inattention to the roadway ahead. Hallmark et al. used the NDS data to analyze distractions during lane departures and determined that lateral and longitudinal control was affected significantly by distracted driving (Hallmark et al., 2015).

Previous studies used different performance attributes to characterize the changes in driver behavior. Yet, some common attributes identified in several studies using driving simulators and NDS data are recognized as most helpful in distracted driving studies. For instance, Klauer et al. (Klauer et al., 2006), in a study based on the NDS data, and Codjoe et al. (Codjoe, 2014), in a study based on the driving simulator, identified five performance attributes to be most influenced by distracted driving. These attributes include speed, longitudinal acceleration, lateral acceleration, yaw rate, and throttle position.

It is clear that most of the literature appears to be focused on the impact of distracted driving on driving behavior. However, only a few studies attempted to detect the involvement of drivers in secondary tasks by observing their driving behavior. Most of these studies however were using traditional statistical techniques that are inadequate for this nonlinear pattern recognition problem. Thus, this study is an attempt to develop a model to detect whether drivers were distracted or not by examining specific attributes of their driving behavior. To achieve this goal, an Artificial Neural Network (ANN) model was developed using the NDS data. The study focuses on cell phone tasks such as talking/listening and texting/dialing with a hand-held device. Aside from being considered traffic violations in some states, these tasks were selected since they were identified in the literature as most significant factors of distractions. Interaction with adjacent seat passenger task was also selected to compare with the cellphone based distractions (Consiglio et al., 2003; Horrey and Wickens, 2004). In addition, as interaction with passengers did not show significant difference with cellphone use, it was also accounted for in the ANN model. In the rest of the paper, these tasks are referred to as: Calling, Texting, and Passenger-Interaction.

The remainder of this paper is organized such that the next section presents a thorough discussion of the research methodology including data acquisition and processing and the ANN model development. The results for each secondary task are then discussed in the results and analysis section. Finally, the study findings are presented in the conclusion section.

3. Methodology

This study used driving performance attributes to detect drivers' engagement in secondary tasks. The ANN modeling tool is used to discern patterns in driving behavior that could be attributed to one of the following secondary tasks: calling, texting, and passenger interaction. This is accomplished in three main steps: (1) data acquisition and preparation, (2) data cleaning and mining, and (3) neural network model development. These steps are discussed in detail in the following sections.

3.1. Data acquisition and preparation

The NDS time series data were acquired for the five performance attributes: speed, longitudinal acceleration, lateral acceleration, throttle position, and yaw rate. Table 1 summarizes the different performance attributes used in the study along with their definitions and units according to the NDS data dictionary, while Table 2 provides summary statistics for the different attributes of a sample event. The data were extracted from 424 baseline events collected in Florida with around 112, 37, and 275 events for calling, texting, and passenger interaction, respectively. To test the model ability to differentiate between distracted and normal driving, an equal number of events (424) with no secondary tasks were also extracted. Each event contains time

Table 1
List of Inputs and Outputs' Definitions and Units.

Input/Output	Variables	Description	Units
Inputs	Speed	"Vehicle speed from GPS"	kph
	Longitudinal Acceleration	"Vehicle acceleration in the longitudinal direction versus time"	g
	Lateral Acceleration	"Vehicle acceleration in the lateral direction versus time"	g
	Yaw Rate	"Vehicle angular velocity around the vertical axis"	Degrees/second
	Throttle (pedal) Position	"Position of the accelerator pedal collected from the vehicle network and normalized using manufacturer specs"	percentage
Output	1/0	1: Involved in a secondary task 0: not involved in a secondary task	N/A