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The effect of fatigue driving on car following behavior

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ABSTRACT

Existing fatigued driving analysis methods mainly focus on lateral driving performance by using the measurements related to the steering wheel or lane position. There is a lack of research on longitudinal car following behavior. In this study, 40 professional drivers are invited to participate in field expressway driving experiment, lasting at least for 6 h. During the test, their performance is measured in terms of their self-reported fatigued driving level according to the Karolinska Sleepiness Scale (KSS), the PERcentage of eye CLOSures (PERCLOS) and the Time Headway (THW). Then the effects of the fatigued driving level on car following behavior are evaluated. The results indicate that the fatigue level (for both KSS and PERCLOS) has significantly impact on THW parameters, including the mean, standard deviation and minimum THW. An increase in KSS and PERCLOS leads to a lower mean and minimum THW. Meanwhile, the standard deviation of THW increases with the increase of KSS and PERCLOS. In conclusion, this study found that a higher fatigue level leads to the driver keeping a smaller THW when following another vehicle and choosing shorter THW to make lane change. More deviation of car following performance was also found with the increase of fatigue level. Therefore, the findings of this study can be used to explain fatigue as one of the major reasons for rear-end collisions. Also, the research findings demonstrate the impact of fatigue on driving behavior in terms of car following performance, which can be used as a measurement for monitoring fatigued drivers.

1. Introduction

The objective of this paper is to present the results of car following driving performance when the drivers are under the influence of fatigue. The motivation for this work is that driver fatigue, also known as drowsy driving behavior, happens in response to various circumstances, such as prolonged driving tasks, lack of sleep, and sleep disorders Strohl et al. (1998). As a result of these conditions, fatigued driving behavior is prevalent in our daily life. To investigate the current status of fatigued driving in the U.S., a survey was conducted in 2010 by the American Automobile Association, which found that approximately 41% of drivers reported that they have at some point fallen asleep or nodded off while driving Tefft (2010). Another study conducted by Centers for Disease Control and Prevention analyzed the data from the Behavioral Risk Factor Surveillance System from 2009 to 2010, which stated that 4.2% among 147,076 respondents reported having fallen asleep at least one time while driving during the previous 30 days Centers for Disease Control and Prevention (2013). Similar, one survey in Finland find that 15.9% of the respondents reporting having been close to falling asleep or having difficulty staying awake when driving during the previous twelve months Radun, Radun, Wahde, Watling, and Kecklund (2015). Another survey

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among Sweden drivers reported that 14% of the drivers had regular sleepiness while driving van den Berg and Landstrm (2006). The prevalence of falling asleep during driving was also found in a study by the National Highway Traffic Safety Administration (NHTSA) Royal (2003).

Many field driving or simulator based studies have been conducted to evaluate the driving performance when the drivers are under the impact of fatigue driving. The results have indicated that drivers abilities to remain alert and concentrate on performing driving activities will become impaired when the drivers are subject to fatigue. Consequently, drivers reaction time Zhang, Zhao, Du, and Rong (2014) and vigilance are likely to be affected as well. NHTSAs study showed that sleepy drivers are less likely than alert drivers to take corrective action to prevent a crash Strohl et al. (1998). In conclusion, both the reaction time and ability to appropriate steering control of vehicle to avoid collision will be impaired when driving under fatigue. Unfortunately, these two factors are critical to keep alert to maintain a safe car following behavior Sangster, Rakha, and Du (2013), Bella and Agostini (2010), and Ma and Andrasson (2006). There would be high risk for drivers when the car following behavior are impaired under the effect of fatigue. Thus, driver fatigue is considered as one major reason for rear-end collisions Zurich Risk Engineering (2011). Compared with other types of traffic crashes, fatigued driving is more likely to result in death or serious injury, as high-speed impacts tend to occur because a driver has fallen asleep and cannot brake or swerve to avoid the impact Royal Society for the Prevention of Accidents (2011). In addition, more drowsy-driving crashes have happened on expressways and major roadways with speed limits over 55 mph Knipling and Wang (1994) and Wang, Knipling, and Goodman (1996). Therefore, fatigued driving crashes are more likely to involve rear-end collisions and to result in injuries and fatalities than non-drowsy driving crashes Strohl et al. (1998).

To better understand car following behavior when drivers are experiencing fatigue, field tests were organized in this study. The impact of the fatigue level on drivers car following behavior in terms of time headway was investigated. The rest of this paper is organized as follows. In the literature review section, studies on lateral and longitudinal measurements for monitoring fatigued driving are reviewed. Next, the experimental design of the field test and data collection process is explained. In the following section, the data analysis results are presented, and finally, the last section is the conclusion.

2. Literature review

Since there is no direct interference with drivers, many studies focus on monitoring the fatigued behavior by using the objective driving performance. Driving performance has been proved to be a reliable measurement that can be used to assess the alertness of drivers who are under the influence of different factors, such as driving for a long time, and lack of sleep Jovanis, Wu, and Chen (2012). The commonly used lateral and longitudinal measurements of drivers operation or vehicle performance are reviewed and discussed in the following sections.

2.1. Lateral measurement of driving performance

Regarding lateral driving performance, the measurements popularly used are steering operation and lane keeping Du, Zhao, Zhang, Zhang, and Rong (2015). Steering wheel is one of the most sensitive measurements for drivers alertness. When drivers are subject to the influence of drowsiness, their movements of low steering frequency will be increased Chikamori, Shimizu, and Ohtani (2001) and this measurement has been proved associated with the subjective evaluation of drowsiness. The steering reversal rate (SRR) is another important parameter used to measure the frequency that the steering exceeded the threshold of angle, and can be used to estimate the stability of steering. Both the simulator Wang, Xu, and Chen (2015) and field driving Zhang, Yan, Wu, and Qiu (2014) test results indicated that the SRR is strongly correlated with the fatigue level.

The lateral position of a vehicle refers to its position on the road in relation to the center of the lane in which the vehicle is being driven. Drivers lane-keeping ability is another critical driving measurement for safety, and lane-keeping performance has been validated as having a strong correlation with the fatigue level as well. Unintended lane crossing and inappropriate lane crossing are associated with the drivers drowsiness or fatigue level Davenne et al. (2012). Other studies also demonstrated that, other than lane crossing, the standard deviation of lane position (SDLP) is another commonly used lateral driving measure for studying fatigued driving Wang et al. (2015), Zhang et al. (2014), Barr, David, Hanowski, and Olson (2005), and Brown, Dow, Trask, and Salisbury (2009).

2.2. Longitudinal measurement of driving performance

The review of fatigued driving studies concluded that current fatigued driving performances are assessed mainly using lateral measurements. Only few papers evaluated the performance regarding drivers response to the leading vehicle when they are under the influence of drowsiness. However, car following is one important behavior that impacts both traffic efficiency Kim, Lovell, Kim, and Oh (2010) and safety Bella and Agostini (2010) and Hoogendoorn, Hoogendoorn, Brookhuis, and Daamen (2010). When drivers are under the influence of fatigue or drowsiness, their failure to make a corrective action in time to avoid impact with the leading vehicle will result in a rear-end collision. In addition, a rear-end collision is usually the result of inadequate car following distance. Typically, the two main safety indicators used in assessing rear-end collisions are headway Yeung and Wong (2014) or gap Hoogendoorn et al. (2010) and time-to-collision (TTC) Yeung and Wong (2014).