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A rear-end collision risk assessment model based on drivers' collision avoidance process under influences of cell phone use and gender—A driving simulator based study

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ABSTRACT

Driver's collision avoidance performance has a direct link to the collision risk and crash severity. Previous studies demonstrated that the distracted driving, such as using a cell phone while driving, disrupted the driver's performance on road. This study aimed to investigate the manner and extent to which cell phone use and driver's gender affected driving performance and collision risk in a rear-end collision avoidance process. Forty-two licensed drivers completed the driving simulation experiment in three phone use conditions: no phone use, hands-free, and hand-held, in which the drivers drove in a car-following situation with potential rear-end collision risks caused by the leading vehicle's sudden deceleration. Based on the experiment data, a rear-end collision risk assessment model was developed to assess the influence of cell phone use and driver's gender. The cell phone use and driver's gender were found to be significant factors that affected the braking performances in the rear-end collision avoidance process, including the brake reaction time, the deceleration adjusting time and the maximum deceleration rate. The minimum headway distance between the leading vehicle and the simulator during the rear-end collision avoidance process was the final output variable, which could be used to measure the rear-end collision risk and judge whether a collision occurred. The results showed that although cell phone use drivers took some compensatory behaviors in the collision avoidance process to reduce the mental workload, the collision risk in cell phone use conditions was still higher than that without the phone use. More importantly, the results proved that the hands-free condition did not eliminate the safety problem associated with distracted driving because it impaired the driving performance in the same way as much as the use of hand-held phones. In addition, the gender effect indicated that although female drivers had longer reaction time than male drivers in critical situation, they were more quickly in braking with larger maximum deceleration rate, and they tended to keep a larger safety margin with the leading vehicle compared to male drivers. The findings shed some light on the further development of advanced collision avoidance technologies and the targeted intervention strategies about cell phone use while driving.

1. Introduction

The great and rapid increase of motorization in 21st century aggravates the road traffic congestion and the high-frequency of traffic crashes in many countries on the world. The World Health Organization reported that over 20 million people around the world were injured annually because of traffic crashes and at least five million were disabled for life. In addition, the cost of dealing with the consequences was estimated at billions of dollars (World Health Organization, 2013). Among all traffic crashes, the rear-end crash is the most common type that results in a high proportion of injuries, fatalities and economic loss (Center for Disease Control, 2009). According to the National Highway Traffic Safety Administration (NHTSA) General Estimates System (2012), there were an estimated

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1.7 million police-reported rear-end crashes in the United States in 2010, accounting for about 32% of a total of 5.4 million crashes. In China, it was reported that over 40% of highway traffic crashes were rear-end collisions, constituting 47.7% of the economic loss of all traffic crashes (National Traffic Administration Bureau, Ministry of Public Security, 2011). From the perspective of driving performance, the occurrence of a crash and the crash severity are deemed to have a close link with the driver's collision avoidance manoeuvres (Kaplan and Prato, 2012; Bélanger et al., 2015). Taking an effective collision avoidance action in precrash situations may help drivers significantly reduce the collision-involvement risk or minimize the crash severity even if the collision is unavoidable (Harb et al., 2009). Therefore, deep investigations into the drivers' rear-end collision avoidance process, the behavioral mechanism, as well as the relevant influencing factors are critical for developing effective countermeasures to reduce crash risk and severities.

1.1. Rear-end collision avoidance process

The rear-end crashes have been investigated in different traffic situations by many researchers, including the rear-end collision risk at signalized intersections (Abdel-Aty et al., 2009; Wang and Abdel-Aty, 2006), urban arterials (Das and Abdel-Aty, 2011), urban road tunnels (Meng and Qu, 2012), work zone areas (Meng and Weng, 2011; Weng et al., 2015), and freeway recurrent bottlenecks (Li et al., 2014), etc. Various statistical methods and models based on the crash data were applied or developed to evaluate the rear-end collision risk and/or crash severity, such as the generalized estimation model (Wang and Abdel-Aty, 2006), the inverse Gaussian regression model (Meng and Qu, 2012), the multinomial logit model (Chen et al., 2015), the head kinematic model (Linder, 2000), decision table and Naïve Bayes method (Chen et al., 2016), and the generalized nonlinear model (Lao et al., 2014). In order to reduce the occurrence of a rear-end collision, many studies have been conducted to develop the rear-end collision warning systems and technologies (Ito and Osawa, 2015; Bella and Russo, 2011). As most of the rear-end crashes occurred in a car-following situation, a better understanding of the car-following behaviors and decision-making habits is important to seek the optimized car-following strategies for reducing the crash risk during the rear-end collision avoidance period (Broughton et al., 2007; Duan et al., 2013).

The general rear-end collision avoidance process is essentially a consecutive process consisted of risk cognition, judgement and decision-making, and vehicular operation. When a sudden braking manoeuvre of the preceding vehicle occurred, any fault in any step of the process might lead to the occurrence of a rear-end crash, such as delayed risk cognition, wrong judgement and decision making, or inappropriate vehicular operation. Prior researches have pointed out that the main reason of rear-end collisions were that the driver followed a leading vehicle too close and was not able to perceive or react to the actions of the leading vehicle (Knipling et al., 1993). However, among the factors that result in a driver's degraded abilities in the collision detection and avoidance process, the driver distraction was regarded as a primary cause, especially for rear-end crashes (Green and Shah, 2004; Muhrer and Vollrath, 2011). Distracted driving that is defined as a specific type of inattention occurs when drivers divert their attention away from the driving task and towards a competing activity (National Highway Traffic Safety Administration (NHTSA, 2016). Among all of the distracted driving behaviors, the cell phone use while driving is commonly regarded as one of the most serious forms (McEvoy et al., 2005). According to statistics in 2014, there were 2955 fatal crashes that occurred on U.S. roadways involved distraction (10% of all fatal crashes), 385 fatal crashes reported to have involved the use of cell phones as distractions (13% of all fatal distraction-affected crashes) and a total of 404 people died in fatal crashes that involved the use of cell phones or other cell phone-related activities as distractions (National Highway Traffic Safety Administration (NHTSA, 2016). In addition, driver characteristics (e.g. gender, age and experience) have been identified to be highly associated with the driving performance in traffic crashes (Ye et al., 2015), and the gender played an important role in the traffic crash involvement (Morgan and Mannering, 2011; Storie, 1977). Thus, it was important to examine how these potential factors, such as cell phone use and gender, impacted the rear-end collision avoidance process.

1.2. Effect of cell phone use on rear-end crash risk

The car-following scenario as the most common driving task in the daily drive requires the driver to constantly respond to the surrounding events including the leading vehicle's acceleration and deceleration, and the merging behavior of other vehicles, etc. When drivers are distracted, a reduction in the driver's abilities to properly detect and respond to these events presents a significant threat to safety. The widespread popularity of cell phone in modern society gives rise to this serious safety concern of driver distraction. A number of studies in the simulated situations (Drews et al., 2008; Beede and Kass, 2006) and in the field (Collet et al., 2010a,b) concluded that the use of cell phones while driving has adverse consequences on a driver's probability of being involved in a crash (Collet et al., 2010a,b; Drews et al., 2008; Rakauskas et al., 2004; Strayer and Johnston, 2001). In addition, a large number of studies showed cell phone use might cause operational and/or cognitive interference with the driving task and impair the driving performance in numerous measures. The impaired performances mainly include the increase in reaction time (Strayer and Drews, 2004; Hancock et al., 2003), the deterioration of speed control (Rakauskas et al., 2004; Reimer et al., 2011), the increased variation of lateral control (Dozza et al., 2015; Haque and Washington, 2015), the limitation in the allocation of visual attention (Harbluk et al., 2007; Reimer et al., 2012), and failure to detect relevant traffic signals (Strayer and Johnston, 2001; Wilson et al., 2003).

Public concern about the effect of distraction on driving has led to legislation in some countries/areas (for example Japan, England, China and some states of the U.S) that limit the use of cell phones while driving. The motivation for such legislation may mainly concern about interference caused by holding and dialling a cell phone, so talking on hand-free phones is usually permitted. The reason behind is that using a hand-held phone is deemed to distract drivers more seriously and thus interferes with driving tasks more than using a hands-free phone. In addition, early studies suggested that the manual aspects of cell phone use were the critical determinant of a decrement in driving performance (Drory, 1985). However, recent studies have shown that driving performance is also disrupted by conversations using hands-free devices (Metz et al., 2015; Backer-Grøndahl and Sagberg, 2011). Through the technique of functional magnetic resonance imaging (fMRI), the results showed that the brain activity decreased up to 37% because of the cell phone use, which required brain to process the auditory sentences while driving (Just et al., 2008). Other research also reported that different types of cell phone uses (whether hands-free or hand-held) constituted the same level of safety hazard (Lamble et al., 1999; McEvoy et al., 2005; Horey and Wickens, 2006). Thus, it was suggested that driving impairment due to cell phone use, to a large extent, is a result of cognitive degradation, rather than physical distractions (Backer-Grøndahl and Sagberg, 2011).

With regard to the rear-end crash, cell phone use distraction seems to play a greater role in this type of crash compared with others (Neyens and Boyle, 2007; Saifuzzaman et al., 2015). Based on investigation of the crash risk associated with hand-held and hands-free cell phones use among 4307 drivers, a significant difference in the percentage of cell phone use during the crash was