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Collision Risk Management of Cognitively Distracted Drivers in a Car-following Situation

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Abstract

Mobile phone distraction has been recognized as an adverse factor that degrades drivers' performance on road. Although research showed that drivers take various compensatory strategies to minimize the risk in distracted driving, little consensus has been achieved regarding the actual change in collision risk because of compensatory behaviours. This study aims to investigate the impact of mobile phone use and drivers' compensatory behaviours on the collision risk in a car-following situation. By using a high-fidelity driving simulator, 37 participants completed the simulation experiment in three mobile phone use conditions: no phone (baseline), hands-free and hand-held. Cluster analysis was adopted to classify the final collision risk into different levels. Two logit regression models were developed to examine the relationships between drivers' characteristics, mobile phone use, collision avoidance performances and their involvement in the collision risk. Results show that compared to no phone and hands-free, drivers using hand-held phone had a longer brake reaction time and also an increased likelihood of being involved in a high risk group. Drivers compensated to reduce the likelihood of safety-critical events through a simultaneous control of car-following speed and distance (i.e. Time-to-collision (TTC)) in distracted condition. Additionally, the results also indicated that female drivers and non-professional drivers were more likely to be involved in high risk group than male drivers and professional drivers. The study provided a systematic method to quantify the impact of mobile phone distraction and drivers' compensation behaviors on collision risk. The effectiveness of compensatory strategy by controlling TTC also shed light on the development of intelligent transport systems to help distracted drivers avoid safety-critical situations.

Keywords: Mobile phone distraction; Collision risk; Compensation behaviour; Car-following; Driving simulator

1. Introduction

Mobile phone use while driving is a growing international safety concern. Although mobile phone distracted driving is widely recognized as a deadly and often illegal activity, drivers from five continents worldwide report frequent mobile phone use while driving. Previous studies in China found that 17.14% and 23.57% of drivers (n = 213) engaged in active mobile phone tasks such as sending text messages and making calls respectively (Zhou et al., 2016). A study in Ethiopia, Africa, showed that 42.3% of respondents from a survey of 350 drivers used a mobile phone while driving (Hassen et al., 2011). In European countries such as Spain (n = 426), 32.2% of drivers have reported phone use for handheld conversations, and 43.7% for text messaging (Prat et al., 2017). A cross sectional study in Oceania, Australia (Oviedo-Trespalacios et al., 2017a) showed that one of every two drivers engaged in mobile phone conversations or texting/browsing while driving on a typical day (n = 443). Lastly, data from North America and South America have found that nearly 60% (n = 1211) of drivers read/text on a mobile phone in the U.S. (Gliklich et al., 2016) and 78% (n = 392) of young drivers in Colombia use their phone for handheld conversations (Oviedo-Trespalacios et al., 2017b). As can be seen from the previous studies, little success has been achieved in stopping mobile phone distracted driving at an international level.

The relationship between mobile phone usage while driving and safety has been a concern from human factors, injury prevention, law enforcement, and social points of view. Up to now, there is partial consensus about how the different use of mobile phone influences driving behaviour and safety. A recent report compiling naturalistic studies by the National Highway Traffic Safety Administration (NHTSA, 2016) has concluded that: (*1*) mobile phone tasks with high visual demands such as texting and browsing while driving increase the risk of collision and safety-critical events and, (2) mobile phone conversations are not strongly associated with the risk of collisions. These results have been also supported by recent literature (Oviedo-Trespalacios et al., 2016) and meta-analysis (Simmons et al., 2016). However, a large number of studies have expressed concerns for the potential cognitive distraction that mobile phone conversations might have in some groups of drivers (Lipovac et al., 2017; Strayer et al., 2016). More research on the impact of cognitive mobile phone task whilst driving is necessary to enhance our understanding of the problem and, potentially, our ability to design interventions.

A clear unresolved issue in the mobile phone distracted driving research is related to the mechanism and impact of behavioural changes observed in driving behaviour that could potentially minimise the safety threats. These alleged compensatory behaviours include reduced driving speed (Metz et al., 2015; Choudhary et al., 2017), increased following distance (Saifuzzaman et al., 2015), hard braking (Li, et al., 2016; Rossi et al., 2012; Haque et al., 2016), and reduced blink frequency (Li, et al., 2018), etc. The main argument is that these behavioural changes are initiated by drivers, intentionally or unintentionally, to cater for the additional workload induced by the mobile phone task. It is important to note that little consensus has been achieved regarding actual change in collision risk because of compensatory behaviours (Huth & Brusque, 2014; Kircher & Ahlstrom, 2016; Oviedo-Trespalacios et al., 2017c&2018), especially in the high-demand driving situations with imminent collision risk.

Car-following is one of the most complex driving situations in daily driving activities. Drivers have to pay continuous attention on the road traffic situation, especially the dynamic speed change of the leading vehicle. The frequent occurrence of rear-end collisions has been mostly due to the delay of drivers in taking evasive actions when the leading vehicle braked suddenly (Wang et al., 2016; Fleiter et al., 2016). Moreover, it has been reported that a large proportion of drivers are inclined to perform distraction activities (e.g. mobile phone use) during slow car-following in a congested road environment, and the mobile phone users while driving had a significant higher rear-end collision rate than the non-users (Backer-Grøndahl and Sagberg, 2011).

A large number of studies have conducted experiments to test the effects of distraction activities on car-following behaviors. For instance, Saifuzzaman et al. (2015) investigated the impact of mobile phone conversations on car-following behaviour and found that drivers tended to select slower driving speed, larger vehicle spacing, and longer time headway as risk compensation behaviour in both hands-free and handheld phone conversations. The difference between cognitive distraction and visual distraction during car-following process was also one of the focus. Kountouriotis and Merat (2016) compared the effects of visual and non-visual distractions in driving situations with/without a leading car. The study found that when there was no leading car, the visual distraction increased variability in both gaze patterns and steering wheel while no visual distraction decreased the gaze and steering variability. However, when the leading car is present, no significant difference was found for both types of distractions compared with baseline. Muhrer and Vollrath (2011) investigated how cognitive and visual distractions influenced drivers' anticipation of events in a car-following situation. The results showed that cognitive distraction negatively influenced drivers' anticipation of possible future actions of leading car while visual distractions deteriorates drivers' perception and reaction to the critical, sudden events. Despite most of the previous research has revealed that driver distraction has negative effects on car-following performance, the specific association between driver distraction, car-following performance, risk compensation strategy and rear-end collision risk is still not fully established.

Therefore, the purpose of this study is to investigate the relationships between mobile phone use, potential compensatory behaviours and risk of collisions. In particular, this study will focus on drivers' performance in a car following task with high rear-end collision risk, which has been identified as one of the most common type of collisions (Fleiter, 2016; Meng and Qu, 2012). Given the ethical and legal restrictions, a driving simulator was used. Collisions are rare events in daily drive. To overcome this constraint, a collision risk escalation and evaluation framework was proposed in this study. The overarching aim of this research is to study the impact of cognitive distraction on car-following situations using a collision risk escalation and evaluation framework. Three questions are investigated in this study:

(1) How to classify drivers into different collision risk groups based on the situational criticality and driver's collision avoidance performances?

(2) What are the effects of mobile phone distraction, driver characteristics and car-following performance on the rear-end collision risk?

(3) Do the distracted drivers employ risk minimizing (compensation) strategies in car-following and collision avoidance process, and do the strategies affect collision risk?

2. Methods

2.1. Collision risk escalation and evaluation framework

Rear-end collisions are consequence of a leading vehicle's sudden or unexpected sharp braking in car following situations. Once the following drivers recognize the danger, they take evasive actions to avoid a collision. Following this process, the collision risk escalation and evaluation framework developed in the study consists of two main stages car-following stage and collision avoidance stage (see Figure 1). The car-following stage refers to the period before the leading vehicle has started to brake and, the collision avoidance stage starts from when the following vehicle has initiated the brake manoeuvre and ends once a maximum collision risk level has been reached. As explained earlier, only a small number of car-following situations result in a collision and most of the time a maximum but recoverable collision risk level will be reached. As there is no obvious lane position deviation in car-following and drivers seldom take lateral evasive manoeuvre to avoid rear-end collisions (Wang et al., 2016), this study only focuses on drivers' longitudinal vehicle control performances.

In this study, the car-following performances are represented by the car-following speed and car-following distance. Variables identified in the collision avoidance process include brake reaction time, braking Time to Collision (TTC), average brake force, maximum brake force and minimum TTC. Mobile phone use conditions (no phone, hands-free and hand-held) and drivers' characteristics (driver gender and driving experience) are considered as potential factors that may be related to collision risk. Since the collision risk level develops with drivers' response dynamically, it is considerable to involve drivers' collision avoidance ability to demonstrate the risk they encounter, instead of simply employing the collision outcome (i.e., collision or not) as the only assessment criteria.

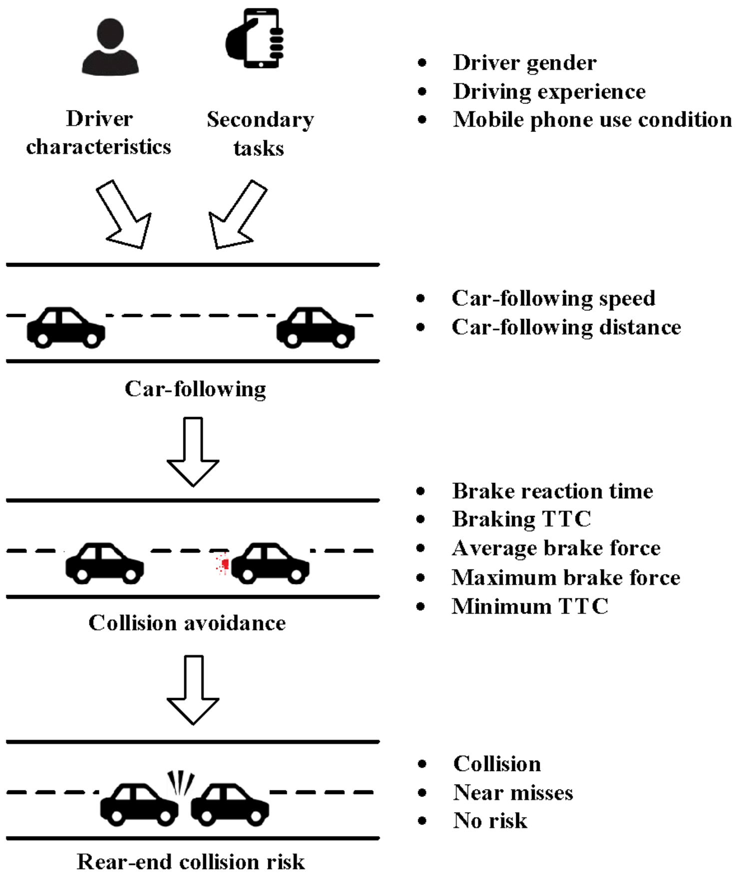

Fig. 1. The collision risk escalation and evaluation framework

2.2. Participants

A sample of 45 participants were recruited to take part in the driving simulator experiment. All participants were required to hold a valid driver license with at least two years of driving experience. As 8 participants dropped from the experiment due to driving simulator motion sickness, a total of 37 participants completed the experiment successfully (see Table 1). The 37 participants consist of 18 professional drivers (11 male vs. 7 female) and 19 non-professional drivers (10 male vs. 9 female). Their age ranged from 31 to 40 years old (M = 34.5; SD = 3.1). The professional drivers were full-time taxi drivers with an average mileage of 72.6 thousand kilometres per year, while the non-professional drivers used their vehicle for daily commute with reported average mileage of 20.1 thousand kilometres per year.

Table 1 Sample characteristics

Characteristics		Professional	Non-professional
Gender	Male	11	10
	Female	7	9
Driving mileage (10^3 km/year)		72.6 (96.2)	20.1 (8.5)
Age		34.5 (3.1)	

Data in bracket represents the standard deviation.

2.3. Equipment

The Beijing Jiaotong University (BJTU) driving simulator was used in the experiment. As shown in Figure 2, the BJTU driving simulator includes a moving simulation system, a linear motion base capable of operating with 1 degree of freedom, a full-size cabin (Ford Focus) with a real operational interface, an environmental noise and vibration system, and a digital video record system. The simulated environment is displayed with five screens (1400 × 1050 pixels) surrounding the vehicle and thus the drivers can have a front/peripheral field of view of 300 degrees. The simulators uses Simvista and Simcreator software for scenario design and operation.

Fig. 2. The BJTU driving simulator

2.4. Scenario and traffic interactions

The scenario included a two-way two-lane road of 4 kilometres with a posted speed limit of 80 km/h. The road environment was created with characteristic of Chinese urban road. The traffic volume was designed to be close to capacity (600~700 vehicles/hour/lane) in order to allow car-following situations and prevent overtaking manoeuvres. The operating speed of the vehicles on road was about 40-50 km/h and the vehicles were programmed to maintain a distance of 20m-50m. Participants encountered a potential rear-end collision situation by the leading vehicle decelerating from 40 km/h to 4 km/h with a deceleration rate of 6 m/s^2. The scenario was created to mimic a common real-life driving situation in which the drivers followed the leading vehicle at a comfortable distance and speed.

Fig. 3. The experiment scenario

2.5. Experimental procedure

Upon arrival, each participant was briefed on the requirements of the experiment and asked to read and sign an informed consent form. The participants were then advised to drive as they normally would in real-life situations. Before the formal test, each participant performed a practice drive of at least 5 minutes to become familiar with the driving simulator (with automatic transmission). In this practice session, the participants exercised manoeuvres including straight driving, acceleration, deceleration, left/right turn and other basic operations, and they also exercised the use of mobile phone while driving. The participants were also notified that they could quit the experiment at any time in case of motion sickness or any kind of discomfort.

During the experiment, each participant was required to drive in three scenarios: a baseline scenario (no phone conversation), a hands-free phone scenario and a hand-held phone scenario in random order. All participants were randomised to drive the three scenarios and the order of the scenarios were counterbalanced among participants to mitigate the order effect. In each test scenario, the leading vehicle's type, colour, and speed-change profile remained the same so as to exclude the confounding effects potentially introduced by such factors. Given that the likelihood of frequent collision situation within a short time is quite small in reality, several measures were taken to reduce learning effects and also discourage them from speculating about the experiment's purpose. Firstly, participants took a rest for at least 10 minutes between each two tests. Secondly, before entering the car-following segments, participants drove through several intersections and gentle curves to increase their driving experience. Thirdly, some ambient vehicles were arranged to travel in front of the simulator and drove away at intersections before the test segments.

The mobile phone conversation task in the experiment was a series of simple unit digit arithmetic questions that the drivers were requested to answer as quickly as they can. In the hand-held situation, the participants were asked to hold the mobile phone to their ear with one hand while in the hands-free task the participants could use both their hands to control the steering wheel.

2.6. Variables

The simulator data were sampled at 60 Hz. Variables representing the vehicle control manoeuvres of drivers in car-following and pre-collision situations were extracted from the raw data and defined as follows.

- **Car-following distance (CFD)**: the headway distance between the simulator and the leading vehicle at the time when the leading vehicle started to brake, in meter.
- **Car-following speed (CFS)**: the speed of the simulator at the time when the leading vehicle started to brake, in km/h.
- **Brake reaction time (BRT)**: the time duration from when the brake light of the leading vehicle was initiated to the time when the simulator driver started to brake, in second.
- **Braking Time to Collision (BTTC)**: the time headway between the simulator and the leading vehicle at the time when the simulator driver started to brake, in second.
- **Maximum brake force (MBF)**: the maximum value of brake force that driver adopted during the collision avoidance, in N (Newton).
- **Average brake force (ABF)**: the average value of brake force during the collision avoidance, in N (Newton).
- **Minimum TTC**: the minimum time headway between the simulator and the leading vehicle during the collision avoidance, in second.

Risk Compensatory Behaviour (RCB) was measured based on the difference of driving behaviour from the baseline (no phone) condition and distracted condition (hand-held and hands-free). Let RCB_i be the risk compensatory behaviour *i* = {CFD, CFS, BRT, BTTC}. As seen in the following equation:

$$RCB_i = DB_{(i,distraction)} - DB_{(i,baseline)} \quad (1)$$

$DB_{i,j}$ is the Driving Behaviour *i* at the experimental condition *j* (*j* = {distraction | baseline}. Therefore, RCB_i represents the risk compensatory behaviour between distraction and baseline conditions. This methodology has been widely utilised to study the use of speed as risk compensatory behaviour among distracted drivers (Oviedo-Trespalacios et al., 2017cd, Choudhary et al., 2017). In this study, it was applied on a wide and various behaviour performance.

2.7. Data analysis techniques

This study used a two-stage data analysis to examine the relationship between collision risk and drivers' vehicle control manoeuvres when interacting with a mobile phone task while driving. The hypothesis testing in this study was based on a significance level of 0.05.

First, cluster analysis was implemented to classify the sample into different risk levels. This inductive multivariate statistical method is useful for establishing homogenous groups within a sample (Westlake & Boyle, 2012). The two-step cluster analysis technique was used as it included a specific feature of automatic selection of the best number of clusters (Chiu et al., 2001). Silhouette measure of cohesion and separation was used to examine the cluster quality. Profiles of these groups were generated using means and standard deviations, while differences were examined with t-test ($p < 0.001$).

Second, based on the cluster analysis results, logistic regression was used to examine associations between drivers' characteristics, mobile phone use conditions, collision avoidance performances and their involvement in the rear-end collision risk. By using the classified risk level as dependent variables, two stepwise binary logit regression models were developed to test (1) the effects drivers' characteristics, mobile phone use conditions and collision avoidance performances, and (2) the effects of drivers' self-regulation and compensatory performances induced by mobile phone use on drivers' involvement in different levels of collision risk.

3. Results

3.1. Driving performance: Experiment results overview

Table 2 listed the descriptive statistics of all the variables and the repeated-measures ANOVA results under different mobile phone conditions. The car-following speed, distance, brake reaction time, braking TTC and minimum TTC showed an increasing tendency from no phone condition to hand-held condition. The average and maximum brake forces seemed to be higher in hands-free condition compared to no phone and hand-held conditions. However, the ANOVA results showed that mobile phone condition only had significant effect on drivers' brake reaction time ($F=3.791$, $p < 0.05$) while the effects on all the other variables were not significant.

Table 2 Descriptive statistics and repeated-measures ANOVA results of variables in three mobile phone conditions

Variables	Mobile phone condition						Repeated-measures ANOVA	
	No phone		Hands-free		Hand-held			
	Mean	S.D.	Mean	S.D.	Mean	S.D.	df	F
Car-following speed	40.30	3.59	40.97	3.43	41.71	3.35	2	1.801
Car-following distance	33.57	17.58	34.38	16.95	43.93	31.45	2	2.855
Brake reaction time	1.17	0.38	1.15	0.43	1.53	1.12	2	3.791*
Braking TTC	4.19	1.62	4.45	2.41	4.36	1.91	2	0.182
Average brake force	83.82	40.36	88.41	55.42	82.94	48.32	2	0.261
Maximum brake force	126.35	62.57	136.67	81.03	123.52	75.37	2	0.611
Minimum TTC	3.04	1.28	3.05	1.67	3.49	1.95	2	1.110

Note: * $p < 0.05$

3.2. Collision risk assessment: A cluster analysis

During the experiment, 7 rear-end collisions were observed in total, among which 4 occurred in hands-free condition and the other 3 occurred in hand-held condition.

Considering that the collision sample size was small and the fact that collision result can only represent the outcome of collision avoidance while ignoring the situational risk perception of non-collision drivers, the collision result was not adopted as a criterion to classify drivers' risk involvement level. Instead, by considering the drivers' braking performance (average brake force and maximum brake force) and situation urgency (minimum TTC), a two-step cluster analysis was conducted to identify the risk level in which drivers were involved during the collision avoidance process.

The two-step cluster analysis results were listed in Table 3. All the samples were classified into two groups automatically by using the average brake force, maximum brake force and minimum TTC. Silhouette measure of cohesion and separation indicated a good cluster quality (see Figure 5). The two groups were defined as low risk group and high risk group which accounted for 62.2% and 37.8% of the total sample respectively. T-test results showed that the two groups had significant differences on the average brake force ($t=16.285$, $p<0.001$), maximum brake force ($t=17.371$, $p<0.001$) and minimum TTC ($t=-7.344$, $p<0.001$). Compared to the low risk group, the high risk group had significantly larger average brake force, maximum brake force and smaller minimum TTC (see Figure 6).

Table 3 Two-step cluster analysis results and t-test results

Variables	Cluster results		T-test results				
	Low risk	High risk	t	df	p	95% CI	
						Lower	Upper
Average brake force	53.64 (19.67)	136.67 (34.10)	16.285	109	<0.001	72.92	93.13
Maximum brake force	80.28 (31.02)	208.62 (46.83)	17.371	109	<0.001	113.70	142.98
Minimum TTC	3.93 (1.55)	1.98 (0.96)	-7.344	109	<0.001	-2.48	-1.43
Group size	69 (62.2%)	42 (37.8%)	-	-	-	-	-

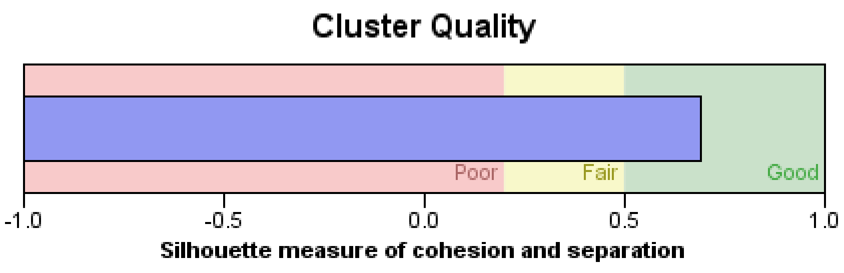

Figure 5: Silhouette measure of cluster quality

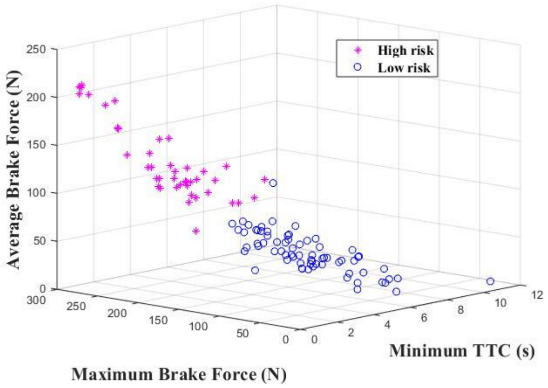

Figure 6: The average brake force, maximum brake force and minimum TTC of different risk groups

3.3. Safety-critical events analysis: A Logit Regression analysis

According to the cluster results, all samples were classified into two risk levels: high risk and low risk. Therefore, the dependent variable in the binary logit regression models was the two levels of collision risk which was a categorical variable. The first model used different mobile phone conditions (no phone, hands-free and hand-held), driver characteristics (drivers' gender and profession) and the collision avoidance behaviours (CFD, CFS, BRT and BTTC) as explanatory variables. The low risk group was designated as the reference category.

Results of the first model were listed in Table 4. The overall percent correct of classification was 83.8%, with correct rate 81.0% for high risk group and 85.5% for low risk group. Model results showed that mobile phone use conditions, driver's gender, driver's profession and car-following distance were included in the model as significant factors. Compared to the baseline condition, drivers in hand-held condition were more likely to be involved in high collision risk. Male drivers and professional drivers were more likely to be involved in the low risk group than female drivers and non-professional drivers respectively. Meanwhile, a large car-following distance also increased the likelihood to be involved in a low risk group.

Table 4 Results of the first logit regression model (reference category: low risk group)

Model Term	Coefficient	S.E.	t	p	95% CI	
					Lower	Upper
Intercept	12.810	2.269	5.644	<0.001	8.310	17.310
No phone	0[a]					
Hands-free	-0.175	0.639	-0.274	0.785	-1.442	1.092
Hand-held	3.311	1.359	2.437	0.016	0.617	6.005
Female	0[a]					
Male	-3.812	0.912	-4.179	<0.001	-5.621	-2.003

Non-professional	0[a]					
Professional	-1.659	0.626	-2.649	0.009	-2.900	-0.417
Car-following distance	-0.402	0.069	-5.865	<0.001	-0.538	-0.266

The second model aimed to examine the association between drivers' self-regulation and compensatory behaviors in distracted condition and the collision risk level. Thus, the difference values of car-following speed, car-following distance, braking TTC and brake reaction time between mobile phone conditions (including hands-free and hand-held) and no phone condition were calculated and used as the input of the model. However, according to the model result, only the difference value of braking TTC (ΔTTC) was a significant factor of collision risk level (Coefficient=-0.57, t=-3.435, $p<0.01$). Despite the lack of comprehensive predictors, the result could still reflect that through a simultaneous control of car-following speed and distance, the more time gap left between drivers and leading vehicle at the initiation of braking, the less likely for a safety-critical event to occur (i.e., near miss or collision).

4. Discussion

By using a driving simulator, the study investigated drivers' rear-end collision avoidance performance and their involvement in the rear-end collision risk with consideration of hands-free/hand-held mobile phone use and driver characteristics. All the drivers were classified into two collision risk levels through a cluster analysis. The effects of mobile phone distraction, driver characteristics, car-following performance and distraction compensation strategy on rear-end collision risk were identified. The three questions raised in the study could be answered with the obtained results.

Regarding research question (1), the findings of this study confirm that car-following and collision avoidance manoeuvres could result in distinctive risk levels. The cluster analysis confirmed that two main risk levels were identified: high and low collision risk. The events classified as high risk do not exclusively include road collisions but are a mixture of safety-critical events, i.e. near misses and collisions. This is theoretically expected given that safety-critical events are stochastic events, meaning that even though one particular collision may be explained by a large (often uncountable) number of factors that led to it. As explained by Laureshyn et al. (2010), it may be considered as an unlucky coincidence that all these factors happened to be there at the same time because if some of the contributing factors had not been present, a collision might have been avoided. Therefore, all events included in the high-risk level group represent a potential hazard for road users and should be avoided.

Safety-critical events during car-following share some common features: higher average brake force, higher maximum brake force, and shorter time-to-collision. All this variables has been linked with road collisions in previous studies (Oviedo-Trespalacios et al., 2016; Li et al., 2015 & 2016). Following the research question (2) on the predictors of rear-end collision risk during car following process, a predictive model was developed using logistic regression. Variables such as the presence of distraction, personal characteristics of the driver, and vehicle control decisions were found to influence safety outcomes. These compositions of variables are consistent with several driving behaviour models such as the Task-Capability Interface that explain that collisions are result of an imbalance between driver capability and driving demands (Fuller, 2000).

Among the different conditions tested in the study, having the mobile phone task in hand-held led to the worst situation. Drivers in hand-held condition had the longest brake reaction time compared to no phone and hands-free conditions, and the hand-held task also increased the likelihood of drivers being involved in a high risk group. Current research has highly agreed on the detrimental effects of hand-held mobile phone use that it impairs driving performance and increases collision risk. However, consensus has hardly reached when it comes to the use of hands-free devices. A large number of research did not find difference between drivers' using mobile phone in hand-held or hands-free condition while driving, suggesting that the hands-free phone does not offer any safety advantage in relation to the hand-held phone (Oviedo-Trespalacios et al., 2016, 2017c&d; Ishigami & Klein, 2009). Meanwhile, Backer-Grøndahl and Sagberg (2011) reported in a survey of a significant increase in collision risk for hand-held mobile users but non-significant tendency for hands-free users, and that hand-held users were more inclined to attribute the accident to mobile phone use than were hands-free users. In a texting while driving task, hands-free phone use was found to be less detrimental to driving performance such as brake response time and headway distance variation than hand-held phone use (He et al., 2014). It is believed that the effects of hands-free phone on drivers largely depends on the environment complexity, the type of conversation and the operation of hands-free phones (e.g. locating, reaching, dialling or talking), which is manipulated differently in previous studies.

Driver characteristics played an important role in the involvement of rear-end risk in this study. Compared to non-professional drivers, professional drivers had a higher likelihood to be part of the low risk group. Due to the high work stress and high exposure on road, driving safety of professional drivers (e.g. bus, taxi and truck drivers) has been a research focus that gained increasing attention (Vetter et al., 2018; Wu et al., 2016). However, when encountering the same traffic situation, professional drivers still outperform non-professional drivers, probably because of a long-time accumulation of driving experience and special work requirement (Yan et al., 2014). In addition, the results also suggested that female drivers were more likely to be involved in high risk group than male drivers. It has been widely reported that male drivers tended to engage more risky behaviours and driving offences such as speeding, distracted driving and drink driving than female drivers (Rhodes & Pivik, 2011; Varet et al., 2018). Nevertheless, research of Özkan and Lajunen (2006) showed that on a perceptual-motor skills assessment, male drivers reported higher scores than female drivers. In a study of relationship between young driver's gender and collision type, Bingham and Ehsani (2012) found that female drivers were more likely to be involved in rear-end collisions compared to male drivers.

To answer research question (3) regarding the use of risk minimization strategies, the differences in driving behaviour between baseline and distracted conditions were considered. No evidence show that drivers initiated changes to reduce the collision risk in car-following stage when they were using a mobile phone, i.e. there were no statistical difference of car-following speed or distance among different conditions. It is argued that car-following situations involve large driving demands and, therefore, drivers dedicate more attention to driving (Tractinsky et al., 2013; Oviedo-Trespalacios et al., 2017c). This explains why the driving behaviour performance was similar between baseline and mobile phone conditions. However, the results confirm that cognitively distracted drivers' speed and headway management, as measured by TTC, could reduce the likelihood of safety-critical events. The TTC was calculated by the headway distance between the simulator and the leading vehicle divided by the speed of the simulator. Compensation for the increased demands of mobile phone use while driving is only achieved if both speed and headway distance are negotiated simultaneously in car-following situation. Only use speed or headway as a compensatory strategy is not sufficient. These findings suggest that the integration of mobile phone use and driving is possible if drivers start engaging in compensatory measures. The development of intelligent transport systems could support this by allowing drivers to use their phone if certain vehicle dynamics and road traffic conditions are met. Recent research such as Choudhary & Velaga (2017) and Oviedo-Trespalacios et al. (2017c&d) have reported similar findings.

5. Limitations

Although findings of study have addressed the raised questions, some limitations still exist and need to be pointed out. Firstly, the study did not take the dynamic manoeuvre of the leading vehicle into consideration in the risk level classification. However, it was suggested that the speed and deceleration rate of the leading vehicle were important factors that could influence the drivers' collision avoidance performance (Wang et al., 2016). Future investigation could design different deceleration patterns of the leading vehicle and explore whether will induce different levels of distraction compensation strategy. Secondly, artificial types of conversation were used in this research mainly to ensure a consistent level of cognitive distraction among participants. The artificiality of the mobile phone tasks could limit generalization of the observed behaviours. For example, research has shown that contentious conversation resulted in different levels of workload compared with emotionless conversations (Lansdown & Stephens, 2013). The results of this study, which only examined the effects of simple cognitive distraction task, should be confirmed or compared with other mobile phone tasks. Besides, other support tasks related to mobile phone interactions in real driving (e.g. locating and reaching the phone, dialling, answering etc.) should also be studied for a complete understanding of mobile phone distracted driving.

6. Conclusions

The present study shows an original framework for the analysis of car-following situation with high rear-end collision risk. The findings demonstrate that it is possible to identify safety-critical events that need to be prevented according to drivers' performances and situational information. In addition, safety-critical events were found to be function of driving demands (including mobile phone use) and drivers' capability. Finally, it is confirmed that speed and headway management strategies could be utilised to compensate for the elevated demands imposed by mobile phone use while driving. Nowadays, community, educational, and enforcement-based interventions have shown very little success in preventing risky mobile phone use while driving (Oviedo-Trespalacios, 2018). Future research should focus on technology-based solutions to support compensatory strategies that allow safe mobile phone use while driving.

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