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## **Impact of mobile phone use on car-following behaviour of**

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### **young drivers**

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## 1 **ABSTRACT**

2 Multitasking, such as the concurrent use of a mobile phone and operating a motor vehicle, is a  
3 significant distraction that impairs driving performance and is becoming a leading cause of motor  
4 vehicle crashes. This study investigates the impact of mobile phone conversations on car-following  
5 behaviour. The CARRS-Q Advanced Driving Simulator was used to test a group of young Australian  
6 drivers aged 18 to 26 years on a car-following task in three randomised phone conditions: baseline (no  
7 phone conversation), hands-free and handheld. Repeated measure ANOVA was applied to examine  
8 the effect of mobile phone distraction on selected car-following variables such as driving speed,  
9 spacing, and time headway. Overall, drivers tended to select slower driving speeds, larger vehicle  
10 spacings, and longer time headways when they were engaged in either hands-free or handheld phone  
11 conversations, suggesting possible risk compensatory behaviour. In addition, phone conversations  
12 while driving influenced car-following behaviour such that variability was increased in driving  
13 speeds, vehicle spacings, and acceleration and decelerations. To further investigate car-following  
14 behaviour of distracted drivers, driver time headways were modelled using Generalized Estimation  
15 Equation (GEE). After controlling for various exogenous factors, the model predicts an increase of  
16 0.33 seconds in time headway when a driver is engaged in hands-free phone conversation and a 0.75  
17 seconds increase for handheld phone conversation. The findings will improve the collective  
18 understanding of distraction on driving performance, in particular car following behaviour which is  
19 most critical in the determination of rear-end crashes.

20

21 **Keywords:** Car-following, mobile phone use while driving, distraction, driver behaviour, risk  
22 compensation

23

## 1 1. INTRODUCTION

### 2 1.1. Distracted driving induced by mobile phone use

3 *Driver distraction* can be defined as a diversion of attention away from activities critical for safe  
4 driving to a competing activity (Lee *et al.* 2009). *Distraction* is also described as multi-task driving  
5 which reduces attention and cognitive resources allocated to the driving task. Studies have shown that  
6 multitasking while driving deteriorates driving performance, increases reaction time, and impacts  
7 lateral lane position and vision. This, in turn, poses serious safety concerns on the roads. A naturalistic  
8 driving study with 43000 hours of driving data from 241 drivers showed that the use of mobile phone  
9 while driving is associated with a higher number of crashes and incidents than driver interactions with  
10 any other source of distraction (Neale *et al.* 2005).

11 An extensive literature has empirically documented the risks associated with mobile phone  
12 use while driving (see Drews and Strayer (2009) for a detail review). Driving with phone conversation  
13 is considered as multitasking where a part of brain is occupied for the processing of the auditory  
14 sentences. An analysis using functional magnetic resonance imaging (fMRI) showed that, mobile  
15 phone distraction requiring the processing of auditory sentences decreases the brain activity by as  
16 much as 37% of the critical tasks associated with driving (Just *et al.* 2008). The increased cognitive  
17 load might cause a withdrawal of attention from the visual scene where not all the information a  
18 driver sees is processed; this phenomena is known as inattention blindness (Strayer *et al.* 2003).

19 Mobile phone use while driving is one of the most common distractions that motor vehicle  
20 drivers engage. In 2012 the National Highway Transportation Safety Administration estimates that  
21 9% of drivers on the roadway at any given daylight moment are using some type of phone (either  
22 handheld or hands-free); for handheld phone use in particular, this estimate was 5% (NHTSA 2014).  
23 White *et al.* (2010) observed 796 Australian drivers aged 17–76 years who owned mobile phones, and  
24 found that 43% of them reported answering calls while driving on a daily basis, followed by making  
25 calls (36%), reading text messages (27%), and sending text messages (18%). Mobile phone use while  
26 driving is more prevalent among young (and less experienced) drivers, who generally possess an  
27 elevated crash risk. A recent survey reported that almost one in two Australian drivers aged between

1 18 to 24 years used a handheld mobile phone while driving, nearly 60% of them sent text messages,  
2 and about 20% of them read emails and surfed the internet (AAMI 2012).

3 In a naturalistic driving study Fitch *et al.* (2013) investigated the effects of distraction from  
4 the use of mobile phones while driving on 204 drivers. On average drivers were estimated to be  
5 talking on a mobile phone 10.6 percent of the time when they were driving with a mean call duration  
6 of 4.02 minutes. The study identifies that mobile phone subtask (locating, answering, dialing,  
7 browsing, text messaging and ending the call) can take driver's eyes off the forward roadway for up to  
8 33.1 to 71.5 percentage of time. Furthermore, locating/answering a handheld mobile phone was found  
9 to be associated with an increased safety risk (crash or near crash).

10 To reduce the negative effect of mobile phone use while driving, hands-free technology is  
11 widely used. However, conversation using both hands-free and handheld mobile phones has adverse  
12 effect on driving. A meta-analysis by Caird *et al.* (2008) reveals that the effect of hands-free versus  
13 handheld phone studies did not differ appreciably from one another in terms of reaction time of the  
14 driver. Overall, a mean increase in reaction time of 0.25 seconds was reported for all phone-related  
15 tasks. A recent simulator study reported that both hands-free and handheld phone conversations are  
16 associated with about 40% increase in reaction times of drivers to peripheral traffic events (Haque and  
17 Washington 2014). Overall, studies did not find any significant difference in relative risk of a crash  
18 for handheld and hands-free phones, both options individually associated with a fourfold increase in  
19 crash risk (McEvoy *et al.* 2005).

## 20 **1.2. Impact of distracted driving on car-following**

21 A few studies specifically have targeted to capture the adverse effect of mobile phone use on car-  
22 following behaviour. Car-following refers to the behaviour of a driver to follow a leading vehicle  
23 longitudinally. It is the most common routine driving situation and an important requirement for the  
24 safe driving (see Saifuzzaman and Zheng (2014) for the latest review).

25 In a driving simulator study Alm and Nilsson (1995) observed the effects of hands-free  
26 mobile phone conversation on car-following behaviour. In their study, 40 participants drove a  
27 simulator vehicle for 80km where a total of 16 car-following events occurred randomly. The

1 participants were randomly exposed to a phone conversation task in 8 of these car-following  
2 situations. They observed an increased reaction time for phone conversation while driving.  
3 Furthermore, the participants did not compensate for their increased reaction time by increasing their  
4 headway during the phone task. However, later studies reported reduction in speed when driving with  
5 phone conversation, a behaviour known as risk compensation (Törnros and Bolling 2006). For  
6 example, Ranney *et al.* (2004) observed higher reduction of speed when driving with handheld phone  
7 conversation compared to other types of phone conversations (headset hands-free and voice dialing  
8 speaker kit hands-free) and baseline (no phone). Furthermore, drivers were found to increase their  
9 time headways during all types of phone conversations.

10 Drews and Strayer (2009) in their detail review about effect of mobile phone use on driving  
11 also reported increased reaction time and reduction of speed. Furthermore, an increase in lane  
12 deviation and fluctuation of speed are also reported which indicates less control over driving due to  
13 distraction caused by mobile phone use. A recent study by Stavrinos *et al.* (2013) also supports these  
14 findings by reporting significantly greater variability in driving speed, lower lane change frequency  
15 and higher lane deviations in distracted driving compared to baseline (no phone use while driving).

16 Strayer *et al.* (2011) in their study asked the participants to follow a pace car that was  
17 programmed to brake at 32 randomly distributed locations over a 24-mile multi-lane highway. They  
18 observed a slower brake reaction time for driver with mobile phone conversation compared to no  
19 phone driving. The distracted drivers also took longer time to recover their speed that was lost  
20 following braking. The drivers conversing on mobile phones tended to have a more cautious driving  
21 profile in terms of speed and following distance (i.e. maintaining lower speed and higher spacing)  
22 than non-distracted driving. However, crash rate was still higher compared to driving with no phone  
23 conversation. No significant difference was observed between driving with handheld and hands-free  
24 phone conversations.

25 Driver reaction time, speed, and following distance are considered key variables in describing  
26 the stability and flow of traffic. Driver engaging in phone conversations while driving can  
27 significantly influence these variables, thus, performs poorly in following the preceding vehicle.  
28 Although aforementioned studies have attempted to document the risk of mobile phone use in car-

1 following situation, overall the literature is scarce, and our understanding on this important issue  
2 remains elusive. For instance, fluctuations in speed and spacing and acceleration noise have been  
3 seldom measured, which could give valuable insight about driver's control over car-following in  
4 distracted situations. Driver demographics could also influence car-following behaviour in distracted  
5 situation, which needs to be explored.

### 6 **1.3. Research objective**

7 This study aims to investigate the effect of both hands-free and handheld mobile phone conversation  
8 on car-following behaviour of young drivers. A simulator experiment was designed where a  
9 participant drove a simulator vehicle in three different phone conditions: baseline (no-phone  
10 conversation), hands-free phone conversation and handheld phone conversation. A wide range of  
11 variables (such as driving speed, spacing, speed difference, time headway and acceleration noise)  
12 were considered to examine car-following behaviour of distracted drivers. The effects of distraction  
13 on the car following behaviour were mainly identified by comparing the driving performances in  
14 distracted and non-distracted (no-phone conversation) conditions. In addition, driver's time headway  
15 was modelled using the Generalized Estimation Equation (GEE) to develop further insights into the  
16 car-following behaviour of distracted drivers.

17

## 18 **2. DRIVING SIMULATOR EXPERIMENT**

### 19 **2.1. Driving simulator**

20 To accomplish this study, an experimental driving simulator study was conducted at the Centre for  
21 Accident Research and Road Safety – Queensland (CARRS-Q), Queensland University of  
22 Technology (QUT). In this experiment a group of distracted drivers were exposed to a number of  
23 traffic events using the CARRS-Q Advanced Driving Simulator<sup>1</sup>.

24 The simulator incorporates a complete Holden Commodore vehicle with working controls and  
25 instruments. When seated in the simulator vehicle, the driver and passengers are immersed in a virtual  
26 environment that includes a 180 degree front field of view (using three front-view projectors),

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<sup>1</sup>Detail about the simulator can be found at <http://www.carrsq.qut.edu.au/simulator/>

1 simulated rear view mirror images, surround sound for engine and environment noise, real car cabin  
2 and simulated vehicle motion. Road images are displayed onto the front view projector, the wing  
3 mirrors and the rear view mirror at 60 Hz to create a photorealistic virtual environment. The simulator  
4 was capable of accurately reproducing motion cues for sustained acceleration, braking manoeuvres,  
5 cornering and interaction with varying road surfaces. The simulator used SCANeR™ studio software.  
6 Driving performances data like position, speed, acceleration and braking were recorded at rates up to  
7 20 Hz.

## 8 **2.2. Participants**

9 Thirty-two volunteers were recruited by disseminating recruitment flyers using university student  
10 email addresses or university social media and distributing recruitment flyers inside the campus. An  
11 eligible participant should meet the following conditions: 1) be aged between 18 and 26 years, 2) hold  
12 either a provisional or open Australian issued driver's licence, 3) not had a history of motion sickness  
13 and epilepsy, and 4) not be pregnant. The participants were reimbursed upon completion of the study.  
14 The participants also filled a survey questionnaire about their driving history, mobile phone use, and  
15 driving behaviour.

16 Descriptive statistics of the participants are presented in Table 1. The participants were on  
17 average 21.47 (SD 1.98) years old and split evenly by gender. About 66% of the participants held  
18 open (non-restricted) licenses and the rest have provisional licenses. Note that in Queensland,  
19 Australia, a newly licensed driver is required to hold a provisional license for up to 3 years before  
20 obtaining an open license. Average driving experience was 4.2 (SD 1.87) years where the provisional  
21 and open license holders had 2.64 (SD 0.75) and 5.01 (SD 1.79) years of average driving experience,  
22 respectively. In terms of vehicle kilometre travelled about 44% drove less than 10,000km, 47% drove  
23 in between 10,000 to 20,000km, and the rest drove more than 20,000km in a typical year.

24 Table 1 also presents the mobile phone use history of the participants. On average a  
25 participant made (or received) 65 (SD 43) calls and sent (or received) 261 (SD 199) text messages in a  
26 typical week. More interestingly, the scenario about mobile phone uses while driving showed that,  
27 about 34% of the sample used it at least once in a day; 47% of used once or twice in a week; and the

1 rest used mobile phones while driving only once or twice in a month or year. About the type of  
 2 mobile phone use while talking and driving 53% of the participants reported using a hand-held phone  
 3 0–25% of the time, 19% reported 25–50%, 12% reported 50–75%, and the remaining 16% reported  
 4 using a handheld phone 76–100% of the talking time whilst driving.

5 **Table 1: Descriptive statistics of the participants**

Driver characteristics	Mean	SD	Count	Percentage
Driver's age (years)	21.47	1.98	-	
Gender				
Male	-	-	16	50.00
Female	-	-	16	50.00
License type				
Open	-	-	21	65.63
Provisional	-	-	11	34.38
Years of driving	4.20	1.87	-	
Kilometres driven in a typical year				
0–10,000 km	-	-	14	43.75
10,000–20,000 km	-	-	15	46.88
>20,000 km	-	-	3	9.38
General mobile phone usage history				
Calls (in a typical week)	65.34	43.41		
Text message (in a typical week)	260.66	198.66		
Frequency of mobile phone use while driving				
at least once in a day	-	-	11	34.38
once or twice in a week	-	-	15	46.88
once or twice in a month or year	-	-	6	18.75
Usage of handheld phone while talking and driving				
0-25%	-	-	17	53.13
26-50%	-	-	6	18.75
51-75%	-	-	4	12.50
76-100%	-	-	5	15.63

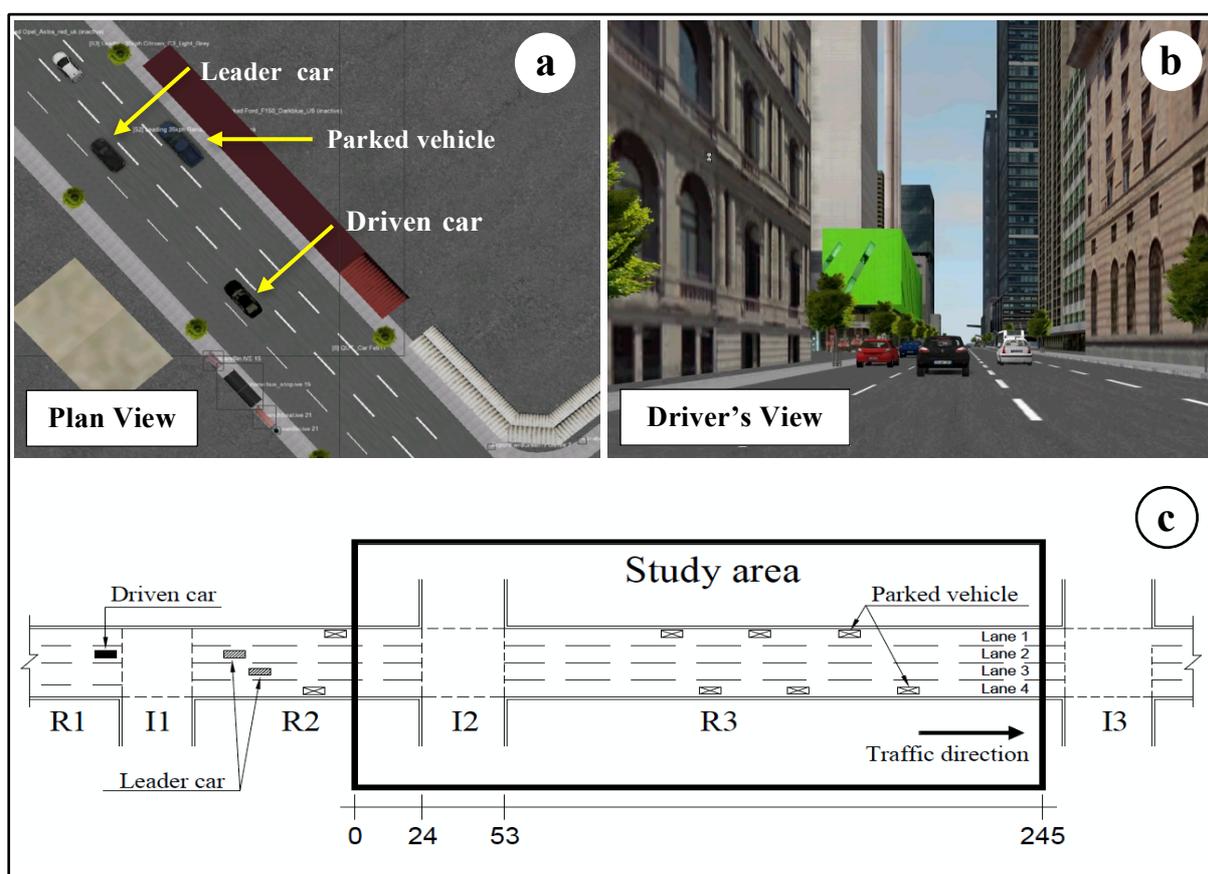
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### 7 **2.3. Experimental setup**

8 The simulated route in the experiment was 7km long that went through Brisbane CBD (central  
 9 business district of Brisbane, Australia) and a hypothetical suburban area. Various traffic events were  
 10 programmed to occur in the course of the simulated driving such as car-following, overtaking,  
 11 pedestrian crossing and sudden breaking of a lead vehicle. A part of the experimental data has been  
 12 used in Haque and Washington (2013) and Haque and Washington (2014) to observe the effect of  
 13 distraction on reaction time. However, in this study the data from car-following event is used which

1 has not been applied before<sup>2</sup>. Details of the participant testing protocol can be found in Haque and  
 2 Washington (2014).

3 The car-following event was occurred along urban roads, where the speed limit was 40 km/h.  
 4 A detail of the car-following scenario is shown in Figure 1. The odd number in this figure represents  
 5 intersection and the even number represents the roadway between two intersections. The roadway has  
 6 four lanes with unidirectional traffic flow. Lane 1 and lane 4 had parked vehicles, leaving only lane 2  
 7 and lane 3 available for driving.



8

9

10 **FIGURE 1** Details of car-following event: (a) plan view showing driven and leader vehicles; (b)  
 11 **driver's view showing leader vehicles and occupied adjacent lanes; (c) detail of the study area.**

12

13 In this car-following scenario, when the driven vehicle (shown as the black rectangle in Figure 1)  
 14 stops at the signalized intersection I1, two lead vehicles appear on the two lanes of road section R2

<sup>2</sup> The data used by Haque and Washington (2014) covered the traffic event where a pedestrian entered a zebra crossing from the sidewalk. Haque and Washington (2013) used data from the traffic event where a lead car breaks suddenly. In contrast, the data used in this paper were collected from a different road segment which was designed for the car-following event only. In addition, the methodology applied in this paper differs from those in the past two studies.

1 (shown as rectangle with hatched lines). They were pre-programmed with selected speeds. When the  
2 signal at the intersection I1 turns green, the two lead vehicles start moving slowly at same speed. No  
3 other cars were present in between the driven vehicle and the lead vehicles. Driven vehicle will be  
4 referred as subject vehicle in rest of this paper. When the spacing between the subject and the lead  
5 vehicle reached 60m, the speed of both lead vehicles increased up to 20km/h. When the spacing was  
6 30m or less, lead vehicles increased the speed to 35km/h with an acceleration of about  $4.0 \text{ m/s}^2$  and  
7 maintained that speed until the end of the car-following event. Both lead vehicles run with same speed  
8 so that the driver neither could overtake nor benefit by changing lane. The signal at intersection I2  
9 was kept green to provide uninterrupted flow from section R2 to R3.

10 Each participant was required to drive in three phone conditions: a baseline condition (without  
11 any phone conversation), and hands-free and handheld phone conditions on the same road. Three  
12 route starting points were designed to reduce learning effects. The driving conditions were  
13 counterbalanced across participants to control for carry-over effects. Before participating in the  
14 experimental drive, each participant performed a practice drive of 5-6 minutes to become familiar  
15 with the driving simulator. The participants in this study did not go through acuity or colour  
16 deficiency testing. The details of the participant testing protocol can be found in Haque and  
17 Washington (2014).

#### 18 **2.4. Mobile phone task**

19 A Nokia 500 phone was used in this study, which had dimensions of 111.3 x 53.8 x 14.1mm. The  
20 participants talked through a Bluetooth headset in the hands-free condition, and were required to hold  
21 the phone to their ear for the duration of the conversation in the handheld condition. The experimenter  
22 called the participant before the start of the drive and the call continued until the end of the drive. The  
23 experimenter was neither able to observe the driving of a participant, nor receive any clues regarding  
24 route progress.

25 The phone conversation was cognitive in nature, which required simultaneous storage and  
26 processing of information, and thus distracted the drivers by increasing their cognitive load.  
27 Conversation dialogues were modified from Burns *et al.* (2002). The participants were required to

1 provide an appropriate response after hearing a complete question, solving a verbal puzzle, or solving  
 2 a simple arithmetic problem.

3

### 4 **3. DATA AND ANALYSIS**

#### 5 **3.1. Dataset for analysis**

6 There was no geographically fixed point where the car-following started, as it depended on the speed  
 7 of the subject vehicle. To observe car-following behaviours from all the participants, a roadway  
 8 segment of 245m length was selected as shown with a thick border in Figure 1. The car-following  
 9 duration within the study area is ranged between 22 to 39 seconds. Similar length of the CF duration  
 10 is reported in the literature (e.g., Muhrer and Vollrath, 2011; and He et al., 2014).

11 The final dataset contained vehicle trajectory data for 32 participant drivers in three phone  
 12 conditions. Hence, a total of 96 car-following trajectories were obtained from the simulator  
 13 experiment. The simulator recorded different driving related variables such as speed of the subject  
 14 vehicle, spacing between the subject and the lead vehicle in the same lane of the driver, position of the  
 15 vehicles, acceleration and braking of the subject vehicle, and speed difference between the subject and  
 16 the lead vehicle. Driver demographic variables like age, gender, licence type, and driving history were  
 17 collected from the questionnaire filled up by each participant before starting the simulator drives

#### 18 **3.2. Statistical analysis**

19 A wide range of car-following related variables is identified in literature. The following variables  
 20 were considered to examine the effect of distraction on car-following behaviour:

- 21 a) Average speed of the subject vehicle  $n$  [ $\mu(V_n)$ ],
- 22 b) Average spacing from the lead vehicle [ $\mu(\Delta X_n)$ ],
- 23 c) Average speed difference [ $\mu(\Delta V_n)$ ,  $\Delta V_n = V_{n-1} - V_n$ ],
- 24 d) Average time headway [ $\mu(\Delta T_n)$ ,  $\Delta T_n = \Delta X_n / V_n$ ],
- 25 e) Fluctuation in speed [ $\sigma(V_n)$ ],
- 26 f) Fluctuation in spacing [ $\sigma(\Delta X_n)$ ],
- 27 g) Acceleration noise.

1 Acceleration noise (AN) is the least used variable among the above mentioned ones. Acceleration  
2 noise is defined as the standard deviation of acceleration/deceleration of a vehicle. It was first  
3 proposed by Herman *et al.* (1959) to describe the driver–car–road interaction under diverse  
4 conditions. In free flowing traffic and in steady driving acceleration noise is relatively small.  
5 However, it may increase for various reasons for example when the roadway conditions deteriorate,  
6 and the level of traffic and congestion increases (Taylor *et al.* 2000). A reckless driver, who drives  
7 fast and applies sudden breaks, will have a larger acceleration noise than the one who drives smoothly  
8 (Jones and Potts, 1962). Farah *et al.* (2012) used acceleration noise to see if drivers' acceleration  
9 behaviours have improved when driving with cooperative systems. Belzet *al.* (2011) found that young  
10 drivers (*i.e.*, 21-35years) have higher acceleration noise than old drivers (*i.e.*, above 70 years old) in  
11 high speed and on grades. Studies (*e.g.*, Jones and Potts, 1962) suggest that higher acceleration noise  
12 indicates potentially dangerous situations.

13 The above-mentioned variables were calculated for each driver in three driving situations. The  
14 dataset represents a panel data where each variable was measured in three different driving conditions.  
15 One-way repeated measures ANOVA test was performed to observe the effect of distraction on  
16 selected dependent variables. Later, a pairwise t-test with adjusted *p*-value was used as post hoc test to  
17 see which driving conditions were significantly different. Holm–Bonferroni (Holm 1979) method had  
18 been applied for *p*-value adjustment.

19 Finally, Generalized Estimation Equation (GEE) (Liang and Zeger 1986) was applied to  
20 model driver's time headway as a function of various independent variables. GEEs represent an  
21 extension of the Generalized Linear Models (GLM; Nelder and Baker 1972) to accommodate  
22 correlated data where the correlation is a result of repeated observations of the same participant. GLM  
23 is based on the maximum likelihood theory (McCullagh and Nelder, 1989) for independent  
24 observations. GEE is based on quasi-likelihood theory (Wedderburn, 1974) where no assumption  
25 needs to be made about the distribution of the response observations, and the response observations  
26 do not necessarily have to be independent. In the context of this study, time headways of the same  
27 driver were observed in three phone conditions, and hence GEE is a suitable modelling technique to  
28 account for possible correlation arising from multiple observations across individuals. While the GEE

1 analysis can accommodate various correction structures, this study adopted an exchangeable  
2 correlation structure which assumes a constant correlation coefficient among multiple observations  
3 from an individual.

4 Since GEE models are particularly suitable for panel data where residuals are not  
5 independent, common likelihood based methods and other measures of model fit of ordinary linear  
6 regression are not applicable here. Pan (2001) proposed quasi-likelihood under independence model  
7 criteria (QIC) to select best working correlation structure. Zheng (2000) introduced a simple extension  
8 of  $R^2$  statistics for GEE models and named as Marginal  $R^2$  to be used as a fitness measure. In this  
9 study, the QIC and Marginal  $R^2$  value were used to measure goodness of fit of the model.

10

## 11 **4. RESULTS**

### 12 **4.1. Driving performances of distracted drivers in car-following situation**

13 To examine the effect of mobile phone use while car-following, bar chart with mean value and  
14 standard error (SE) for selected CF variables are presented in Figure 2.

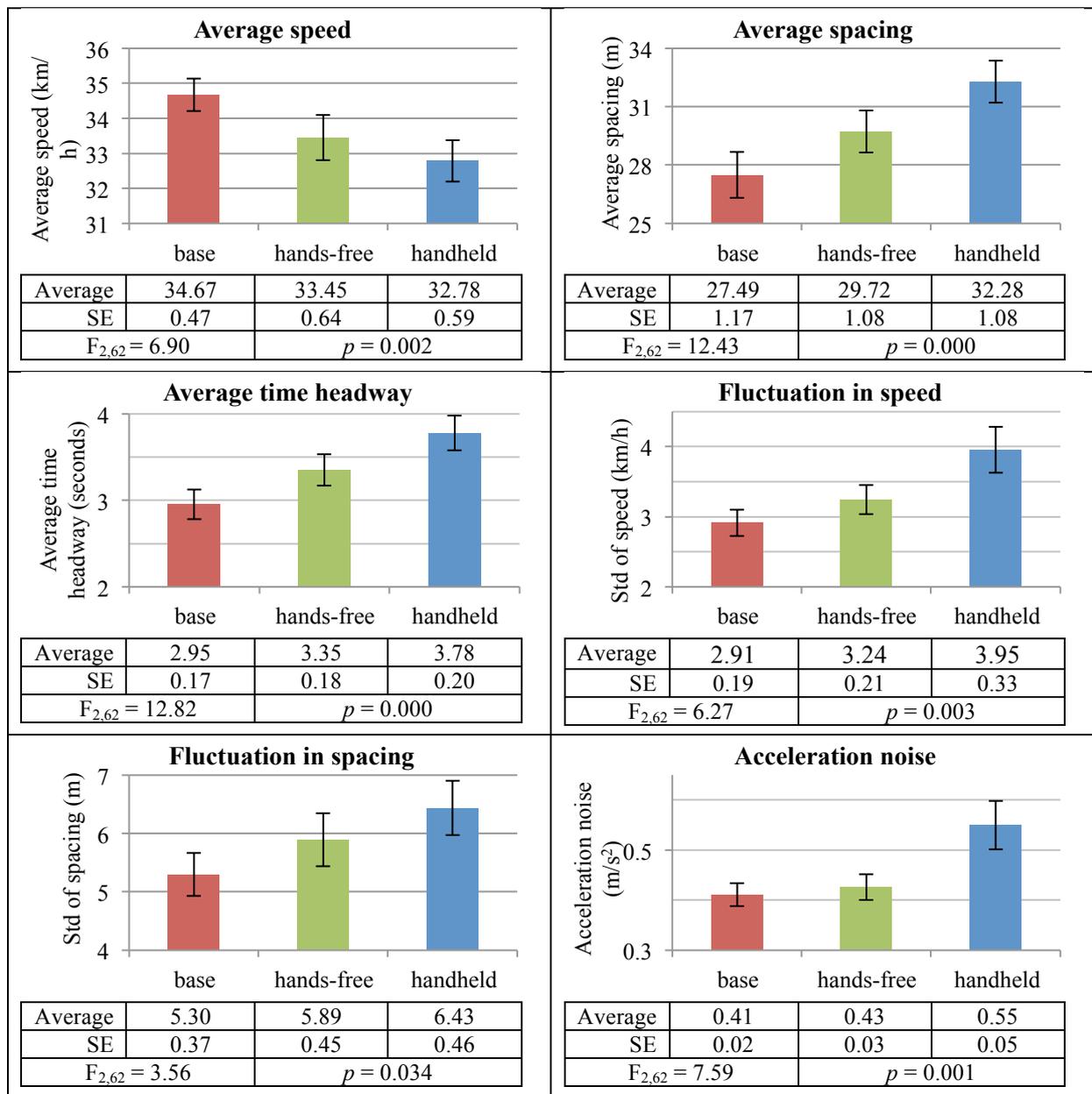
#### 15 **Average speed**

16 It is the average of speeds obtained from car-following trajectories. Figure 2 shows that the average  
17 speed of the subject vehicle reduces with distraction level. A significant effect of distraction on speed  
18 selection is found from the repeated measures ANOVA test ( $F_{2,62}=6.90, p=0.002$ ). Post hoc test  
19 further suggests that the difference in baseline vs. handheld phone condition is most significant  
20 ( $p=0.004$ ) and baseline vs. hands-free are least significant ( $p=0.029$ ). In general the average speed  
21 was 5.5% and 3.5% slower from baseline when drivers were distracted by a handheld and hands-free  
22 phone conversation respectively.

#### 23 **Average spacing**

24 Average spacing is the mean distance the subject vehicle maintained from the lead vehicle while car-  
25 following. A significant increase in spacing choice is observed as an effect of distraction ( $F_{2,62}=12.43,$   
26  $p=0.000$ ). Average spacing was 17.4% ( $p=0.000$ ) higher in handheld and 8.1% ( $p=0.045$ ) higher in  
27 hands-free compared to baseline condition.

1

2 **FIGURE 2 Effect of distraction on different traffic flow parameters (error bar represents SE).**

3

4 **Average speed difference**

5 It is the mean speed difference between the subject and lead vehicle during the car-following event.

6 No significant difference is observed in average speed difference ( $F_{2,62}=0.51$ ,  $p=0.604$ ), and standard7 deviation of speed difference ( $F_{2,62}=1.90$ ,  $p=0.158$ ) in distracted situation. A driver in car-following

8 situation continuously attempts to match their speed with the lead vehicle. Hence, it is expected that

9 the speed difference would be similar in all three driving conditions.

### 1 **Average time headway**

2 Time headway for driver  $n$  at an instant  $t$  is defined as the elapsed time between the front of the lead  
3 vehicle passing a point on the roadway and the front of the following vehicle passing the same point  
4 (Evans 1991). A significant effect of distraction on average time headway during car-following is  
5 observed ( $F_{2,62}=12.82$ ,  $p=0.000$ ). The mean values suggest that time headway increases with  
6 distraction level. Compared to baseline condition the average time headway was 28.0% ( $p=0.000$ )  
7 higher for handheld and 13.5% ( $p=0.018$ ) for hands-free phone conversation while driving.

### 8 **Fluctuation in speed**

9 It is the standard deviation of speed of the driven vehicle during car-following. A significant effect of  
10 distraction on fluctuation in speed is observed ( $F_{2,62}=6.27$ ,  $p=0.003$ ). The mean suggest that  
11 fluctuation in speed increases with distraction level. The fluctuation in speed was 35.9% ( $p=0.022$ )  
12 higher when driving with handheld phone conversation compared to baseline condition. The  
13 difference between hands-free and baseline was not statistically significant ( $p=0.232$ ).

### 14 **Fluctuation in spacing**

15 It is the standard deviations of spacing between the subject and lead vehicle during car-following.  
16 Similar to fluctuation in speed, a significant effect of distraction on fluctuation in spacing is observed  
17 ( $F_{2,62}=3.56$ ,  $p=0.034$ ). Figure 3 suggests that fluctuation in spacing increases with distraction level.  
18 The fluctuation in spacing was 21.5% ( $p=0.023$ ) higher when driving with handheld phone  
19 conversation compared to baseline. The difference between hands-free and baseline was not  
20 statistically significant ( $p=0.378$ ).

### 21 **Acceleration noise**

22 It is the standard deviation of acceleration of the subject vehicle. A significant increase in acceleration  
23 noise is observed as an effect of distraction ( $F_{2,62}=7.59$ ,  $p=0.001$ ). The bar chart in Figure 3 and Post  
24 hoc test suggest that the distraction effect is not significant for hands-free driving ( $p=0.557$ ), but  
25 acceleration noise was significantly higher (33.9%,  $p=0.015$ ) when driving with handheld phone  
26 conversation compared to the baseline condition. Acceleration noise is an indicator of driving  
27 smoothness. An increased acceleration noise in handheld condition explains less control over driving.

28

## 1 4.2. Speed, spacing and time headway profile

2 To observe the car-following behaviour along the road segment, four most important car-following  
 3 variables were considered. They were speed, spacing, time headway and speed difference. The  
 4 average values of these variables were plotted against distance travelled. The variable values are  
 5 averaged over every 4m segment (which is the size of the driven car) using the formula shown in  
 6 Equation (1):

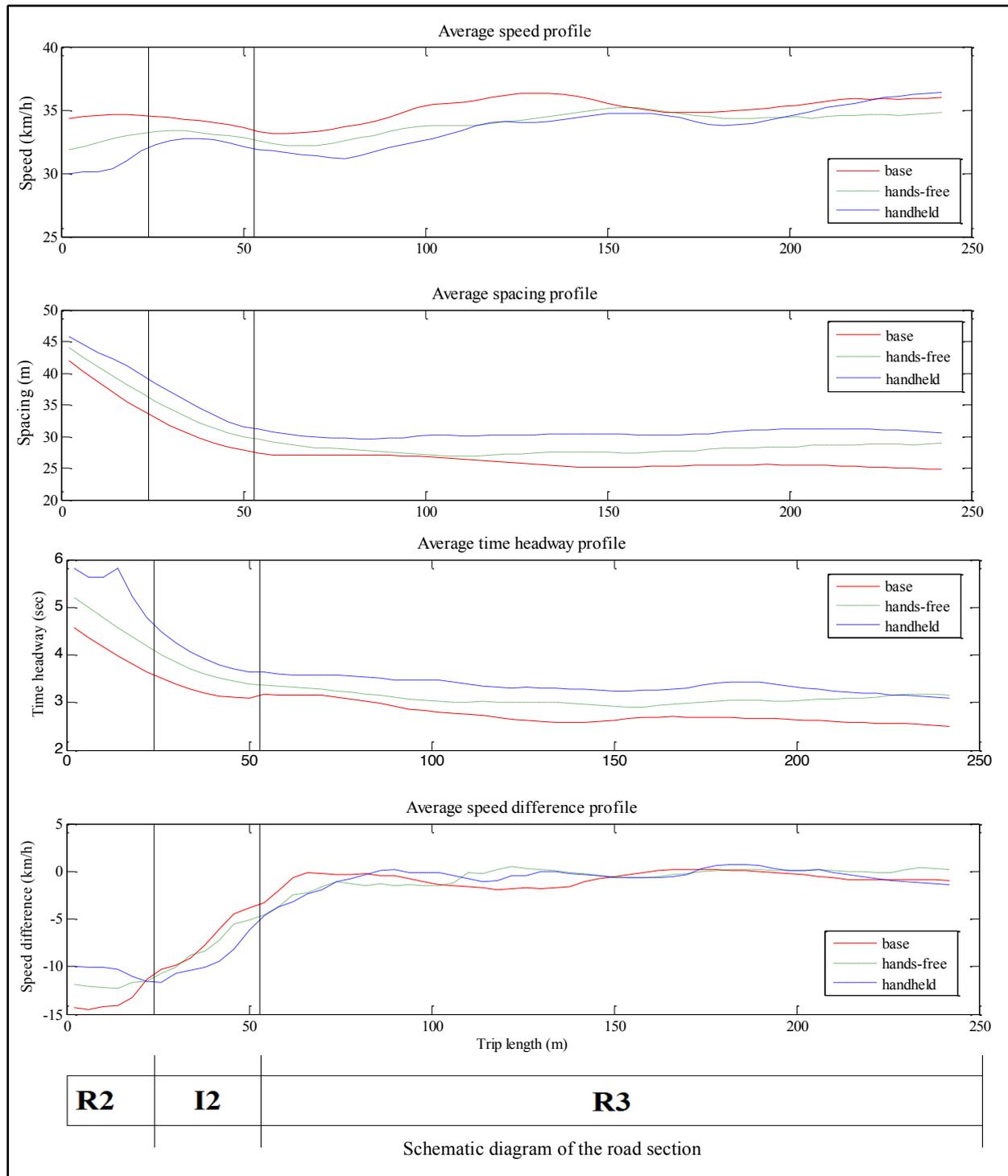
$$X_{ij} = \frac{1}{32} \sum_1^{n=32} X_{nij} \quad ; \quad \text{where } \begin{cases} i = \text{segment id [1:61]} \\ j = [\text{base, handsfree, handheld}] \end{cases} \quad (1)$$

7

8 where  $X$  denotes the variable value,  $i$  is the segment id and  $j$  is the phone condition. The profiles are  
 9 shown in Figure 3.

10 The speed, spacing and time headway profile shows clear difference between the three driving  
 11 conditions. In general, distracted drivers tend to select a slower driving speed and maintain a higher  
 12 spacing and longer time headways with the lead vehicle throughout the length of the road where car-  
 13 following situation existed. Maximum difference is observed between baseline condition and driving  
 14 with handheld phone conversation. No clearly noticeable difference is observed in speed difference  
 15 since drivers were exposed in a car-following situation. As a result, drivers appear to match their  
 16 speed with the lead vehicle, which was maintaining a constant speed.

17



**FIGURE 3 Profile for average speed, average spacing ( $\Delta X$ ), average time headway ( $\Delta T$ ) and average velocity difference ( $\Delta V$ ).**

### 4.3. GEE analysis

GEE was applied to model driver's time headway as a function of various independent variables. The analysis will identify what factors may affect driver's time headway selection. Time headway was

1 selected as the dependent variable because it considers both the speed and spacing together. The  
 2 potential explanatory variables for the statistical model included phone condition, driver  
 3 demographics (age, gender, licence type and driving experience) and average speed difference with  
 4 the lead vehicle. Descriptive statistics of these variables are presented in Table 2. Data from all 32  
 5 drivers are available in three phone conditions, which created a balanced panel data with 3  
 6 observations per driver.

7 **Table 2: Descriptive statistics of variables for GEE**

Variable name	Description of variables	Min	Max	Average	SD	Count
Phone condition						
Base	No phone conversation = 1, otherwise = 0	-	-	-	-	32
Hands-free	Hands-free phone conversation = 1, otherwise = 0	-	-	-	-	32
Handheld	Handheld phone conversation = 1, otherwise = 0	-	-	-	-	32
Driver's age	Continuous variable	18	26	21.47	1.98	-
Gender						
Male	If a driver was male = 1, otherwise = 0	-	-	-	-	16
Female	If a driver was female = 1, otherwise = 0	-	-	-	-	16
License type						
Open	If a driver held an open license = 1, otherwise = 0	-	-	-	-	21
Provisional	If a driver held a provisional license = 1, otherwise = 0	-	-	-	-	11
Years of driving	Continuous variable	1	9	4.20	1.87	-
Average time headway	Continuous variable	1.23	6.36	3.36	1.10	-
Average speed difference	Continuous variable	-5.93	3.10	-2.46	1.68	-

8  
 9 Time headway selections of drivers were modelled with a Generalized Estimation Equation with  
 10 exchangeable correlation structure. The model results are presented in Table 3. The best-fit model was  
 11 derived from a set of models with all possible independent variables following Marginal  $R^2$  and QIC  
 12 criteria. This model produced the smallest QIC value from a set of alternative models with different  
 13 independent variables and correlation structures. Smallest QIC value ensures the selection of best  
 14 working correlation structure (exchangeable in this case). The model also estimated a value of 0.50  
 15 for the exchangeable correlation parameter, which indicates a significant correlation among  
 16 observations of each driver and thus further ensures the appropriateness of the GEE model. This  
 17 model produced highest Marginal  $R^2$  value among the tested models. The Marginal  $R^2$  value suggests  
 18 that the model can explain 49% of the variability in the dataset. In this model, all parameters are

1 significant. The best-fit model retained four significant variables including phone condition, average  
2 speed difference, driver gender and driver licence type.

3 The parameters for both phone conditions have been found to be positive and significant at  
4 5% significance level in the GEE model. Results clearly indicate that distracted driving influences the  
5 time headway selection of drivers in car-following situation. Parameter estimates suggest that  
6 distracted drivers, on average, tend to keep 0.33 seconds more headways when engaged in hands-free  
7 phone conversation compared to baseline driving. The corresponding headway difference for  
8 handheld phone driving condition was about 0.75 seconds. The effects of distraction are higher in  
9 driving with handheld phone conversation since this condition has both cognitive and manual  
10 distraction. Consequently, handheld driving may be associated with the highest time headway among  
11 the three driving scenarios.

12 **Table 3: GEE Model Estimates for Mean Time Headway.<sup>ab</sup>**

Variable	Estimate	SE	Wald statistic	p-value
<b>Constant</b>	3.77	0.21	308.32	0.0000***
<b>Phone Condition</b>				
<b>Hands-free</b>	0.33	0.13	6.54	0.011*
<b>Handheld</b>	0.75	0.16	21.63	0.000***
<b>Average speed difference</b>	0.29	0.03	92.47	0.000***
<b>Gender</b>				
<b>Female</b>	-0.68	0.28	5.66	0.017*
<b>Licence Type</b>				
<b>Provisional</b>	0.81	0.30	7.24	0.007**
<b>Estimated scale parameters (intercept)</b>	0.61	0.11		
<b>Estimated Correlation Parameters (alpha)</b>	0.50	0.12		
<b>QIC</b>	-30.84			
<b>Quasi-Likelihood</b>	-29.47			
<b>Marginal R<sup>2</sup></b>	0.49			
<b>Number of Observations</b>	96			
<b>Number of clusters</b>	32			
<b>Maximum cluster size</b>	3			

13 Signif.codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

14 <sup>a</sup> Model equation: Average time headway =  $b_0 + b_1 * \text{Phone condition} + b_2 * \text{Average speed difference} +$   
15  $b_3 * \text{Gender} + b_4 * \text{Licence type}$

16  
17  
18 Average speed difference, which represents the speed difference between the subject and lead vehicle,  
19 has also been significant and positive in the GEE model of time headways in car-following situation.

1 Results suggest that time headway increases with the increase in speed differences. A 1 km/h increase  
2 in speed differences leads to about 0.29 seconds increase in time headways. Speed difference can have  
3 both positive and negative values. When a lead vehicle is travelling faster than the subject vehicle, the  
4 speed difference is positive and the corresponding time headway increases. On the other hand, when  
5 the subject vehicle is approaching to a slower vehicle, the speed difference is negative and the  
6 corresponding time headway decreases.

7 It is interesting to notice that female drivers keep less time headway than male drivers. The  
8 parameter associated with gender suggests that in general female drivers keep 0.68 seconds less time  
9 headway than a male driver in same car-following situation. Driving experience seems to have an  
10 impact on time headway selection as the model shows that 'provisional' license holders (less  
11 experienced driver) prefer to keep longer time headway than 'open license holders (experienced  
12 driver). The effect is even higher than gender. According to the model, a provisional licence holder  
13 will keep 0.81 seconds longer time headway than an open licence holder in car-following situation. It  
14 is understandable as provisional drivers might have less confidence on their driving ability and thus  
15 drive with longer time headway.

16

## 17 **5. DISCUSSION**

18 Types of phone conversation (hands-free or handheld) affect the car following behaviour differently.  
19 When driving with hands-free phone conversation the car-following performance did not deteriorate  
20 significantly from the baseline. As a result no significant difference was observed for variables like  
21 average spacing, fluctuation in spacing and speed, and acceleration noise. This can be partially  
22 explained by the prevalence of mobile phone use among the young participants (on average the  
23 participants reported to make 65 calls and send 260 text messages in a typical week). However,  
24 similar tests on older drivers are needed to confirm this finding.

25 The findings were different for drivers engaged in handheld phone conversations, with the  
26 additional physical constraint of holding the phone. This multitasking configuration increased the  
27 workload to the highest level among the three phone conditions. The handheld condition placed an

1 additional manual load on the driver, which together with the mental demand, leads to a greater  
2 distraction effect on drivers during the two phone conversations (Higher workload in handheld phone  
3 condition was also reported in Matthews et al. (2003) who discovered no difference in mental demand  
4 between hands-free and handheld phone conversation, however, physical demand was higher for  
5 handheld phone). As a result, the car-following performance was significantly deteriorated. The  
6 largest difference between driving conditions was the fluctuation in speed between handheld and  
7 baseline driving condition. The second largest difference was acceleration noise between the handheld  
8 and baseline conditions. Compared to the baseline condition, a 35.9% increase in speed fluctuation  
9 along with 33.9% increase in acceleration noise revealed a significant impact of distracted behaviour  
10 caused by handheld phone conversations. Increased fluctuation in speed and acceleration explains less  
11 control over driving situation in handheld situation compared to baseline. However, drivers have  
12 perceived the risk associated with distraction caused by phone conversation while driving. To  
13 compensate the risk they showed risk compensatory behaviour by increasing spacing and decreasing  
14 speed from baseline condition. The risk compensatory behaviour is observed in both phone  
15 conditions. However, the magnitude is highest for handheld phone conversation which is most likely  
16 caused by highest perception of risk in this situation.

17 Fluctuation of spacing increased when driving with handheld phone conversation compared to  
18 baseline. However, in Figure 3 the spacing profiles become fairly stable in all three conditions after  
19 about 70m from the start point of car-following. Additional descriptive analysis is performed on car-  
20 following data within 70-245m road section. The new analysis shows similar conclusion for all  
21 variables except that the difference in fluctuation of spacing becomes insignificant ( $F_{2,62}=0.618$ ,  
22  $p=0.541$ ). It appears that distracted drivers have more variations in spacing when they try to achieve  
23 their desired spacing for car-following. Once the desired spacing is reached, drivers try to maintain  
24 that unless any change occurs in driving environment.

25 The time headway selection of drivers was modelled using GEE. The model shows that a  
26 typical driver increases the time headway by 0.33 seconds when conversing using hands-free devices  
27 and by 0.75 seconds when using handheld mobile phones. In general, female drivers maintain shorter  
28 time headways than male drivers. Less experienced drivers (provisional license holders) maintain

1 greater time headways than experienced drivers (open license holder) on average. Female drivers with  
2 open driving licenses maintain the shortest time headways in this model, while male drivers with  
3 provisional licences maintain the longest time headways. Distraction further increases time headways  
4 for all drivers.

5

## 6 **6. CONCLUSION**

7 This study investigates car-following behaviour of drivers distracted by mobile phone conversations.  
8 Participants were exposed to a car-following task in a motion-based driving simulator where the lead  
9 vehicle maintained a predefined speed profile depending on the spacing between the driver and the  
10 lead vehicle. Focus was given to the behaviour of young drivers only with an age cohort between 18  
11 to 26 years. The sample size was good enough to identify some patterns and factors affecting the car-  
12 following behaviour of young drivers, although a larger sample size may increase the statistical  
13 reliability of the results. A set of variables was selected to capture car-following behaviour. Repeated  
14 measures ANOVA tests were implemented to identify the effect of mobile phone distraction on the  
15 selected car-following variables. The study finds evidence of a significant effect of distraction on  
16 speed selection, vehicle spacing, and time headways. Overall, drivers maintained lower speeds, larger  
17 vehicle spacings, and longer time headways when engaged in phone conversations compared to  
18 baseline without phone conversations. This finding may indicate the presence of risk-compensatory  
19 behaviour, which has been elsewhere observed and reported in the literature (Ranney *et al.* 2004,  
20 Strayer *et al.* 2011).

21 The repeated measures ANOVA test also revealed significant effects of distraction on  
22 fluctuation in speed and spacing, and acceleration noise. These increases suggest that distracted  
23 driving results in less consistent control in maintaining speed and vehicle spacing in car-following  
24 situations. The reduction in speed and increase in vehicle spacing could reflect drivers' attempts to  
25 compensate for the increased risk associated with the mobile phone conversations, or could be an  
26 artefact of the distraction itself. If the reduction reflects risk compensation, there is insufficient  
27 evidence to assess whether the reduction in crash risk would offset the increased crash risk arising

1 from distraction. Other evidence on crash risk while distracted suggests that crash risk overall is  
2 increased while distracted. For example, both hands-free and handheld phone uses while driving are  
3 associated with a fourfold increase in accident risk (McEvoy *et al.* 2005, Redelmeier and Tibshirani  
4 1997). These findings suggest that observed risk compensation is insufficient to offset risk increment  
5 caused by cognitive distraction.

6         These results can foster a better understanding of the consequence of distracted driving on  
7 road crashes, and shed light on the complexity involved with modelling driving behaviour. Driving  
8 behaviour modelling is one of the oldest and most studied topics in Traffic Engineering. Many models  
9 have been developed to describe two primary driving tasks: car following (see Saifuzzaman and  
10 Zheng (2014) for the latest review) and lane changing (see Zheng (2014) for a comprehensive  
11 review). Despite notable progress in the last few decades on this important topic, efforts to incorporate  
12 human factor effects are limited. For most driving behaviour models, information on vehicular  
13 movements is the only input. The potential complexity introduced by human drivers is by and large  
14 ignored. This omission is not surprising due to our limited understanding on human factor issues.  
15 More specifically, there is a clear need to comprehensively investigate and accurately quantify how  
16 drivers perform when distracted because of its importance to both road safety and driver behaviour  
17 modelling. This research gap partially motivated this study. The findings clearly show that drivers  
18 behave differently when distracted by hand-held phone conversations. Unfortunately, most of the  
19 existing car-following models do not consider such impacts on driving because they are developed for  
20 normal (i.e., non-distracted) driving situations (Saifuzzaman and Zheng 2014). Recently, researchers  
21 in the traffic flow community have realized the importance of improved and more comprehensive  
22 reflection of human factor dimensions in car-following models, and have started exploring new ideas  
23 (e.g., Hamdar and Mahmassani (2008)). We believe that empirical evidence on how distracted driving  
24 influences car-following behaviour (e.g., speed, spacing, and time headway) revealed in this study can  
25 facilitate such efforts. In keeping, the authors are working currently on improving car-following  
26 model performance by incorporating behavioural differences caused by distraction.

27         Current study did not address reaction time differences arising from distracted driving, as this  
28 topic is covered in Haque and Washington (2013), and Haque and Washington (2014). This study is

1 focused on car-following behaviour of young drivers only; further study is required to investigate the  
2 effect of mobile phone distraction in a wider range of driver ages to compare the car-following  
3 behaviour across different age groups. Future studies are also required to investigate distracted car-  
4 following behaviour in other scenarios, for example, on longer road section, with different speed  
5 limits, and on curve segments. Influence of other type of human factors (for example, fatigue,  
6 drowsiness, alcohol and drug use, emotion and stress) on car-following behaviour should also be  
7 investigated in future to obtain a better picture about human car-following behaviour in different  
8 circumstances.

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