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Stopping behaviour of drivers distracted by mobile phone conversations

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Abstract

Increased cognitive load—due to talking on a mobile phone whilst driving—has been shown to impair decisions and actions of distracted drivers in numerous ways including speed selection, lane keeping, and compliance with traffic signals to name a few. In contrast, the stopping behaviour of distracted drivers has not been examined in detail, despite the fact that improper stopping might lead to rear-end and angle collisions. As such, the aim of this study was to examine the stopping behaviour of drivers distracted by a mobile phone conversation. In particular, the stopping behaviour of drivers after detecting a pedestrian entering a zebra crossing was examined.

The CARRS-Q Advanced Driving Simulator was used to test participants on various simulated driving tasks including an interaction with a pedestrian at a zebra crossing. Thirty-two licensed drives drove the simulator in three phone conditions: baseline (no phone conversation), hands-free and handheld. In addition to driving the simulator, each participant completed questionnaires related to driver demographics, driving history, usage of mobile phones while driving, and general mobile phone usage history. The drivers were 21 to 26 years old and split evenly by gender. An analysis of speed profiles along the roadway before the pedestrian crossing revealed increased decelerations among distracted drivers, particularly during the initial 20 kph speed reduction. Drivers' initial 20 kph speed reduction time was modelled using a parametric accelerated failure time (AFT) survival model with a Weibull distribution and clustered heterogeneity, accounting for the repeated measures design.

Factors significantly influencing the survival time included vehicle dynamics variables like initial speed and maximum deceleration, driver-specific variables such as phone condition, crash involvement history, and self-reported experience using a mobile phone whilst driving. Distracted drivers on average appear to reduce the speed of their vehicle faster and more abruptly than non-distracted drivers, revealing an element of risk compensation. Abrupt stopping by distracted drivers might pose significant safety concerns to following vehicles in a traffic stream.

Keywords: Traffic safety, accelerated failure time, hazard analysis, advanced driving simulator, young driver safety

1. Introduction

Research on the mobile phone use whilst driving has been the focus of a large body of literature over the past decade. Distraction imposed by a mobile phone use—particularly increased cognitive distraction—has been shown to impair the performance of drivers in numerous measures. Common impaired performances of distracted drivers include a deterioration of speed control, an increase of variation of lateral control, a failure to maintain appropriate headways, an increase in reaction time in responding to hazards, a limitation in visual scanning behaviour particularly a decline in peripheral eye scanning and an impairment in perceiving relevant stimuli (e.g., Caird et al., 2008; Horrey & Wickens, 2006; Regan et al., 2009).

A study using an advanced driving simulator by Burns et al. (2002) reported that mobile phone conversations impaired speed control and response to road signs more than by having a blood alcohol level at the legal limit of 8% or 80mg/100ml legal limit. Rakauskas et al. (2004) reported that mobile phone conversations caused driver to have a higher variation of accelerator pedal position and drive slowly with a greater speed variation. The speed reduction of distracted drivers has often been interpreted as a risk compensatory effort for the increased mental workload (e.g., Törnros & Bolling, 2006). A desktop simulator study by Dula et al. reported that driving performances like percent time spent speeding and centre line crossings were significantly higher when drivers were engaged in different types of phone conversations compared to no conversation. Another desktop simulator study by Beede and Kass (2006) reported that talking on a hands-free phone while driving impacted driving performances in four categories of driving behaviour including traffic violations, driving maintenance, attention lapses and response time. Haque et al. (2013) reported that novice and young drivers were more likely to run through the yellow light of a signalized intersection while distracted by a mobile phone conversation, indicating the combined effect of being inexperienced and distracted particularly risky.

One of the most often reported performance detriments as a result of mobile phone distraction is the reaction time—often considered as a surrogate measure of crash risk. A meta-analysis conducted by Caird et al. (2008) reported an average 0.25 second increase of reaction times for all phone related tasks and the amount of decrements varied depending on age, task, event or stimuli. Another meta-analysis by Horrey and Wickens (2006) revealed that mobile phone distraction increased the reaction times to unexpected hazards with similar effects for hands-free and handheld phone conditions. A recent study by Haque and Washington (Haque & Washington, 2013a) using an advanced driving simulator showed that cognitive distractions due to mobile phone conversations impaired the reaction times of distracted young drivers while they responded to a traffic event in their peripheral vision, but not when they responded to a traffic event in their central vision.

Braking performances of distracted drivers have generally been measured by brake response time and amount of braking. Consiglio et al. (2003) examined the braking response of distracted drivers upon the activation of a red lamp in a laboratory setting and found that both hands-free and handheld phone conversations resulted in a slower response in braking performances. Al-Darrab et al. (2009) reported that the brake response time to a lead vehicle in a real driving environment is positively correlated with mobile call duration, and the impairment was greater during night time driving. An experiment on a test-track facility, where participants distracted by a visual-manual task were instructed to perform a quick stop before reaching the stop line of an intersection upon the onset of a red light, showed that drivers were slower in response to the light change and braked more intensely in distracted condition (Hancock et al., 2003). In another on-road experiment study by Harbluk et al. (2007) reported that there were more occasions of hard braking with the longitudinal acceleration exceeding 0.25g in demanding cognitive task condition which required drivers to add double digit numbers while driving.

While prior research has documented a variety of performance measures that are impacted by the distracting effects of mobile phone use, comparatively little is known about the speed profile of distracted drivers while they are stopping. A good understanding on the stopping behaviour is important since improper stopping might lead to rear-end or angle collisions. Indeed, an analysis on the US crash data has shown that teenage drivers distracted by mobile phones were more likely to be involved in rear-end collisions (Neyens & Boyle, 2007). However, there is a little research on the stopping behaviour of distracted drivers.

As such, the objective of this study was to examine the stopping behaviour of drivers distracted by mobile phone conversations. In particular, the stopping behaviour was studied and modelled when drivers stopped in response to a pedestrian at a zebra crossing. A statistical model is used to examine and compare the performance in distracted and non-distracted conditions, after controlling for the effects of various exogenous variables like vehicle dynamics, driver demographics, driving experience, and self-reported history of mobile phone usage. To accomplish these aims, a group of distracted drivers were exposed to a number of traffic events including an interaction with a pedestrian at zebra crossing while driving a series of routes within the CARRS-Q Advanced Driving Simulator.

The remainder of the paper first describes the experimental details including a brief description of the driving simulator, experimental procedure, participants, and data collection approach. The next section describes the dataset and statistical model used to aid the analysis, briefly describing the hazard-based duration modelling approach suitable for modelling stopping behaviour after accounting for repeated measures experiment design. The results of the analysis are then discussed, followed by overall research conclusions.

2. Method

2.1 Driving Simulator

The experiment was conducted in the CARRS-Q Advanced Driving Simulator located at the Queensland University of Technology (QUT). This high fidelity simulator consisted of a complete car with working controls and instruments surrounded by three front-view projectors providing 180-degree high resolution field view to drivers. Wing mirrors and the rear view mirror were replaced by LCD monitors to simulate rear view mirror images. Road images and interactive traffic were generated at life size onto front-view projectors, wing mirrors and the rear view mirror at 60 Hz to provide photorealistic virtual environment. The car used in this experiment was a complete Holden Commodore vehicle with an automatic transmission. The full-bodied car was rested on a 6 degree-of-freedom motion base that could move and twist in three dimensions to accurately reproduce motion cues for sustained acceleration, cornering, braking manoeuvres and interaction with varying road surfaces. The simulator was also capable of producing realistic forces experienced by drivers through the steering wheel while they were negotiating curves. The simulator used SCANeR™studio software with eight computers linking vehicle dynamics with the virtual road traffic environment. The audio system of the car was linked with the simulator software so that it could accurately simulate surround environment sounds for engine noise, external road noise and sounds for other traffic interactions, and thus further enhancing the realism of the driving experience. Driving performances data like position, speed, acceleration and braking were recorded at rates up to 20 Hz.

2.2 Participants

The participants recruited for the study included thirty-two volunteers who were reimbursed upon completion of the study. They were recruited by disseminating recruitment flyers using university student email addresses or university facebook portals and posting recruitment flyers in a few key university locations, e.g. library, canteen. In order to qualify as a participant they had to fulfil a number of requirements, including 1) be aged between 18 and 26 years, 2) hold either a provisional or open Australian issued driver's licence, 3) not had a history of motion sickness and epilepsy, and 4) not be pregnant. All data not collected in the simulator were self-report.

The mean age of the participants was 21.47 (SD 1.99) years and they were split evenly by gender, consisting of sixteen males and sixteen females. The mean ages for male and female were, respectively, 21.8 (SD 1.80) and 21.1 (SD 2.19) years. The average driving experience was 4.2 (SD 1.89) years; about 44% drove less than ten thousand kilometres; about 47% drove about ten to twenty thousand kilometres; and the remainder drove more than twenty thousand kilometres in a typical year. About 34% of the participants held provisional licences and the rest had open (non-restricted) licences. Note that a provisional licence in Queensland, Australia is issued to a newly licensed driver for duration of up to 3 years before they receive an open licence. The average driving experience of provisional and open licence holders were, respectively, 2.64 (SD 0.75) and 5.01 (SD 1.79) years. About 34% of the participants were involved in a traffic crash in last three years and about 38% of the participants received an infringement notice due to driving related offences like speeding, red light running and mobile phone use while driving during the last year. All participants owned a mobile phone and they made or received an average of 65 (SD 43) calls using their mobile in a typical week and sent or received an average of 261 (SD 197) text messages in a typical week. All of the participants had prior experience using mobile phones while driving for any purpose including talking or texting; 34% of the participants used mobile phones at least once in a day; 47% of the sample used mobile phone once or twice in a week; and the remaining 19% used mobile phones while driving once or twice in a month or year. When asked "what proportions of *talking time whilst driving* do you use the handheld phone", about 53% of participants responded using a hand-held phone 0-25% of their talking time, about 19% responded 25-50%, about 12% responded 50-75%, and the remaining 16% responded using a handheld phone 76-100% of their talking time while driving.

2.3 Experimental Setup

The designed driving route in the CARRS-Q Advanced Driving Simulator contained simulated routes in both urban and rural areas. The simulated route was about 7 km long and included a detailed simulation of the Brisbane CBD with a great deal of accuracy, and a hypothetical suburban area which was created to meet the purpose of this research. The speed limit in the CBD was mostly 40 kph, whereas the speed limit in sub-urban areas varied between 50 and 60 kph. The simulated route was programmed to incorporate various 'traffic events' including a pedestrian who entered a zebra crossing from the sidewalk, an overtaking scenario, a leading car that braked suddenly, gap acceptance manoeuvres at a number of intersections, and a car that drifted towards the driven car from the opposite direction. Three route starting points were designed to reduce learning effects and allow driving under the three different phone conditions, i.e. baseline, hands-free and handheld. All three routes had the same geometry and road layout but the locations of traffic events were randomized across the routes. To examine the stopping behaviour of distracted drivers along the roadway before a zebra crossing, 'a pedestrian entering a zebra crossing from sidewalk' scenario was included and analysed in this paper.

In this simulated traffic event, a driver needed to respond to a pedestrian who crossed the road at a zebra crossing from the sidewalk. The event took place on a four-lane road with two lanes in each direction separated by a continuous centre line. The event took place within the CBD, where the speed limit was 40 kph. Although there were two lanes in each direction, the curb lane was mostly filled with parked vehicles, leaving the median lane available for driving. The pedestrian in the sidewalk, however, was not occluded by parked vehicles and drivers had a clear view to the pedestrian and zebra crossing. Pedestrian crossings were designed by putting appropriate zebra markings and traffic signs for pedestrian crossing following the roadway standards of Australia. There were three zebra crossings in the CBD but a pedestrian entered the zebra crossing from the sidewalk on only one zebra crossing in each driving route. The pedestrian scenario was randomized across the zebra crossings to control for carry-over effects. The event was scripted so that a pedestrian started to move from a sidewalk towards the zebra crossing when the driven car was about 10 seconds or about 110m away from the zebra crossing. Therefore, the drivers had ample distance available to comfortably stop the car on an approach with a speed limit 40 kph that required a stopping distance of only 9m.

2.4 Mobile Phone Task

The mobile phone used in this study was a Nokia 500 phone which had dimensions of 111.3mm x 53.8mm x 14.1mm. For hands-free conversation, the drivers used a Plantronics

Voyager PRO HD Bluetooth Headset connected with the phone through Bluetooth technology, which provided HD streaming audio wirelessly without interruption.

The phone conversation was engaged respondents cognitively. Conversation dialogues were modified from Burns et al. (2002) for this study. Dialogues required the participant to provide an appropriate response after hearing a complete question, solving a verbal puzzle, or solving a simple arithmetic problem. An example question requiring a response was ‘Jack left a dinner in his microwave for Jim to heat up when he returned home. Who was the dinner for?’ A verbal puzzle example was ‘Felix is darker than Alex. Who is lighter of the two?’ An example arithmetic question was ‘If three wine bottles cost 93 dollars, what is the cost of one wine bottle?’ These types of questions required simultaneous storage and processing of information, and thus distracted drivers by increasing their cognitive loads.

2.5 Participant Testing Protocol

Prior to the experiment, participants were greeted by a 21 year old female host who gave all instructions, and engaged in all remaining interactions with participant including the mobile phone conversations. An informed consent was first completed by each participant. The participants were then briefed about the project and completed a questionnaire that required about 20-25 minutes. The questionnaire items included driver demographics, driving history, usage of mobile phones while driving, and general mobile phone usage history. The participants were then briefed about the nature of phone conversations and how to use the mobile phone apparatus during the experiment. The host and participant then practiced several conversation dialogues using the hands-free device and handheld phone.

Participants were required to drive in three phone conditions: a baseline condition (without any phone conversation), and while engaged in hands-free and handheld phone conditions. The driving conditions were counterbalanced across participants to control for learning or carry-over effects. Before inviting a participant to step into the simulator, they were briefed about the driving simulator controls and instruments. Participants were instructed to drive as they normally would. Instructions were given to obey the posted speed limits and follow the directional signs towards the airport—thus participants had a navigational task. Before participating in the experimental drive, each participant performed a practice drive of 5-6 minutes to become familiar with the driving simulator. Participants encountered various traffic events including traffic lights, stop-sign intersections, overtaking scenarios, and gap acceptance manoeuvres during the familiarization drive.

For experimental drives in the hands-free and handheld phone conditions, the experimenter called the participant before the start of the drive and there was a single continuous call until the end of the drive. The participants talked through a Bluetooth headset in the hands-free condition, and were required to hold the phone to their ear for the duration of the conversation in the handheld condition. The host engaged in the phone conversation was seated in a room away from the driving simulator and hence was neither able to observe a participant’s driving, nor receive any clues regarding route progress. When a participant reached the route starting point, after a closed loop drive of about 7 km through the Brisbane CBD and suburban areas, the scenario automatically ended. After each of the experimental drives, i.e. baseline, hands-free and handheld, participants completed a driving activity load index questionnaire while seated in the simulator vehicle. Participants took brief breaks while remaining in the vehicle between each experimental drive while the scenarios were loaded onto the simulator display system.

3. Data and Analysis

3.1 Dataset for Analysis

Stopping behaviour of each participant was observed while they stopped in response to a pedestrian entering a zebra crossing from the sidewalk. Speed profiles were measured for each participant across three phone conditions, i.e. baseline, hands-free and handheld. A statistical model of survival time for speed changes was developed using vehicle dynamics, phone condition, driver demographics, driving history, general mobile phone usage history and record of mobile phone use while driving as explanatory variables. Summary statistics of variables included in the model are presented in Table 1. Vehicle dynamics included two variables like initial speed and maximum deceleration. Initial speed was measured at the instant just before a driver started braking in response to the pedestrian and maximum deceleration was measured as the highest deceleration over a range of braking duration. Driver demographics included three variables including *age*, *gender* and *licence type*. Driver age variable was included as a continuous variable. Driver licence type had two categories, a *provisional licence* holder and an *open licence* holder. Explanatory variables related to driving history included *years of driving*, *kilometres driven in a typical year*, *proportion of trips usually driven with a passenger*, *involvement in traffic offences in the last year* and *involvement in traffic crashes during last three years*. General mobile phone usage history included variables like *total calls* or *text messages* sent or received in a typical week. History of mobile phone use while driving included two variables including *frequency of mobile phone use while driving* and *usage of handheld phone while talking and driving*. Frequency of mobile phone use while driving had three categories including *frequent users* who used mobile phone while driving at least once in a day, *moderate frequent users* who did so once or twice in a week and *less frequent users* who used mobile phone while driving once or twice in a month or year. Usage of handheld (HH) phone while driving and talking had four categories according to the usage behaviour, including *HH1* who used a handheld phone 0-25% of their talking and driving time, *HH2* used 26-50%, *HH3* used 51-75% and *HH4* used a handheld phone 76-100% of their talking and driving time.

There were seven occasions when drivers did not stop for pedestrians at zebra crossing, including one in a baseline condition, four in the hands-free condition, and two in the handheld condition. There were five other observations for which drivers' responses from the brake pedal were not clear enough to distinguish whether or not a driver was stopping in response to the pedestrian. These observations were discarded from the analysis, forming an unbalanced panel dataset of 84 observations.

Table 1: Summary statistics of explanatory variables included in the survival model

Variable	Description of variables	Mean	St. Dev.
Phone condition			
Baseline	If a participant drove without any phone conversation=1, otherwise=0	0.333	0.474
Hands-free	If a participant drove with hands-free phone conversation=1, otherwise=0	0.333	0.474
Handheld	If a participant drove with handheld phone conversation=1, otherwise=0	0.333	0.474
Vehicle dynamics			
Initial speed	Speed in kph: Continuous variable	36.97	5.027
Maximum deceleration[1]	Deceleration in m/s^2: Continuous variable	2.84	1.276
Demographics			
Driver's Age	Age in years Continuous variable	21.47	1.979
Gender			
Male	If a driver was male=1, otherwise=0	0.500	0.503
Female	If a driver was female=1, otherwise=0	0.500	0.503
Licence type			
Open	If a driver held an open licence=1, otherwise=0	0.344	0.477
Provisional	If a driver held a provisional licence=1, otherwise=0	0.656	0.477

Variable	Description of variables	Mean	St. Dev.
Driving History			
Years of driving	Continuous: years	4.203	1.867
Kilometres driven			
0-10,000 km	If a driver drove 0-10,000 km on an average year=1, otherwise=0	0.438	0.499
10,000-20,000 km	If a driver drove 10,000-20,000 km on an average year=1, otherwise=0	0.469	0.502
> 20,000 km	If a driver drove more than 20,000 km on an average year=1, otherwise=0	0.094	0.293
Driving with passenger			
0-50% of trips	If a driver usually takes a passenger in 0-50% trips=1, otherwise=0	0.750	0.435
> 50% of trips	If a driver usually takes passenger in more than 50% trips=1, otherwise=0	0.250	0.435
Traffic offences			
Received	If a driver received an infringement notice (e.g. speeding, drink driving, mobile phone using) last year=1, otherwise=0	0.375	0.487
Not received	If a driver did not receive any infringement notice last year=1, otherwise=0	0.625	0.487
Crash involvement history			
Involved	If a driver was involved in a crash during last three years=1, otherwise=0	0.344	0.477
Not involved	If a driver did not involve in any crash during last three years=1, otherwise=0	0.656	0.477
General Mobile Phone Usage History			
Calls	Continuous: Average number of calls made or received in a typical week	65.344	42.951
Text message	Continuous: Average number of text messages sent or received in a typical week	260.656	196.558
History of Mobile Phone Use while Driving			
Frequency of mobile phone use while driving			
Frequent	If a driver usually uses mobile phone while driving at least once in a day=1, otherwise=0	0.344	0.477
Moderate frequent	If a driver usually uses mobile phone while driving once or twice in a week=1, otherwise=0	0.469	0.502
Less frequent	If a driver usually uses mobile phone while driving once or twice in a moth or year=1, otherwise=0	0.188	0.392
Usage of handheld (HH) phone while talking and driving			
HH1 (0-25%)	If a driver usually uses hand-held phone 0-25% of his time of talking and driving=1, otherwise=0	0.531	0.502
HH2 (26-50%)	If a driver usually uses hand-held phone 26-50% of his time of talking and driving=1, otherwise=0	0.188	0.392
HH3 (51-75%)	If a driver usually uses hand-held phone 51-75% of his time of talking and driving=1, otherwise=0	0.125	0.332
HH4 (76-100%)	If a driver usually uses hand-held phone 76-100% of his time of talking and driving=1, otherwise=0	0.156	0.365

[1]maximum deceleration over the range of initial speed to 20 kph is reported

3.1 Hazard-based Duration Model

A hazard-based duration model, also known as survival model, is a probabilistic method that is well suited for analysing time related data where a need arises to study the elapsed time until the end (or occurrence) of an event or the duration of an event (Washington et al., 2011). In this study, the survival time of speed changes—the time taken by a driver to reduce the speed to zero or certain threshold from the initial speed—was the duration variable. The accelerated failure time (AFT) approach to survival modelling allows the covariates to rescale (accelerate) time directly in a baseline survivor function, which is the survivor function when all covariates are zero (Washington et al., 2011). The AFT assumption allows for the estimation of an acceleration factor which can capture the direct effect of exposure on survival time. This characteristic of the AFT model also facilitates simpler interpretation of results because the estimated parameters quantify the corresponding effect of a covariate on the mean survival time. Due to their appealing qualities and appropriateness of the stopping time data, AFT models were applied in this study.

In the AFT model, the natural logarithm of the survival time, *T*, is expressed as a linear function of covariates, yielding the linear model

$$\ln(T) = \boldsymbol{\beta}\mathbf{X} + \varepsilon \tag{1}$$

where $\boldsymbol{X}$ is a vector of explanatory variables, $\boldsymbol{\beta}$ is a vector of estimable parameters and ε is the error term (Washington et al., 2011). In the fully parametric setting, survival models are estimated by assuming an appropriate distribution of the duration variable. Common distribution alternatives include Weibull, lognormal, exponential, gamma, log-logistic and Gompertz distribution (Washington et al., 2011). A distribution is often selected based on theoretical appeal and statistical evaluation, since selection of a specific distribution has important implications relating to the shape of the underlying hazard function and to the efficacy and potential biasedness of the estimated parameters. The Weibull distribution is quite flexible—and allows the modelling of data with monotone hazard rates that either increase or decrease exponentially with time or are constant over the duration, depending on the value of its scale parameter—and thus is applied to model the survival time (time from initial speed to stop or certain threshold) in this study. The hazard function of the Weibull duration model is expressed as

$$h(t) = (\lambda P)(\lambda t)^{P-1}, \tag{2}$$

and the survival function of the Weibull duration model is expressed as

$$S(t) = EXP(-\lambda t^{P}) \tag{3}$$

where λ and P are two parameters, respectively, known as the location and scale parameter (Washington et al., 2011).

A modification on the above Weibull AFT survival model was necessary to account for the structured heterogeneities resulting from the repeated measures design of this study. Since each individual driver was observed in three driving routes in the simulator, observations are subject to individual level heterogeneity or frailty. Without accounting for shared frailty or heterogeneities and potential correlations, the survival model would suffer from specification error that could lead to erroneous inferences on the shape of the hazard function. In addition, the standard error estimates of the regression parameters might be underestimated and inferences from the estimated model misleading.

To account for the repeated measures experiment design, two possible extensions of the duration model were considered. First one is the Weibull regression model with a specification for clustered heterogeneity. This model first fits a standard duration model as described previously and then adjusts the standard error estimates to account for the possible correlations induced by the repeated observations within individuals (Cleves et al., 2008; McGilchrist & Aisbett, 1991). The second modelling approach is the Weibull regression model with shared frailty which is analogous to a random effect model in panel-data setting (Gutierrez, 2002). In this model the shared frailty parameter is assumed to be gamma distributed with mean one and variance θ. Inclusion of a driver-specific random effect or shared frailty parameter induced a correlation among observations obtained from the same driver but maintained independence among observations across different drivers.

The above models were estimated by the standard maximum likelihood methods and candidate models were compared using likelihood ratio tests (Washington et al., 2011) and the Akaike's Information Criteria (AIC) (Akaike, 1973). To gain further insights into the marginal effects of explanatory variables of the AFT models, the exponents of coefficients were calculated. The exponent of the coefficients provides an intuitive way of interpreting the results by translating to a percent change in survival time duration resulting from a unit increase for continuous explanatory variables and a change from zero to one for categorical or indicator variables.

4. Results

4.1 Speed Profile Descriptive Analysis Results

The speed profiles of drivers—stopping from initial speed in response to a pedestrian at zebra crossing in three phone conditions, i.e. baseline, hands-free and handheld are presented in Table 2. Speed profile variables like initial speed, deceleration and times taken to reduce the speed to certain threshold were tested and compared across phone conditions by using the repeated measures ANOVA in the form of a Linear Mixed Model as used by Haque and Washington (2013a). Differences in drivers' initial speeds across phone conditions—measured at the instant just before a driver applied the vehicle brakes in response to the pedestrian at the zebra crossing—were not statistically significant ($F_{2,\ 55.04} = 1.51$, *p-value* = 0.229). Speed profiles were analysed after dividing *the entire speed profile into three segments: initial speed to 20 kph, 20 to10 kph and 10* to 5 kph; the speed profile below 5 kph was not included due to large random variations.

Table 2: Speed profile during braking performance on an approach to a zebra crossing

Speed Profile	Phone Conditions			Significance by a Linear Mixed Model	Remark
	Baseline	Hands-free	Handheld		
Initial speed (kph)	37.90	35.71	37.28	$F_{2,\ 55.04} = 1.51, p = 0.229$	Not significant
Time taken to reduce speed (seconds)					
Initial speed to 20 kph	5.18	3.99	3.71	$F_{2,\ 53.12} = 12.03, p < 0.001$	Significant
20 kph to 10 kph	2.44	2.39	2.28	$F_{2,\ 53.04} = 0.03, p = 0.968$	Not significant
10 kph to 5 kph	2.06	2.56	1.88	$F_{2,\ 54.14} = 2.39, p = 0.101$	Not significant
Average deceleration (m/s^2)					
Initial speed to 20 kph	0.99	1.26	1.45	$F_{2,\ 53.60} = 4.20, p = 0.020$	Significant
20 kph to 10 kph	1.89	1.78	2.07	$F_{2,\ 53.88} = 0.25, p = 0.778$	Not significant
10 kph to 5 kph	1.25	0.85	1.28	$F_{2,\ 53.71} = 2.18, p = 0.123$	Not significant

In the segment of *initial speed to 20 kph*, both time taken to reduce the speed to 20 kph ($F_{2,\ 53.12} = 12.03$, *p-value* < 0.001) and average deceleration ($F_{2,\ 53.60} = 1.51$, *p-value* = 0.020) were significantly different across phone conditions. On average, the time taken to reduce the initial speed to 20 kph was about 1.19 seconds ($t = 3.32$, *p-value* = 0.002) and 1.47 seconds ($t = 4.0$, *p-value* < 0.001) faster respectively in hands-free and handheld phone condition compared to baseline or no phone conversation. The average deceleration in hands-free and handheld phone condition in this segment was respectively 0.27 m/s^2 ($t = 1.95$, *p-value* = 0.05) and 0.46 m/s^2 ($t = 3.21$, *p-value* = 0.002) higher compared to no phone conversation condition. There was no difference between hands-free and handheld phone condition both for speed reducing time and average deceleration in the segment of *initial speed to 20 kph*. There was no difference in speed profile variables like speed survival time and average deceleration across distracted and non-distracted conditions in the segments of *20 to 10 kph* and *10 to 5 kph*.

Speed profiles appear to be quite different across phone conditions in the segment of *initial speed to 20 kph* but not for other segments. Therefore, interest is centred on the initial braking or speed reduction behaviour of drivers stopping in response to a pedestrian at a zebra crossing. To gain insight into the drivers' stopping or speed reducing behaviour, the survival time for speed changes from the initial speed to 20 kph was modelled using hazard-based survival models.

4.1 Survival Model Results

The survival time from the initial speed to 20 kph was modelled using the Weibull accelerated failure time (AFT) model with gamma frailty and the Weibull AFT model with clustered heterogeneity. A likelihood ratio test comparing these two models yielded a χ^2 statistic of 0.637 with 1 *df* and *p-value* of 0.425, indicating no significant difference between these two models. The likelihood ratio statistic of the Weibull AFT model with gamma frailty and clustered heterogeneity model was, respectively, 76.67 and 79.84, and hence the clustered heterogeneity model was marginally preferable. In addition, the AIC for these models was, respectively, 15.37 and 14.0, further indicating a marginally superior fit of the clustered heterogeneity model with a lower AIC.

Table 3: Weibull AFT with clustered heterogeneity model estimates of survival time from initial speed to 20 kph on an approach to a zebra crossing

Variable	Estimate	SE	z-statistic	p-value	exp(β)	95% CI	
						Lower	Upper
Initial speed	0.047	0.006	7.41	< 0.001	1.05	0.034	0.059
Maximum deceleration	-0.135	0.031	-4.36	< 0.001	0.87	-0.195	-0.074
Phone condition							
Hands-free	-0.154	0.051	-3.04	0.002	0.86	-0.253	-0.055
Handheld	-0.245	0.062	-3.98	< 0.001	0.78	-0.365	-0.124
Licence type							
Provisional	-0.130	0.055	-2.38	0.018	0.88	-0.238	-0.023
Crash involvement history							
Involved	0.158	0.051	3.10	0.002	1.17	0.058	0.258
Frequency of mobile phone use while driving							
Frequent	-0.128	0.051	-2.53	0.011	0.88	-0.227	-0.029
Less frequent	0.159	0.091	1.75	0.080	1.17	-0.019	0.337
Constant	0.301	0.218	1.38	0.167		-0.126	0.728
P	4.919	0.405				4.187	5.779
Log-likelihood at convergence (Pseudo)	3.00						
Log-likelihood at zero	-36.92						
AIC	14.00						
No of observations	84						
No of groups	32						

Table 3 presents the significant parameter estimates of the Weibull AFT model with clustered heterogeneity for speed survival time up to 20 kph. The estimate of the scale parameter *P* was 4.92 which is significantly (*t = 9.7, p-value < 0.001*) greater than 1, implying that the survival time of the speed decreased with time. For instance, the speed survival probability after 4 seconds was about 15 times (i.e. $(4/2)^{4.919-1}$) higher than that after 2 seconds on average. A *P* value greater 1 in the Weibull AFT model indicated an event with monotone hazard function and positive duration dependence which was resembled to the scenario of stopping or speed reduction behaviour of drivers in response to a pedestrian at a zebra crossing, and thus ensured the appropriateness of this model.

The parsimonious model identified six significant variables affecting the speed survival time of drivers stopping in response to a pedestrian at zebra crossing. These were vehicle dynamics like *initial speed* and *maximum deceleration*, *phone condition*, *licence status* and self-reported variables like *crash involvement history* and *frequency of mobile phone use while driving*.

A drivers' *initial speed* at the approach to the pedestrian crossing had a significant effect (at 5%) on time to reach 20 kph. The exponent of the parameter estimate indicates that 1 kph increase in a drivers' initial speed is associated with about 5% increase in time required to reach 20 kph.

Maximum deceleration—measured as the highest one-twentieth second deceleration over the time range of drivers' speed reduction to 20 kph—was also significant and negatively associated with the speed survival time. Speed survival time is shown to decrease by 13% with each 1 m/s^2 increase in maximum deceleration.

Both *hands-free* and *handheld* phone conditions were significant at the 5% significance level and negatively associated with the survival time from the initial speed to 20 kph. Compared to the baseline or no phone conversation condition, drivers took respectively about 14% and 22% less time in reducing their speed to 20 kph while engaged in hands-free and handheld phone conversations.

Licence status of drivers was significant in explaining the speed reduction time of drivers stopping in response to a pedestrian in the zebra crossing. *Provisional licence* holders appeared to be associated with quick braking, with a braking time about 12% lower compared to open licence holders.

Drivers reporting prior *involvement of a traffic crash* during last three years revealed slower braking performance compared to drivers who were not involved in any crash, with the corresponding slowing time about 17% longer on average

Speed reduction time was significantly influenced by self reported *frequency of mobile phone use while driving*. The drivers who reported using a mobile phone while driving frequently (at least once per day) showed quicker slowing times compared to moderately frequent users (use mobile phone while driving once or twice in a week), with the time required for speed reduction to 20 kph about 12% lower. In contrast, less frequent users who reported using a mobile phone while drive once or twice per month or year revealed slower slowing times at 10% significance level, with the corresponding times about 17% longer on average.

5. Discussions and Conclusion

This study analysed the speed profile of drivers stopping during an approach to a pedestrian within a zebra crossing. The effects of distraction were evident during the initial stage of speed profiles. Drivers' initial braking behaviour, measured as the time taken to reduce the initial speed to 20 kph, was modelled using hazard-based survival models like the Weibull AFT model with shared frailty and the Weibull AFT model with clustered heterogeneity. A parsimonious model identified six significant factors affecting survival time (slowing time from initial speed to 20 kph), including vehicle initial speed and maximum deceleration, driver-specific variables including phone condition, licence status, crash involvement history and self-reported use of mobile phone while driving. The fitted Weibull AFT model facilitated examining the effects of mobile phone distraction on various combinations of significant variables after adjusting for vehicle dynamics and other driver related factors.

To compare the braking patterns and behaviour in response to cognitive distraction, survival curves were plotted using the estimates of the Weibull AFT model with clustered heterogeneity. Speed survival probabilities were estimated using the survival function reported in equation (3) and corresponding parameter estimates from Table 3. For instance, speed survival probabilities of a driver distracted by a hands-free phone conversation after 3 and 4 seconds were computed as follows:

$$S(t=3) = EXP[-\{EXP(-4.919(0.301+0.047*36.97-0.135*2.84-0.154))\}\times(3)^{4.919}] = 0.87$$

$$S(t=4) = EXP[-\{EXP(-4.919(0.301+0.047*36.97-0.135*2.84-0.154))\}\times(4)^{4.919}] = 0.57$$

Using this generalized approach, Figure 1 presents the model predicted speed survival probabilities as a function of time for different phone conditions.

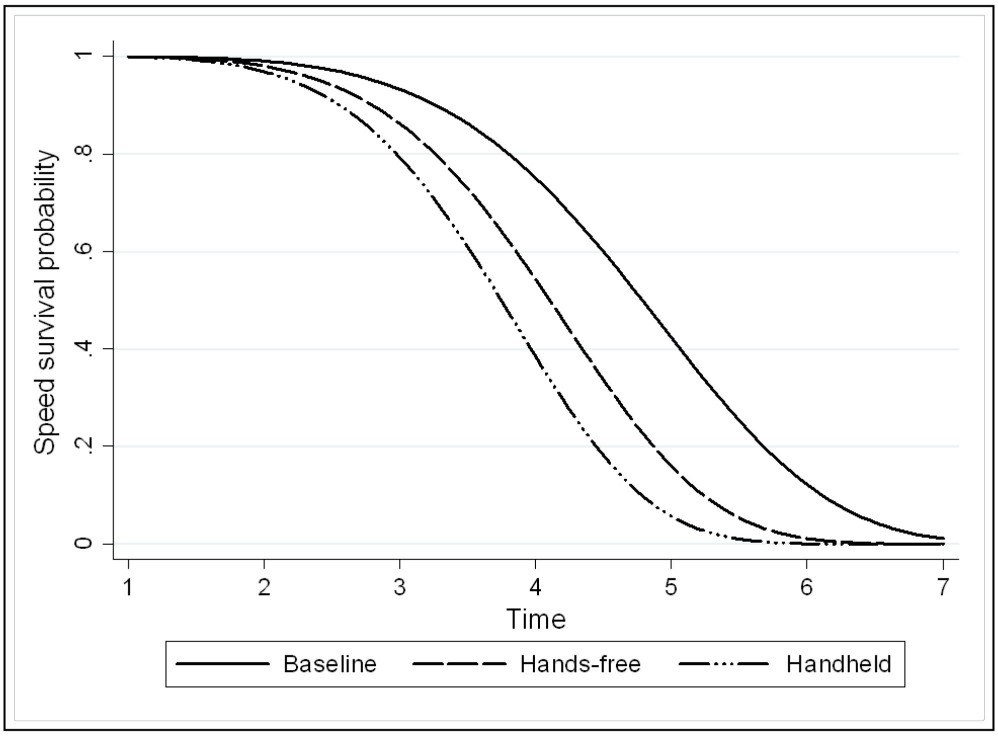

Figure 1: Speed (initial speed to 20 kph) survival graphs across phone conditions

In general, speed survival probabilities decrease with the elapsed time. Distracted drivers appear to reduce their initial speed earlier compared to non-distracted drivers. For instance, the speed survival probability at 4 seconds was 77% during the baseline driving condition, while the corresponding probabilities for hands-free and handheld phone conditions were 57% and 40% respectively. The time to reduce initial speed to 20 kph took about 7 seconds on average for non-distracted drivers, while distracted drivers on average survived a second less, requiring more aggressive braking to reduce the speeds. These findings suggest that distracted drivers may be compensating for their increased sense of risk by decelerating more rapidly while distracted.

In the literature, distracted drivers have been repeatedly reported to compensate for the risk of phone conversations by reducing their driving speeds (Caird et al., 2008). Haque et al. (2013) reported a different type of risk compensation behaviour of distracted drivers where they increased the probability of stopping at the onset of yellow light as the time-distance to the stop line increased. Distracted drivers—often being delayed in monitoring, gathering and synthesis of appropriate information about speed, distances and other stimuli related to driving—might brake harder to compensate for the delay in initiating braking (Harbluk et al., 2007). Hancock et al. (2003) also reported that distracted drivers were slow in responding to a change of a traffic light and subsequently demonstrated stronger vehicle braking in compensation. In a companion paper using the same dataset, we found that drivers distracted by mobile phone conversations took over 40% longer to detect a pedestrian in a zebra crossing (Haque & Washington, 2013b). One might suspect that harder braking of distracted drivers might be due to delay in response and compensation for the perceived lack of adequate stopping distance. However, drivers in the study had more than 110m available for braking in response to a pedestrian in the zebra crossing, and needed only 9m to stop the vehicle smoothly on the road with initial speed of 40 kph. Therefore, there was no limitation regarding adequate stopping distance, which might require hard braking by distracted drivers due to delay in identifying the pedestrian. It is therefore concluded that distracted drivers purely compensate for their perceived risk of phone conversations by braking harder to limit future potential risks to which they may be less capable of responding.

It is evident from Figure 1 that there were slight differences, though might not significant, in braking behaviours between hands-free and handheld phone conditions. In general, drivers distracted by handheld phone conversations took about 8% less time than hands-free condition in reducing their initial speed to 20 kph while stopping at an approach to pedestrian crossing. The difference in speed survival probabilities between hands-free and handheld phone conditions at 3, 4 and 5 seconds were respectively 7%, 16% and 11%, implying that drivers in the handheld phone condition were braking more aggressively, resulting in lower speed survival probabilities. Conversations via handheld phone appear to trigger slightly larger compensatory behaviour than in the hands-free condition. In other words, drivers appear to estimate the risks associated with conversations less when engaged in hands-free conversations. Similar risk compensation efforts across hands-free and handheld phone conversations in terms of speed reduction have been reported elsewhere (e.g., Caird et al., 2008; Törnros & Bolling, 2006).

Stopping behaviour of open and provisional licence holders across distracted and non-distracted conditions is presented in Figure 2. Provisional licence holders appear to reduce their initial speed earlier than open licence holders, as their speed reduction lasted about 0.75 seconds less on average. The speed survival probability for distracted open licence holders at 4 seconds was about 50%, while the corresponding probability for distracted provisional licence holders was about 25%. The difference between hands-free and handheld phone conditions is similar for open and provisional licence holders. In summary, distraction seems to affect provisional license holders in terms of aggressive braking after detecting a pedestrian at zebra crossing compared to non-distracted driving. The relatively larger effects of mobile phone distraction on provisional licence holders, who are inexperienced drivers, support stricter legislation and enforcement around mobile phone usage for these high risk drivers.

Drivers who reported having a crash prior to the experiment showed slower braking times compared to drivers who did not report having a prior crash. It is not clear whether these drivers have lesser driving skill or have modified their driving as a result of a prior crash. This finding deserves further exploration.

There was a higher tendency of aggressive braking among drivers who self-reported using a mobile phone frequently while driving. In real world driving and normal driving conditions without mobile phone distractions, self-reported frequent users of mobile phones while driving were reported to be involved in risky driving activities like driving faster, changing lanes more frequently, and importantly engaging in more instances of hard braking (Zhao et al., 2012). This study added further support for this finding where self-reported frequent users of mobile phone while driving were found to be involved in more aggressive braking while distracted.

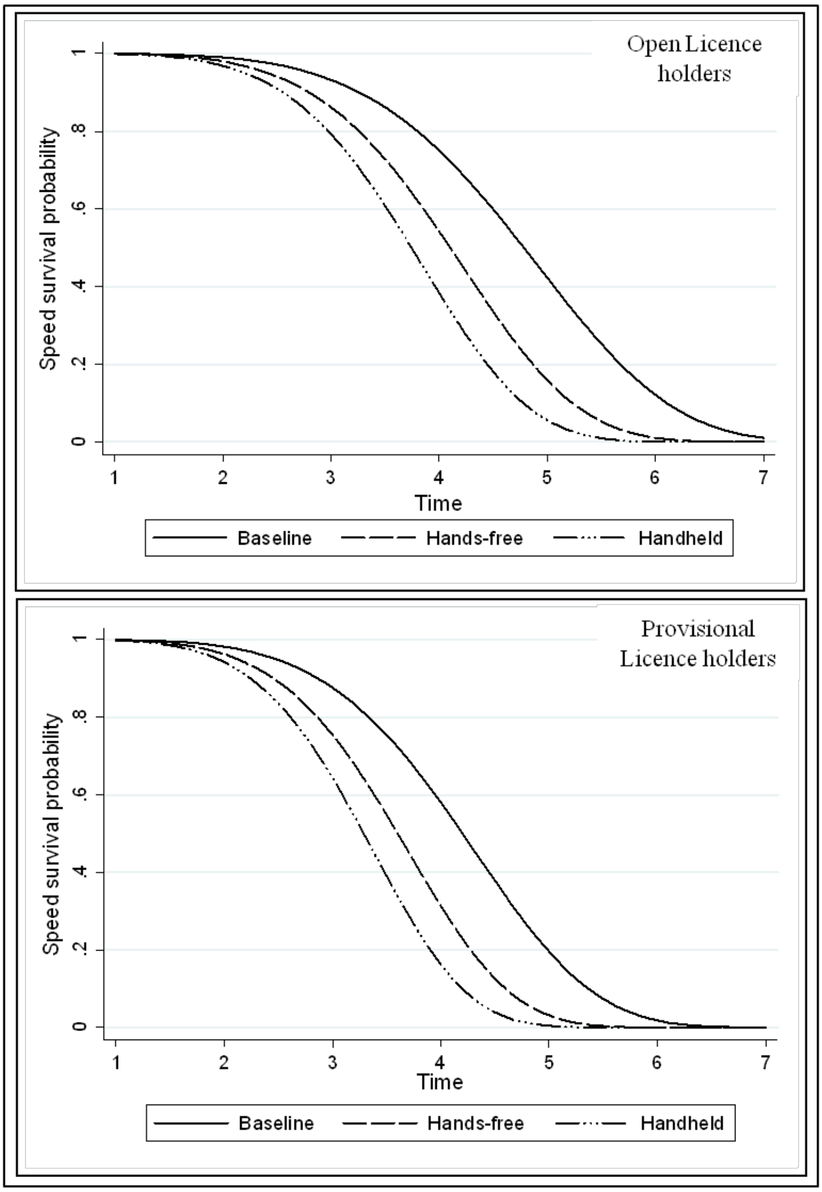

Figure 2: Effects of phone conversation and licence type on driver's speed reduction from initial speed to 20 kph

Overall the model suggests that drivers distracted by mobile phone conversations were more likely to reduce their initial speeds by aggressively braking while responding to a pedestrian at zebra crossing. Aggressive braking by distracted drivers might create surprise situations for following vehicle drivers in a traffic stream, and might lead to a greater likelihood of rear-end collisions. Behavioural and technological innovations are needed to combat the problem of mobile phone distractions while driving. Importantly, the stopping behaviour was marginally different between hands-free and handheld phone condition, and there was little evidence to support that a hands-free phone conversation results in a fundamentally different response from drivers compared to hand held. Recognizing that the braking behaviour of provisional licence holders was more aggressive than for open license holders supports that provisional license holders are more sensitive to and affected by distraction compared to open license holders—thus likely translating to relatively heighted crash risk for these drivers.

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