| United States |
| --- |
| American Society of Safety Engineers (ASSE): ANSI/ASSE Z15.1–2012, Safe Practices for Motor Vehicle Operations. Des Plaines, IL: ASSE. Voluntary fleet safety standard targeted to organisations operating small to medium sized vehicles not regulated by trucking policy: http://www.asse.org/publications/standards/z15/docs/Z15_1_Tech_Brief_4_2012.pdf |
| FMCSA: |
| •  Cross-border safety, inspection, and collision statistics by their country of domicile, for registered intrastate and interstate motor carriers operating in the United States: http://ai.fmcsa.dot.gov/international/border.asp |
| •  CMV Web-based Driving Tips: collection of defensive driving tips focusing on common driving errors made by commercial vehicle drivers: http://www.fmcsa.dot.gov/about/outreach/education/driverTips/index.htm |
| •  Safety is Good Business: resources to help motor carriers better understand business responsibilities and economic benefits of safety: http://www.fmcsa.dot.gov/safety-security/good-business/index.htm |
| •  Safety Belt Partnership: initiative to increase use of seat belts among drivers of large trucks and buses: www.fmcsa.dot.gov/safety-security/safety-belt/index.htm |
| Network of Employers for Traffic Safety (NETS): www.trafficsafety.org |
| National Institute for Occupational Safety and Health (NIOSH): http://www.cdc.gov/niosh/topics/motorvehicle |
| National Safety Council (NSC): |
| •  'Cell Phone Policy Kit' (free for download) and other distracted-driving resources for employers: |
| •  http://shop.nsc.org/NSC-Cell-Phone-Policy-Kit-Downloadable-P2222.aspx |
| •  http://www.nsc.org/safety_road/Distracted_Driving/Pages/EmployerPolicies.aspx |
| •  Our Driving Concern: a comprehensive safety manual for use by organisational fleet managers, with numerous checklists and sample policies as well as articles on topics such as distracted driving: |
| •  http://www.nsc.org/safety_road/EmployerTrafficSafety/Pages/NationalHome.aspx |
| Occupational Safety and Health Administration (OSHA): http://www.osha.gov/SLTC/motorvehiclesafety/index.html |
| Transportation Research Board (TRB): produces succinct reviews of a wide range of trucking health and safety topics such as driver wellness, fatigue management, driver selection, and management practices: http://www.trb.org/Publications/PubsCTBSSPSynthesisReports.aspx |
| U.S. Department of Transportation initiative on distracted driving. Role of employer policies in reducing distraction-related crashes, and materials to encourage employer and employee involvement: http://www.distraction.gov/content/get-involved/employers.html |

# Effects of mobile phone distraction on drivers' reaction times

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## Abstract

Distraction resulting from mobile phone use whilst driving has been shown to increase the reaction times of drivers, thereby increasing the likelihood of a crash. This study compares the effects of mobile phone conversations on reaction times of drivers responding to traffic events that occur at different points in a driver's field of view. The CARRS-Q Advanced Driving Simulator was used to test a group of young drivers on various simulated driving tasks including a traffic event that occurred within the driver's central vision - a lead vehicle braking suddenly; and an event that occurred within the driver's peripheral vision - a pedestrian entering a zebra crossing from a footpath. Thirty-two licenced drivers drove the simulator in three phone conditions: baseline (no phone conversation),

and while engaged in hands-free and handheld phone conversations. The drivers were aged between 21 to 26 years and split evenly by gender. Differences in reaction times for an event in a driver's central vision were not statistically significant across phone conditions, probably due to a lower speed selection by the distracted drivers. In contrast, the reaction times to detect an event that originated in a distracted driver's peripheral vision were more than 50% longer compared to the baseline condition. A further statistical analysis revealed that deterioration of reaction times to an event in the peripheral vision was greatest for distracted drivers holding a provisional licence. Many critical events originate in a driver's periphery, including vehicles, bicyclists, and pedestrians emerging from side streets. A reduction in the ability to detect these events while distracted presents a significant safety concern that must be addressed.

## Keywords:

mobile phone distraction; advanced driving simulator; driver reaction times; young drivers; peripheral vision, road safety

# Introduction

## Mobile phone distraction

The widespread use of mobile phones whilst driving has become a serious public health threat and is linked to an increased risk of involvement in road crashes. Mobile phone distraction alone claimed about 995 lives and another 24,000 injuries on US roads in 2009 [1]. An epidemiological study indicated that distraction resulting from mobile phone conversations quadrupled the crash risk of drivers [2]. Violanti and Marshall [3] reported similar findings where drivers talking more than 50 minutes in a vehicle were associated with a 5.6 fold increase in crash risk.

A significant safety concern is that the use of mobile phones while driving is more prevalent in younger and less experienced drivers; a driving cohort with elevated crash risk. An Australian study reported that among 2400 driving distraction-related incidents in New South Wales, young drivers had the highest frequency of mobile phone use-related injurious crashes [4]. Horberry et al. [5] reported that more than 60% of drivers who use a mobile phone whilst driving were less than forty years old. A recent survey [6] reported that almost one in two Australian drivers aged between 18 to 24 years used a handheld mobile phone while driving, nearly 60% of them sent text messages and about 20% of them read emails and surfed the internet.

The use of a mobile phone while driving influences numerous common driving behaviours, including a deterioration of speed control, speed reductions, a failure to maintain appropriate headway, an increase of the

variation of lane position, a limitation of peripheral eye scanning, a decline in braking performance, and impairment in the perception of relevant stimuli [7]. Rakauskas et al. [8] reported that mobile phone use caused drivers to have higher variation in accelerator pedal position, drive slowly with more speed variation and report a higher workload. Tornos and Bolling [9] studied the effects of phone conversation using the VTI driving simulator II and observed risk compensation behaviour, where drivers tended to reduce their speed while talking on the phone. Using a desktop driving simulator, Dula et al. [10] reported that driving tasks like percentage of time spent speeding and centre line crossings were significantly different among drivers engaged in different types of conversations in comparison to no conversation.

## Reaction times of distracted drivers

A mobile phone conversation distracts drivers by shifting their attention away from the primary driving task. As such, the reaction times of drivers has been of research interest - as a surrogate measure of the crash risk of mobile phone conversation - and under various study situations including laboratory, driving simulator, and in-field trials. Consiglio et al. [11] examined the braking performances of distracted drivers upon the activation of a red lamp in a laboratory and found that both hands-free and hand-held mobile phone conversations resulted in slower reaction times in performing the braking task. Slower responses of distracted drivers were also observed in a desktop simulator experiment where drivers tended to take one-third of a second longer to begin driving from a stop sign while engaged in a phone conversation [12]. Using an advanced driving simulator, Tornos and Bolling [9] examined the reaction times of distracted drivers in a peripheral detection task (PDT) under various environmental complexities, and reported that the PDT response time was longer and accuracy was worse in mobile phone conditions, irrespective of phone type and environmental complexity. Similarly, Amado and Ulupinar [13] reported that mobile phone conversations had negative effects on attention and peripheral detection of stimuli. An in-field experiment on the stopping decisions of a group of mobile phone distracted drivers, where participants were instructed to perform a quick stop before reaching the stop line of an intersection upon the onset of a red light, showed that the non-response to a red light increased by 15% on average among distracted drivers [14].

Conversations using either hands-free or handheld mobile phones had been found to impair the reaction times of drivers more than driving under the influence of alcohol at the 8% or 0.08gm/100ml legal limit [15]. A meta-analysis conducted on 33 studies, by Caird et al. [16], reported a 0.25 second increase in reaction time for all types of phone-related tasks and both hands-free and handheld phone conversations had similar effects on reaction

times. Another meta-analysis of 23 studies revealed that mobile phone distraction increased the response times to unexpected hazards with similar effects for both hands-free and handheld phone conditions [17]. A recent review by Ishigami and Klein [18] reported a similar conclusion of slower reaction times of distracted compared to non-distracted drivers.

Several studies have examined the reaction times of distracted drivers across age and gender. The reaction times of older drivers appeared to be impaired by 0.29 seconds by a mobile phone conversation, while the corresponding impairment of young drivers was only 0.11 seconds - less than half of older drivers [14]. Similar reaction time impairment was reported by Caird et al. [16], where the reaction times were 0.46 seconds and 0.19 seconds slower, respectively, for distracted older and young drivers. An experiment on an advanced driving simulator by Nilsson and Alm [19] showed that elderly drivers' reaction times to an unexpected event was approximately 0.40 seconds greater than for young drivers when distracted by a mobile phone conversation. Research on the effects of gender showed that mobile phone distraction had a greater influence on females than males with corresponding impairments of 0.25 seconds and 0.14 seconds respectively [14].

The human brain manages all tasks needed for driving including visual, auditory, manual and cognitive. An analysis using the functional magnetic resonance imaging (fMRI) showed that mobile phone distraction requiring the processing of auditory sentences decreased the brain activity as much as 37% of the critical tasks associated with driving [20]. The increased cognitive load of a mobile phone conversation might cause a withdrawal of attention from the visual scene - where all the information a driver sees is not processed - yielding a form of inattention blindness [21]. In other words, the human brain compensates for receiving increased information by not sending some visual information to the working memory, leading to a tendency to 'look at' but not 'see' objects by distracted drivers [22]. The effect of a mobile phone distraction on drivers' vision was further evident from optometry research by Maples et al. [23], who reported that mobile phone conversations tended to reduce the visual field, particularly by constricting the peripheral vision and awareness.

To the authors' knowledge, none of the prior studies on mobile phone distraction have examined the reaction times of distracted drivers across routine traffic events that occur directly in the central vision of a driver compared to events that occur within a driver's peripheral vision. Because vision- and brain-focused research has noted important peripheral vision effects, an investigation of the reaction times under these two conditions is useful for developing insights into the impairment of reaction times of mobile phone distracted drivers and represents the unique contribution of this research.

## Research objective

The objective of this study is to investigate the effects of mobile phone conversation on reaction times of drivers while they respond to traffic events in their peripheral and central vision. To accomplish this study, a group of distracted drivers were exposed to a number of traffic events using 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 methods used for analysis, briefly describing the linear mixed modelling approach that accounts for repeated measures among individuals. The results of the analysis are then discussed, followed by overall conclusions of the research.

## Method

### 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 updated on front-view projectors, wing mirrors and the rear view mirror at 60 Hz to provide a 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 six degree-of-freedom motion base that could move and twist in three dimensions to accurately reproduce motion cues for sustained acceleration, braking manoeuvres and interaction with varying road surfaces. 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 sounds for engine and environment noise and sounds for other traffic interactions, e.g. a crash. Driving performance data like position, speed, acceleration and braking were recorded at rates up to 20 Hz.

### Participants

The participants recruited for the study include 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. the library and canteen. In order to qualify as a participant they had to fulfil a number of requirements, including:

- be aged between 18 and 26 years;

- hold either a provisional or open Australian issued driver's licence;

- not had a history of motion sickness and epilepsy and;

- not be pregnant.

All data not collected in the simulator were self-reported.

The mean age of the participants was 21.47 (±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 (±1.80) and 21.1 (±2.19) years. The average driving experience was 4.2 (±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 licenced driver for a duration of up to three years before they receive an open licence. The average driving experience of provisional and open licence holders were, respectively, 2.64 (±0.75) and 5.01 (±1.79) years. 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 one time per day; 47% of the sample used a mobile phone one or two times in a week; and the remaining 19% used mobile phones while driving one or two times per month.

## Experimental setup

The designed driving route in the CARRS-Q Advanced Driving Simulator contained simulated routes on both urban and rural areas. The simulated route was about seven kilometres 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 leading car that brakes suddenly, a pedestrian on a footpath that enters a zebra crossing, an overtaking scenario, gap acceptance manoeuvres at a number of intersections, and a car that drifts 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 randomised across the routes. To examine the reaction times of distracted drivers to traffic events in their central and peripheral vision, two specific traffic events were included and analysed in this paper.

The first event occurred within a drivers' central vision, in which a driver needed to respond to a leading car that braked suddenly. This event occurred on a two lane road with one lane in each direction, separated by a broken centre line and the speed limit of 60 kph. The event was scripted such that the lead car maintained the same speed of the driven car by keeping a constant separation distance of about 36m. After travelling about 400m at the same speed, the lead car applied brakes; turning on the rear brake lights. The reaction time of a driver was measured as the time taken to press the brake pedal upon activation of the rear brake light of the lead car at the onset of braking. Maintaining speed behind the lead car did not require constant accelerator pedal pressure and hence the reaction time was deduced from the brake pedal and not the lifting of the accelerator pedal.

The second traffic event involved the peripheral vision of drivers, whereby a driver needed to respond to a pedestrian on a footpath who crossed the road at a zebra crossing. This 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 event was scripted so that a pedestrian started to move from a footpath towards the zebra crossing when the driven car was about 10 seconds away from the zebra crossing. Since the zebra crossing in all three driving routes was placed mid-block after an intersection, drivers were accelerating to reach the posted speed limit after a recent turn at the prior intersection. Hence releasing the accelerator pedal in this event represented the initial reaction after detecting a pedestrian attempting to cross. As such, the reaction time was measured as time taken to release the accelerator pedal after the pedestrian that started to cross the road was perceived by the participant.

## Mobile phone task

The mobile phone used in this study was a Nokia 500 phone which had dimensions of 111.3 x 53.8 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 cognitive in nature. Conversation dialogues were modified from Burns et al.

[15] 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 load.

## 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 participants 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, general mobile phone usage history, usage of mobile phones while driving, and driver behaviour related to aggressiveness and sensation seeking. 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 hands-free and handheld phone conditions. The driving conditions were counterbalanced across participants to control for 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 five to six 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 familiarisation 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 seven kilometres 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.

# Data and analysis

## Dataset for analysis

Reaction times were calculated for each participant during the two traffic events described previously - a lead vehicle braking suddenly and a pedestrian entering a zebra crossing from a footpath. Reaction times were measured for each participant across each of the three phone conditions, i.e. baseline, hands-free and handheld. Reaction times were compared across phone conditions and other explanatory variables such as driver age, gender and licence type. Driver age variable had three categories including age-group 1 (18-20 years), age-group 2 (21-22 years), and age-group 3 (23-26 years). Driver licence type had two categories, a provisional holder and an open licence holder. In addition, the approaching speed of drivers in these two traffic events was also collected and tested across phone conditions to investigate whether there is any correlation between speed selection and phone condition on influencing reaction times. An approaching speed was measured as the driven car's speed at the time of activation of the simulated traffic event, e.g. at the moment when the lead car braked.

There was one observation where a participant selected a wrong lane to follow the lead car that braked suddenly and thus was discarded; forming a total of 95 observations for this event. There were seven occasions when drivers did not stop for pedestrians at the zebra crossing, including one in a baseline condition, four in the hands-free condition and two in the handheld condition. There were three other observations where drivers' responses from the accelerator pedal were missing and hence reaction times were not possible to extract. These observations were discarded from the analysis of reaction times for this traffic event. In total there were 85 observations for 32 drivers representing an unbalanced panel data with a minimum of two and a maximum of three observations per driver.

## Statistical analysis

Mean reaction times of individuals were computed for each traffic event across the three phone conditions, and compared using a repeated measures ANOVA and t-tests.

A repeated measures ANOVA in the form of a Linear Mixed Model was tested across phone conditions and other explanatory variables like driver age, gender and licence type to examine their effects and interactions in differentiating reaction times to a particular traffic event.

Since the dataset of this study had unbalanced repeated measurements, a repeated measures ANOVA in the form of a Linear Mixed Model was applied [24]. The Linear Mixed Model is superior to typical repeated measures techniques because it does not discard all results on any driver with a single missing measurement; rather it allows other data on drivers to be used as long as the missing data meets the missing-at-random definition. The Linear Mixed Model is capable of analysing variations between and within subjects of correlated data, where the correlation is a result of repeated observations of the same driver at multiple points in time.

Suppose $Y = (Y_{i1}, Y_{i2},......., Y_{ik})'$ be the $k_i \times 1$ vector of reaction times in responding to a traffic event for driver $i$ $(i = 1, 2, . . ., n)$ at driving route $k$. The general Linear Mixed Model for longitudinal data is

$$Y_i = X_i \beta + Z_i \gamma_i + \varepsilon_i \qquad (1)$$

where $X_i$ is a $k_i \times p$ model matrix for the fixed effects for observations in driver $i$, $\beta$ is the $p \times 1$ vector of fixed-effect coefficients, $Z_i$ is the $k_i \times q$ model matrix for the random effects for observations in driver $i$, $\gamma_i$ is the $q \times 1$ vector of random-effect coefficients, and $\varepsilon_i$ is the $k_i \times 1$ vector of errors for observations in driver $i$. Random coefficient vector $\gamma_i$ is assumed to be distributed as $\gamma_i \sim N_q (0, \psi)$, where $\psi$ is a $q \times q$ covariance matrix for the random effects. Similarly, $\varepsilon_i$ is assumed to be distributed as $\varepsilon_i \sim N_{ki} (0, \sigma^2 \Lambda_i)$, where $\sigma^2 \Lambda_i$ is the $k_i \times k_i$ covariance matrix for the errors in driver $i$. The covariance matrix structure of the error term allows accommodating various forms of correlation originated from the repeated measures design. A compound symmetry structure that has constant variance and constant covariance was applied in this study. The general Linear Mixed Model in equation (1) is subject-specific and

hence it can have varying numbers of observations among subjects. A Mixed Model with fixed-effect regressors only, as is the case here, provides an analysis of variances for an unbalanced repeated measures dataset without losing information due to a missing measurement on any subject.

## Results

The results discussed here refer to the reaction times of drivers to an event in the central vision and the reaction times of drivers to an event in the peripheral vision.

### Reaction times to an event in the central vision

Table 1 shows the reaction times of drivers responding to a traffic event that occurred in their central vision (a lead car braking suddenly) as a function of phone condition and gender.

The reaction time differences in milliseconds were not statistically significant $(F_{2, 61.74} = 0.47, p\text{-value} = 0.63)$ across phone conditions as estimated by the Linear Mixed Model. In general, the reaction time was about 44 ms (3.75%) higher when a participant was engaged in a hands-free phone conversation compared to baseline and the difference between reaction times of the handheld phone condition compared to baseline was -23 ms (-1.94%). None of the other explanatory variables like driver age, gender, and licence type was significant in explaining the variation of reaction times of drivers to the central event of a lead car braking.

Since participants may approach traffic events at different speeds, as evidenced by prior research [e.g., 8] that has shown reductions in speed selection while distracted, drivers at reduced speeds may have quicker reaction times. Drivers' approaching speeds to a lead car were statistically significant across phone conditions at 10% significance level $(F_{2, 61.05} = 2.48, p\text{-value} = 0.09)$. The mean approaching speed in the baseline condition was 55 ($\pm 8.1$) kph, while the approaching speeds in the hands-free and handheld condition were, respectively, 52.6 ($\pm 8.5$) and 51.7($\pm 8.4$) kph. A lower speed selection on

**Table 1. Reaction times to a traffic event that happened directly in line of sight of a driver: a lead vehicle suddenly braking**

| Participants | Statistic | Phone condition | | | % increase from baseline | |
|---|---|---|---|---|---|---|
| | | Baseline | Hands-free | Handheld | Hands-free | Handheld |
| Reaction time in milliseconds (ms) | | | | | | |
| All | Mean | 1182 | 1226 | 1159 | 3.75 | -1.94 |
| | St. Dev | 188 | 412 | 295 | | |
| Male | Mean | 1197 | 1287 | 1181 | 7.58 | -1.30 |
| | St. Dev | 174 | 553 | 352 | | |
| Female | Mean | 1167 | 1165 | 1137 | -0.09 | -2.50 |
| | St. Dev | 208 | 192 | 233 | | |

distracted conditions might have counteracted the effects of distraction on reaction times behind a lead car as observed in Table 1.

To test the effect of speed selection on reaction times, the approaching speed variable was included in the Linear Mixed Model after categorising into two categories, a low approaching speed group whose speed was less than or equal to 50 kph and a high approaching speed group whose speed was more than 50 kph at the time of lead car braked. While the effect of speed on reaction times was significant $(F_{1,\,88.59} = 4.60, p\text{-value} = 0.04)$, the interaction between speed and phone condition was not significant in explaining reaction times $(F_{2,\,78.88} = 0.34, p\text{-value} = 0.71)$. The mean reaction time for drivers with a low approaching speed was 1,095 milliseconds, while the reaction time for drivers with a high approaching speed was 1,239 milliseconds (Figure 1).

## Reaction times to an event in the peripheral vision

Table 2 shows the reaction times of drivers when they responded to a traffic event occurring in their peripheral vision (pedestrian entered a zebra crossing from footpath) by phone condition and gender. Results are also graphically presented in Figure 2.

Reaction time differences in milliseconds were statistically significant across phone conditions $(F_{2,\,54.29} = 10.15, p\text{-value} < 0.001)$. In general the reaction times were about 55.2% $(t = 2.77, p\text{-value} = 0.007)$ and 56.4% $(t = 3.13, p\text{-value} = 0.003)$ higher when drivers were, respectively, distracted by a hands-free and handheld phone conversation compared to the baseline condition. The reaction time difference was not significant $(t = 0.05, p\text{-value} = 0.957)$ between the hands-free and handheld phone conditions.
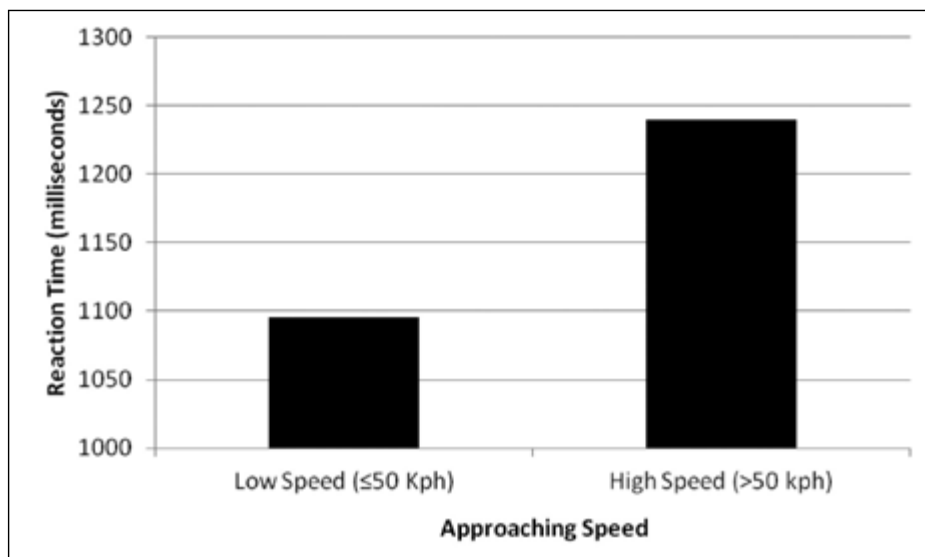


**Figure 1. Reaction times across approaching speeds to an event where a lead vehicle braked**

**Table 2. Reactions times to an event originating in a drivers' peripheral vision: a pedestrian entering a zebra crossing from a footpath**

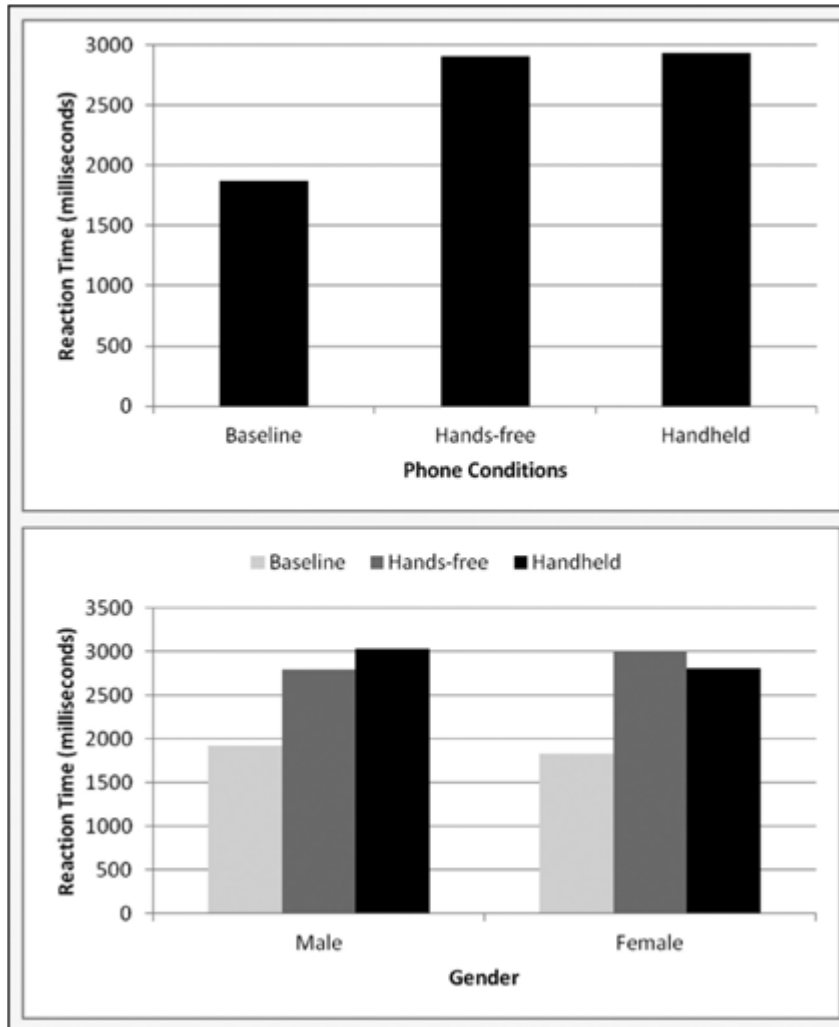| Participants | Statistic | Phone condition | | | % increase from baseline | |
|---|---|---|---|---|---|---|
| | | Baseline | Hands-free | Handheld | Hands-free | Handheld |
| Reaction time in milliseconds (ms) | | | | | | |
| All | Mean | 1873 | 2907 | 2929 | 55.20 | 56.38 |
| | St. Dev | 1138 | 1669 | 1399 | | |
| Male | Mean | 1917 | 2800 | 3039 | 46.06 | 58.53 |
| | St. Dev | 1188 | 1620 | 1574 | | |
| Female | Mean | 1830 | 3014 | 2811 | 64.70 | 53.60 |
| | St. Dev | 1125 | 1771 | 1236 | | |

**Figure 2. Reaction time across phone conditions and gender for an event in the peripheral vision of drivers**

An interaction between phone condition and gender was not significant $(F_{2, 47.29} = 0.92, \textit{p-value} = 0.41)$, and hence similar deteriorations of reaction time were observed for distracted males and females. For males, the reaction times were 46.1% higher $(t = 1.68, \textit{p-value} = 0.10)$ in the hands-free and 58.5% higher $(t = 2.18, \textit{p-value} = 0.04)$ in the handheld compared to the baseline condition. For females, the reaction time difference was higher by 64.7% $(t = 2.17, \textit{p-value} = 0.039)$ in the hands-free and 53.6% $(t = 2.20, \textit{p-value} = 0.037)$ in the handheld compared to the baseline condition. There was no significant difference between reaction times in the hands-free and handheld phone condition both for males $(t = 0.40, \textit{p-value} = 0.70)$ and females $(t = 0.35, \textit{p-value} = 0.75)$.

Reaction times were statistically different at 10% significance level across licence types $(F_{1, 30.58} = 3.45, \textit{p-value} = 0.073)$ but not significant when an interaction between phone condition and licence type was considered $(F_{2, 52.1} = 1.45, \textit{p-value} = 0.245)$. The mean reaction time for drivers with an open licence was 2,275 milliseconds,

while the reaction time for drivers with a provisional licence was 3,051 milliseconds. Figure 3 shows the reaction time across phone conditions and licence types when drivers responded to a traffic event in their peripheral vision. For drivers with an open licence, the reaction times were about 43.7% $(t = 1.78, \textit{p-value} = 0.08)$ and 39.2% $(t = 1.77, \textit{p-value} = 0.09)$ higher, compared to the baseline condition, when drivers were distracted by a hands-free and hand-held phone conversation respectively. The reaction times for provisional licence holders were higher by 72.5% $(t = 2.17, \textit{p-value} = 0.04)$ in the hands-free and 80.7% $(t = 2.88, \textit{p-value} = 0.01)$ in the handheld conversation compared to the baseline condition. In summary, the deterioration of reaction times due to a phone conversation was almost double for provisional than open licence holders. Reaction time differences between hands-free and handheld condition were not significant both for open $(t = 0.16, \textit{p-value} = 0.87)$ and provisional $(t = 0.25, \textit{p-value} = 0.81)$ licence holders.
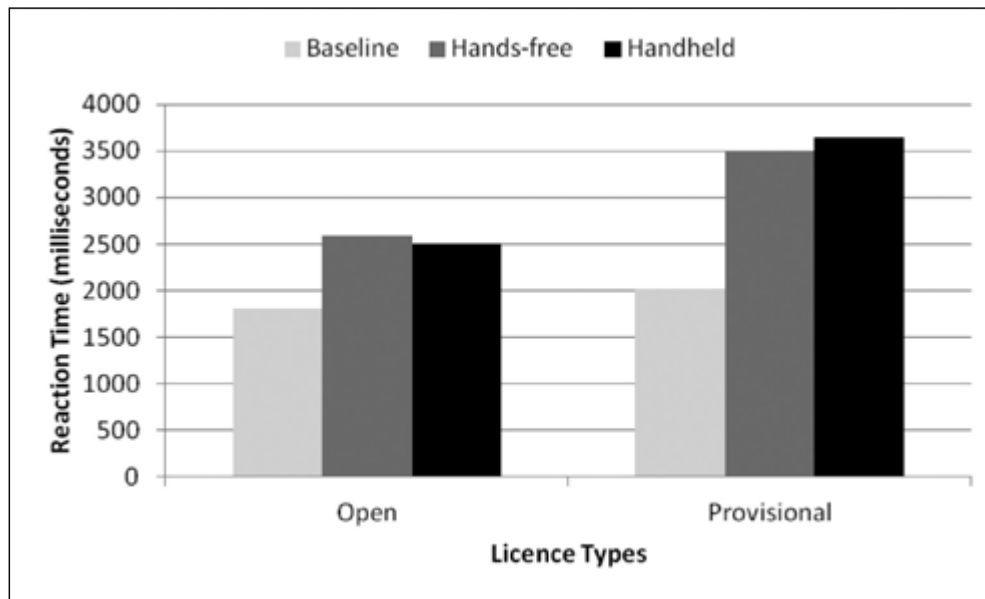
**Figure 3. Reaction time across phone conditions and licence types for an event in the peripheral vision of drivers**

Drivers' approaching speeds to a pedestrian crossing were not statistically significant across phone conditions $(F_{2, 55.61} = 0.26, p\text{-value} = 0.77)$. The mean approaching speed in the baseline condition was 35.1 (±4.5) kph, while the approaching speeds in the hands-free and handheld condition were, respectively, 34.8 (±5.4) and 35.2 (±5.6) kph.

## Discussions and conclusion

Much research has established that reaction times increase when mobile phones are used whilst driving. Research has also revealed that mobile phone use constricts the field of view of drivers. This research set out to examine and quantify the extent to which reaction times differ when coping with traffic events in a driver's central vision compared to an event in the peripheral vision.

It was confirmed in this study that reaction times are slowed when drivers are distracted. Importantly, reaction times were not statistically different in the baseline compared to hands free and hand held conditions of young drivers in this study when confronted with events in their central vision - suggesting that both perceptions and reactions were not affected when the phone was used. In contrast, an event originating in a driver's periphery was found to be quite problematic for drivers to detect and thus raises some significant safety concerns.

Speed selection appears to play a role in compensating for the distracting effects of phone use for the traffic event in the central but not peripheral vision. Approaching speeds were different across phone conditions in an event occurring in the central vision, where drivers were slower when distracted. This effect suggests risk compensation, an affect that has also been noted in other research [e.g., 9, 16], where drivers compensate for their increased perceived risk of talking on the phone by lowering their driving speed. The approaching speed when confronted with an event in the periphery, however, was slightly lower but not statistically significant compared to the baseline condition. Two driver responses might explain this finding. First, drivers were on an accelerating phase to catch up the speed limit after a prior turn at this point in the simulation, and second, the magnitude of the risk compensation may be comparatively less when drivers are confronted by a peripheral event or when drivers are not confronted by any direct traffic interaction like the case of lead vehicle in the central vision.

The role of a provisional licence played an important role and is associated with greater risk. Previous research has reported that the combined effect of being inexperienced and distracted is particularly risky in case of a critical driving situation like responding to an amber light at signalised intersections [25]. Clearly, driving experience also seems to influence reaction times, particularly to a traffic event in the peripheral vision. It is also quite possible that less experienced drivers are less skilled at scanning the field of view and this effect is higher when they are distracted.

Many critical events originate in a driver's periphery, including vehicles, bicyclists and pedestrians emerging from side streets. A reduction in the ability to detect these events while distracted presents a significant safety concern that must be addressed. There were seven occasions when drivers did not stop for pedestrians at zebra crossing, including one in the baseline condition, four in the hands-free condition, and two in the handheld condition - six out of seven cases were when drivers were distracted. In reality these conditions may have resulted in a crash and potential injury.

Distracted driving as a result of mobile phone conversations impaired the reaction times of young drivers to a traffic event in their peripheral but not central vision. It is worth noting that a lead vehicle braking in the central vision and a pedestrian entering a zebra crossing from the footpath in the peripheral vision have different object size and event dynamics, which hinders a quantitative comparison across these events. Additional simulator studies with controlled object size and dynamics would be helpful to develop further insights into the problem, as well as to identify ways to mitigate the effects of distraction particularly in encountering traffic events in a driver's periphery. Furthermore, reaction times for the peripheral event in this study were measured from the time of use of accelerator pedals, mainly because zebra crossings were located at mid-blocks after intersections. This experimental set up required drivers to accelerate to reach the speed limit after a recent turn at the prior intersection. Realising the fact that a brake-related action is a more indicative response to a hazardous event, an additional simulator study could be designed where a series of zebra crossings are placed along a straight segment of road and distracted driver responses to pedestrians entering random zebra crossings are measured.

## References

1. NHTSA, Traffic Safety Facts: Distracted Driving 2009. 2010, National Highway Traffic Safety Administration: Washington DC, USA.

2. Redelmeier, D.A. and R.J. Tibshirani, The association between cellular telephone calls and motor vechicle collisions. New England Journal of Medicine, 1997. 336(7): p. 453-458.

3. Violanti, J.M. and J.R. Marshall, Cellular phones and traffic accidents: An epidemiological approach. Accident Analysis and Prevention, 1996. 28(2): p. 265-270.

4. Lam, L.T., Distractions and the risk of car crash injury: The effect of drivers' age. Journal of Safety Research, 2002. 33(3): p. 411-419.

5. Horberry, T., C. Bubnich, L. Hartley, and D. Lamble, Drivers' use of hand-held mobile phones in Western Australia. Transportation Research Part F: Traffic Psychology and Behaviour, 2001. 4(3): p. 213-218.

6. AAMI. 11th AAMI Young Drivers Index. 2012; Available from: http://www.aami.com.au/sites/default/files/fm/news/11th_aami_young_drivers_index.pdf.

7. Regan, M.A., K. Young, and J. Lee, eds. Driver Distraction: Theory, Effects, and Mitigation. 2009, CRC press: New York.

8. Rakauskas, M.E., L.J. Gugerty, and N.J. Ward, Effects of naturalistic cell phone conversations on driving performance. Journal of Safety Research, 2004. 35(4): p. 453-464.

9. Törnros, J. and A. Bolling, Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments. Transportation Research Part F: Traffic Psychology and Behaviour, 2006. 9(4): p. 298-306.

10. Dula, C.S., B.A. Martin, R.T. Fox, and R.L. Leonard, Differing types of cellular phone conversations and dangerous driving. Accident Analysis and Prevention, 2011. 43(1): p. 187-193.

11. Consiglio, W., P. Driscoll, M. Witte, and W.P. Berg, Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. Accident Analysis and Prevention, 2003. 35(4): p. 495-500.

12. Beede, K.E. and S.J. Kass, Engrossed in conversation: The impact of cell phones on simulated driving performance. Accident Analysis and Prevention, 2006. 38(2): p. 415-421.

13. Amado, S. and P. Ulupınar, The effects of conversation on attention and peripheral detection: Is talking with a passenger and talking on the cell phone different? Transportation Research Part F: Traffic Psychology and Behaviour, 2005. 8(6): p. 383-395.

14. Hancock, P.A., M. Lesch, and L. Simmons, The distraction effects of phone use during a crucial driving maneuver. Accident Analysis and Prevention, 2003. 35(4): p. 501-514.

15. Burns, P.C., A. Parkes, S. Burton, R.K. Smith, and D. Burch, How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol. 2002, TRL Limited: Crowthorne, UK.

16. Caird, J.K., C.R. Willness, P. Steel, and C. Scialfa, A meta-analysis of the effects of cell phones on driver performance. Accident Analysis andamp; Prevention, 2008. 40(4): p. 1282-1293.

17. Horrey, W.J. and C.D. Wickens, Examining the impact of cell phone conversations on driving using meta-analytic techniques. Human Factors, 2006. 48(1): p. 196-205.

18. Ishigami, Y. and R.M. Klein, Is a hands-free phone safer than a handheld phone? Journal of Safety Research, 2009. 40(2): p. 157-164.

19. Nilsson, L. and H. Alm, Effects of mobile telephone use on elderly drivers' behaviour including comparisons to young drivers' behaviour. 1991.

20. Just, M.A., T.A. Keller, and J. Cynkar, A decrease in brain activation associated with driving when listening to someone speak. Brain Research, 2008. 1205(0): p. 70-80.

21. Strayer, D.L., F.A. Drews, and W.A. Johnston, Cell phone induced failures of visual attention during simulated driving. Journal of Experimental Psychology: Applied, 2003. 9(1): p. 23-32.

22. NSC. Understanding the distracted brain - Why driving while using hands-free cell phones is risky behavior. 2010 23 July 2012]; Available from: http://www.fnal.gov/pub/traffic_safety/files/NSC%20White%20Paper%20-%20Distracted%20Driving%203-10.pdf.

23. Maples, W.C., W. DeRosier, R. Hoenes, R. Bendure, and S. Moore, The effects of cell phone use on peripheral vision. Optometry - Journal of the American Optometric Association, 2008. 79(1): p. 36-42.

24. Raudenbush, S.W. and A.S. Bryk, Hierarchical linear models: applications and data analysis methods. 2nd ed. 2002: Thousand Oaks: Sage Publications.

25. Haque, M.M., A.D. Ohlhauser, S. Washington, and L.N. Boyle, Examination of distracted driving and yellow light running: Analysis of simulator data, in 92nd Annual Meeting of Transportation Research Board (TRB). 2013: Washington DC, USA.