Conversations in Cars: The Relative Hazards of Mobile Phones

Final Report

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CONVERSATIONS IN CARS:
THE RELATIVE HAZARDS OF MOBILE PHONES REPORT

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Conversations in Cars: The Relative Hazards of Mobile Phones

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1 Executive summary

Mobile phones have been associated with increased collision risk if used while driving. The aim of this study was to benchmark the distraction caused by hands-free mobile phone conversations in relation to other conventional in-car tasks and to the distraction caused by similar conversations held with a front seat passenger.

This study examined participants' performance in a driving simulator while simultaneously performing one of several tasks. These tasks were talking on a hands-free phone, talking to a passenger, and using the radio and climate controls of the vehicle (referred to as in-vehicle tasks). For comparison two experimental control conditions were also included; a *driving control*, where there was no additional task, and a *conversation control* where the participant simply completed the conversation task without driving. Conversations were standardised to ensure the same level of task involvement across the experimental conditions.

A comprehensive combination of measures were used to assess the impact of distraction: driver performance, visual behaviour, subjective workload, and conversation performance.

For *driving performance*, vehicle measures, visual behaviour and subjective workload comparisons were made between the hands-free, passenger, in-vehicle and driving control conditions. For *conversation performance*, only hands-free, passenger and conversation control were compared.

The results showed a complex but consistent picture of distraction. Measures of car following ability and general measures of speed control showed that all additional conversation and in-vehicle tasks produced more variable performance consistent with the additional load imposed. Looking at these measures alone it was not possible to differentiate between the various tasks.

Self-report subjective workload measures showed that both in-vehicle and passenger conversation tasks were rated equally more difficult than control driving. Hands-free conversations were rated yet more difficult. This pattern was repeated in the results of choice reaction time tasks. When drivers were required to respond selectively to road signs, it was shown that the best performance was achieved in the driving control condition, with a significant deterioration from in-vehicle and passenger conversation conditions, and yet further deterioration in the hands-free conversation drive. The pattern of missed signs was similar.

It was of interest to examine carefully the visual behaviour of the drivers in the different task conditions. There was a significant difference between the control condition and when the drivers were also engaged in tasks operating the radio or ventilation systems. Drivers took their eyes off the road for longer. However when drivers were engaged in conversations either with the front seat passenger or via the hands-free carphone, the time they spent looking away from the road ahead actually reduced. The number of glances to the speedometer was reduced and this distraction from monitoring vehicle speed was reflected in higher speed variation. Though looking ahead at the road scene the increase in response time and number of missed road signs shows that the drivers were not paying the same level of attention to the road scene as in the control condition. These results are consistent with other experimental work that has shown a reduction in situation awareness when drivers are engaged in conversations.

It should also be emphasised that the act of driving also had a distinct effect on the quality and character of a conversation. The rate of talking, the number of pauses, number of errors and performance on verbal and numerical reasoning tasks all deteriorated when driving at the same time. This result is intuitive. A more interesting comparison is between the conversations held over the carphone and with the front seat passenger. There was a clear difference on all conversation measures showing that performance was worse when the response was via the hands-free carphone.

2 Aims and Objectives

2.1 Background

The IEGMP report (Stewart, 2000) concluded that drivers should be dissuaded from using phones while driving. This is because an increased risk of motor vehicle collision has been associated with mobile phone use while driving using real world collision data (Redelmeier and Tibshirani, 1997). This has also been supported by experimental research showing carphone conversations impair driving performance both in driving simulators and in real road trials (Fairclough et al, 1991; Parkes, 1991a; Parkes, 1991b; Parkes et al, 1993).

2.2 Objectives

The objective of the study was to compare the distraction from hands-free phone conversations with the distraction caused by conversations with passengers and conventional in-vehicle tasks within a highly controlled simulated driving environment. The study was designed to present the driver with a variety of traffic environments and to require a range of driving skills that cover not only basic operational skills of speed control and lane position, but also to include responses to road signs and other traffic. The study combines vehicle data, self report measures of workload, analysis of visual behaviour and measures of choice response performance.

A further objective was to develop an insight into the effect of driving on the ability to hold a conversation and make decisions. The study employs standardised conversations that include elements of numerical and verbal reasoning, and also the requirement to talk at length on routine topics. The study is designed to allow direct comparison between conversations over a hands-free carphone with those conducted with a front seat passenger. Further comparisons can be made with similar conversations conducted away from the vehicle where the conversation becomes the primary task, rather than being a shared secondary task.

3 Participants

A M Parkes, P C Burns, S Burton, R K Smith, T Luke – TRL

T Lansdown – Heriot Watt University

4 Achievements

4.1 Method

4.1.1 Subjects

Thirty experienced drivers were selected from over 1300 volunteers on the TRL database. They were aged between 21 and 64 (M = 40.9, SD = 12.39), split evenly by gender and all owned a mobile phone. A small fee was made as compensation for their time and reimbursed of travelling expenses.

4.1.2 Method

The participants were invited to the laboratory for information about the experiment and a pre-trial test drive to allow them to become familiar with the Driving Simulator Car and environment.

The trial was scheduled about a week after their familiarisation session and started with a drive in the simulator where they were given a chance to practice the in-vehicle tasks. The participants were asked to drive as they normally would and to respond to the requests of the experimenter at various times. The order of the five conditions was balanced and as follows:

- **Passenger** – Conversation with the experimenter as a passenger while driving
- **In-vehicle** – Adjustment of the in-car controls while driving
- **Hands-free** – Driving and talking with the experimenter using a hands-free mobile phone system
- **Driving control** – Driving only, no simultaneous tasks
- **Conversation control** – conversation only, without driving

Video and audio recordings were taken of the conversations and tasks. The computer running the simulation automatically captured the driving behaviour. Subjective workload measures were taken using the Rating Scale for Mental Effort (Zijlstra and Van Doorn, 1985) at the end of each condition.

4.1.3 Equipment

Figure 1 – TRL driving simulator

The TRL driving simulator is one of the most sophisticated and realistic driving simulators available in Europe. It consists of a medium size saloon car surrounded by 3 x 4 meter projection screens giving 210 degree front vision and 60 degree rear vision, enabling the normal use of vehicle mirrors. Advanced Silicon Graphics computers generate the road images. The car body shell is mounted on hydraulic rams that provide motion simulating heave, pitch and roll experienced in normal braking, accelerating and cornering. When negotiating curves, the simulator provides realistic forces experienced by the driver through the steering wheel. The provision of car engine noise, external road noise, and the sounds of passing traffic further enhance the realism of the driving experience.

A Nokia 3310 phone was used for the study installed into a professionally fitted phone bracket situated on the upper left side of the centre stack within easy reach and view from the driving position. A CCD colour video camera was mounted on the cowl above the instrument cluster in a position to capture a clear view of the drivers' eye movements. The camera images were recorded on a video mixed together with the forward view of the simulated road scene and the speedometer.

Figure 2 – Interior of driving simulator and hands-free phone

The in-vehicle radio tasks were performed on an aftermarket Radio/ CD player (Sony CDX - CA600). The original climate controls of the Rover 400 series car were used for the climate tasks.

4.1.4 Route and Traffic Scenarios

Following Task
Participants drove a 17 km route that was composed of four different segments. The route started with a car following task on a motorway lasting 3.5km. Whilst stationary, drivers were instructed to study the distance to a vehicle parked ahead and to maintain this initial distance. The lead vehicle started driving and oscillated its speed gradually between 50 and 70 mph (80 and 113 km/h).

Figure 3 – Example car following scene

Normal Motorway Traffic
After completing the car-following task, drivers were instructed to drive as they would normally on a motorway. The motorway had 3 lanes and a moderate amount of traffic. The speed limit was 70 mph (113 km/h), the standard speed for motorways in the UK. The other vehicles were programmed to vary their speeds in relation to the subject's vehicle and could overtake or be overtaken depending on how the subject drove. The motorway continued for 4.7 km.

Figure 4 – Example motorway traffic scene

Lane and Speed Control Curved Section
A section of curved road was used to measure the driver's ability to control the vehicle on a more demanding type of rural road. The curves had a full length of 3.6km including straight segments connecting the loops. The loops were modelled on the TRL research track and each had a continually changing radius. Drivers were instructed to maintain a speed of 60 mph (96.6 km/h) and a central position within the left lane.

Figure 5 – Example curved section of route scene

Reaction Events
The curves were followed by a 5.3km section of dual carriageway (2 lane road), which ended in traffic lights. During this section, drivers had to respond selectively to 24 warning signs at various points along the dual carriageway. They were instructed to flash their headlights whenever a particular target sign appeared. There were 4 different warning signs in this choice reaction time task: Elderly pedestrians, Pedestrian crossing, Cyclists and Roadwork. Each sign appeared 6 times.

Figure 6 – Example target sign scene

4.1.5 Conversation Task

4.1.5.1 Hands free carphone conversation

Questions from the Rosenbaum Verbal Cognitive Test Battery (RVCB) were given by the experimenter over the hands-free phone. The RVCB measures judgement, flexible thinking and response times (Waugh et al, 2000). The battery is composed of a 30 item remembering sentences task and 30 verbal puzzle tasks. The test battery has five levels of difficulty with six items within each level of both tests. These questions were split across the conditions and also included short monologues on familiar topics

4.1.5.2 Passenger conversation

The procedure and conversation materials were the same as in the carphone condition, but in this case the experimenter occupied the front passenger seat of the vehicle alongside the driver.

4.1.6 In-Vehicle Tasks

In a separate trial run, participants were asked to perform a set of tasks in the vehicle (see Table 1). Full instructions for the use of the in-vehicle systems were given to the participant and there was an opportunity to practice using all of the controls. During the practice and the in-vehicle task conditions, the instructions to operate the climate and entertainment controls were given to the participant by the experimenter via an intercom system installed in the car. Instructions were given at points along the route comparable to the spacing of the conversation tasks in the other conditions.

Figure 7 – In-car CD player

Figure 8 – Car ventilation controls

Conditions	Tasks
1. Hands-free Conversation	Verbal Puzzles (numerical and verbal reasoning) Sentence recall Monologue
2. Passenger Conversation	Verbal Puzzles (numerical and verbal reasoning) Sentence recall Monologue
3. In-vehicle condition • Climate Controls • Audio System	 Adjust fan Change fan mode Adjust temperature Turn on/ off Adjust volume Change station (track) Find station (track)
4. Driving Control	No tasks
5. Conversation Control	Verbal Puzzles (numerical and verbal reasoning) Sentence recall Monologue

Table 1 - Summary of tasks in each condition

4.1.7 Driving Control Condition

On a separate trial run, drivers were given the same performance tasks (car following, curve negotiation, choice reaction, and so on), but were not distracted by conversation or in-vehicle tasks.

4.1.8 Conversation Control Condition

As a baseline for the carphone and passenger driving and conversation conditions, data was collected for similar standardised conversation conducted in a relaxed seating area. The task was paced in a similar fashion to the passenger condition, enabling an assessment of the effect of driving the simulated vehicle on the quality of the conversation itself.

4.1.9 Questionnaires

A mobile phone questionnaire consisted of 28 questions designed to investigate all aspects of participant's mobile phone use:

- General questions about phone model owned, typical phone conversations and frequency of use.
- Phone user attitudes towards penalties for being caught whilst driving and using a mobile phone.
- Participants’ own experiences of driving whilst using a mobile phone.
- Lists of tasks that people typically do while driving with a distraction rating.
- Questions about conversations with passengers

Task mental load was measured using a subjective rating scale; (rating Scale for Mental Effort or Zijlstra, 1993. With the RSME the amount of invested effort into the task is indicated, and not the more abstract aspects of mental workload (e.g., mental demand, as is in the NASA-TLX, Hart and Staveland, 1988).

4.1.10 Analysis

The data was analysed to determine the hazards of hands-free phone use while driving, and the quality of conversation while driving. Descriptive analyses were performed on all of the data from the experiment (central tendencies and distributions). The data was screened for anomalies and violations of parametric assumptions. This was followed by inferential analyses. The main analysis was a repeated measures analysis of variance (ANOVA). Comparisons in driving performance across conditions were made for the same segment of road. For example, the mean standard deviation of lane keeping for curves while using the hands free phone was compared with the mean for those same curves during the passenger conversations, as well as for the in-vehicle tasks and control drive.

The null hypothesis was that there would be no difference in driving performance among the different treatment conditions (hands-free phone conversations, passenger conversations, conventional tasks, control drive and control conversation).

4.2 Results

4.2.1 Driving Performance

Different measures were used to examine driver performance in each condition. Each drive was split into four functional elements: car following on a motorway, free drive in motorway traffic, curve negotiation, and responses to signals on a dual carriageway. The measures are summarised below.

1. Car following	Headway of < 1 sec Headway error on following task
2. Motorway traffic	Carriageway departures Headway of < 1 sec
3. Curve negotiation	Lane departures Error of lane position Speed error on curved road section
4. Dual Carriageway	Reaction time to road signs False alarms

4.2.1.1 *Car following task*

A one-way repeated measures ANOVA was calculated for the SD of time headway in the car following section of the route across the four driving conditions. The main effect by condition for SD of time headway was not significant. However, there were significant contrasts between the control condition and the passenger condition {F (1,28)=10.999, p=.004} and the control condition and the in-vehicle condition {F(1,28)=4.296, p=.048}. SD of time headway was significantly lower in the control condition than in the passenger and in-vehicle conditions. There were no significant differences between the passenger, in-vehicle and hands-free conditions. (See figure 9).

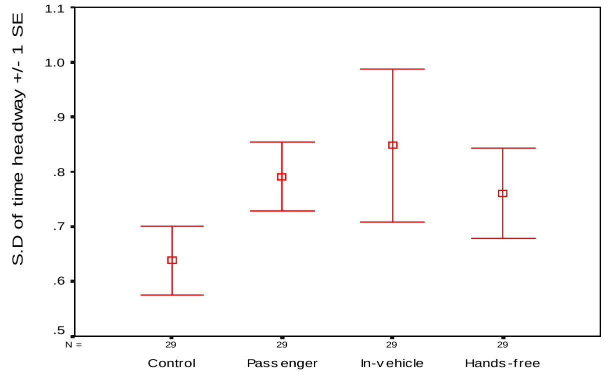

Figure 9 – Standard deviation of time headway on car following task

Each of the task conditions led to higher difficulty in the ability to maintain a set distance from the lead vehicle. It is worth noting the wide variation in results observed within the in-vehicle condition. No headways of less than one second were observed in the car following task.

4.2.1.2 *Motorway traffic*

There were no carriageway departures or headways of less than one second in any of the conditions.

4.2.1.3 *Curve negotiation*

Mean Speed

A one-way repeated measures ANOVA was calculated for the mean speed on the curved section across the four driving conditions. There was a significant main effect by condition for the mean speed on the curved section {F(3,87) = 16.7, p < .001}. Mean speed was significantly higher in the control condition than the passenger {F(1,29)=39.749, p < 0.001, MSE = 1.643} hands free {F(1,29) = 17.331, p < 0.001, MSE = 1.62} and in-vehicle conditions {F(1,29) = 44.282, p < 0.001, MSE = 1.164}. There was no significant difference between the passenger, in-vehicle and hands-free conditions (see figure 10).

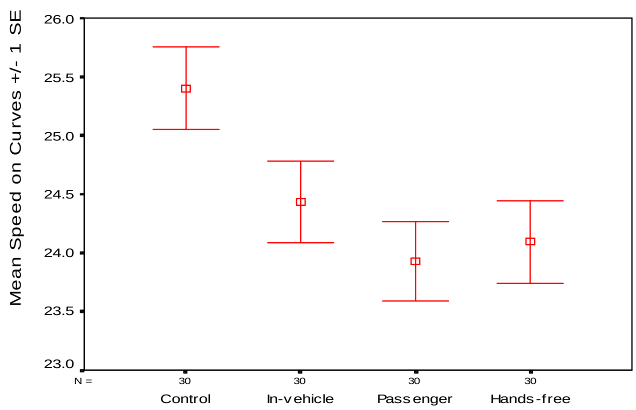

Figure 10 – Mean speed on curved sections (m/sec)

Speed Error

On the curved section of the route the driver was required to maintain a speed of 60 mph. A one-way repeated measures ANOVA was calculated for the speed error on this section across all four conditions {$F(3, 87) = 9.13$, $p < 0.001$, MSE = 0.24}. Speed error was significantly lower in the control condition than in the passenger {$F(1,29)=15.635$, $p < 0.001$, MSE = 76.66} in-vehicle {$F(1,29) = 8.244$, $p = 0.008$, MSE = 64.190} and hands free conditions {$F(1,29) = 17.092$, $p < 0.001$, MSE = 57.574}. There was no significant difference between the passenger, in-vehicle and hands-free conditions (see figure 11).

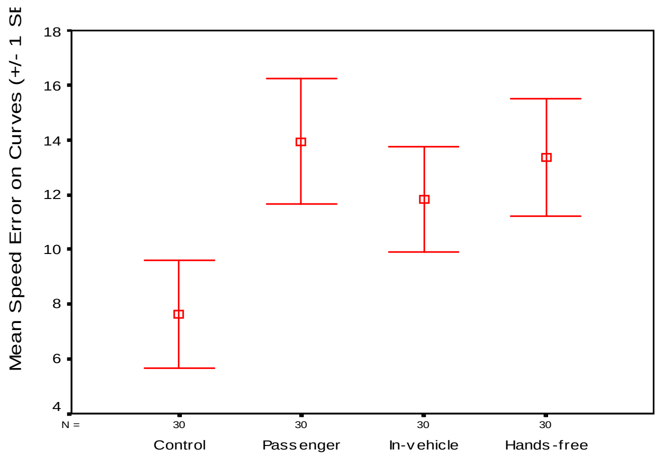

Figure 11 – Speed error on curves

Lane Position Errors

A series of one-way repeated measures ANOVA were calculated for lane position errors on the curved, dual carriageway and following sections of the route. It should be emphasised that error is defined operationally a the instantaneous variance in position from the centre of the lane. There was no significant effect of condition on lane position errors for the following section of the route. There was a significant main effect of condition on the number of lane errors on the curved section {$F(3,87) = 4.665$, $p = 0.005$, MSE = 0.0085}. There were significantly less errors in the passenger condition compared to the control {$F(1,29) = 10.343$, $p = .003$, MSE = 0.018} and in-vehicle conditions {$t(29) = 2.850$, $p = .008$). There were no significant differences between the control, in-vehicle and hands free conditions (See figure 12)

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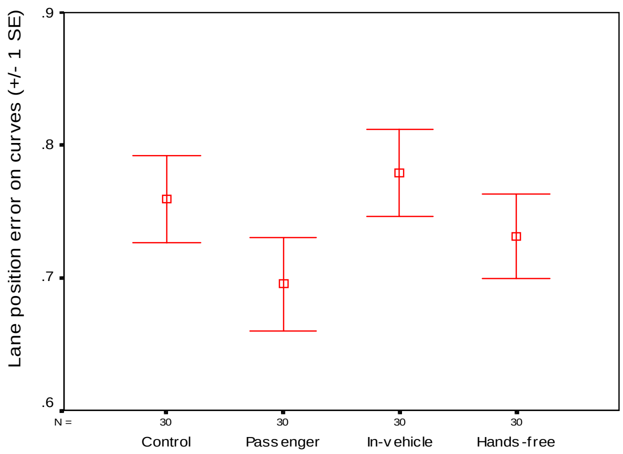

Figure 12 – Lane position errors on curves

4.2.1.4 Dual Carriageway

S.D. of Mean Speed

A one-way repeated measures ANOVA was calculated for the SD of mean speed on the dual carriageway across all four conditions. {$F(3, 87) = 9.13$, $p < 0.001$, MSE = 0.15}. SD of mean speed on the dual carriageway was significantly lower in the control condition than in the passenger {F(1,29)=14.034, p = 0.001, MSE = 0.338} in-vehicle {F(1,29) = 15.050, p < 0.001, MSE = 0.355} and hands free conditions {F(1,29) = 23.077, p < 0.001, MSE = 0.256}. There was no significant difference between the passenger, in-vehicle and hands-free conditions (see figure 13).

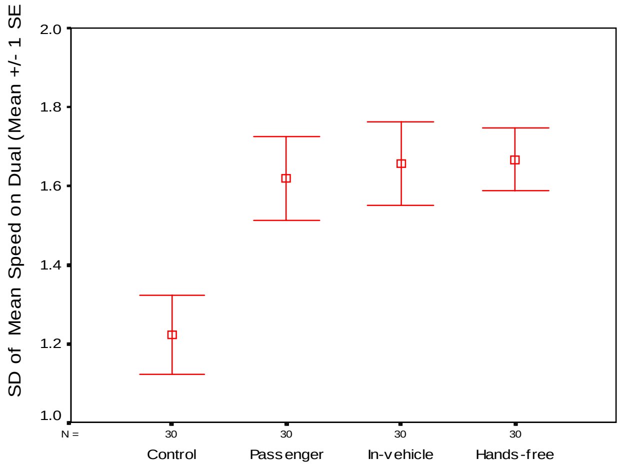

Figure 13 – SD of mean speed on dual carriageway

Lane position

There was also a significant main effect of condition on lane position errors for the dual carriageway section of the route {F(3,87) = 7.299, p < 0.001, MSE = 0.0019}. There were significantly more errors in the in-vehicle condition compared to the control {F(1,29) = 5.516, p = 0.026, MSE = 0.0044}, Hands-free {F(1,29) = 14.767, p = 0.001, MSE = 0.0032} and passenger conditions {F(1,29) = 17.795, p < 0.001, MSE = 0.0042}. There were no significant differences between the control, passenger and hands-free conditions (See figure 14).

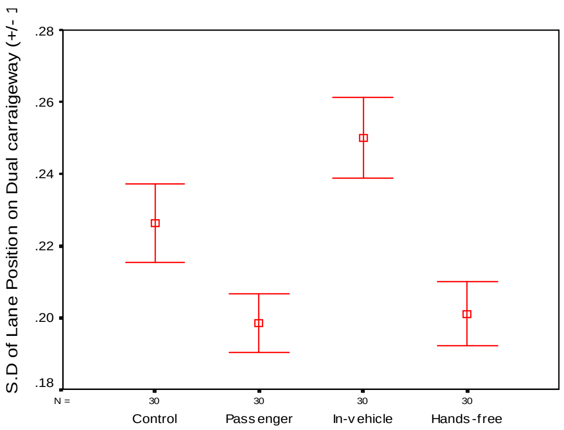

Figure 14 – S.D. of lane position on dual carriageway

S.D of Lane Position

A one-way repeated measures ANOVA was calculated for the S.D. of lane position on the dual carriageway across the four conditions. There was a significant main effect of condition in the SD of lane position on the dual-carriageway {$F(3, 87) = 17.55$, $p < 0.001$, MSE = 0.38}. Standard deviation of lane keeping was significantly lower during the two conversation conditions than during the control or in-vehicle task condition (see figure 15).

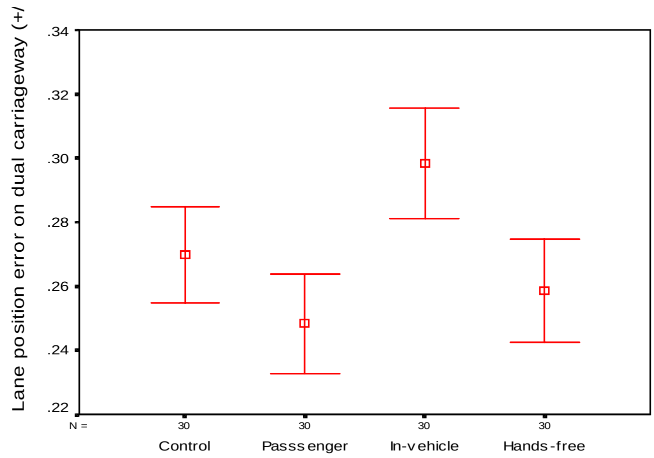

Figure 15 – Lane position errors for dual carriageway section

4.2.1.5 Reactions to Warnings

Reaction times

A one-way repeated measures ANOVA was calculated for the median reaction time ratings across the four conditions (see Figure 16). The mean reaction time data was skewed so the median reaction time for the six events was used. This median data was normally distributed. There was a significant main effect by condition for median reaction time {$F(2.4, 84) = 24.39$, $p < 0.001$, MSE = 0.47}. There was a significant problem of sphericity with the data, so a Huynh-Feldt correction was used. Post hoc tests were run to compare the reaction times. Reaction time was significantly slowest for the hands-free phone condition in comparison to the in-vehicle tasks ($p = 0.046$, one-tailed), talking with a passenger ($p = 0.03$, one-tailed) and the control drives ($p < 0.001$). Reaction times in the control drive were also significantly faster than during the in-vehicle task ($p < 0.001$) and passenger drives ($p < 0.001$).

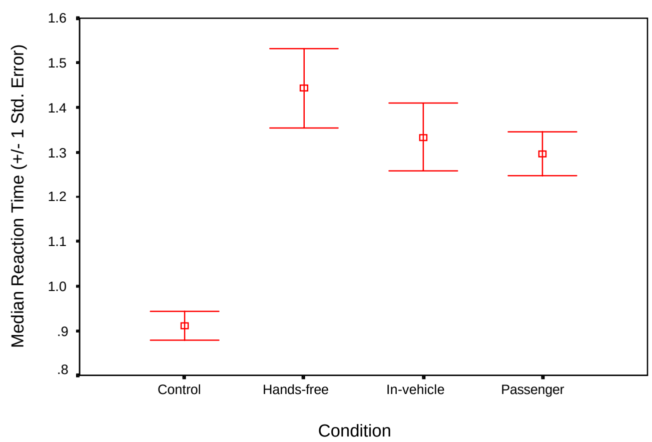

Figure 16 – Median reaction times

False Alarms

There were no significant differences in the number of false alarms across the four conditions
The greatest number of missed target occurred in the hands-free drive (n = 31) followed by the in-vehicle task drive (n = 27) and passenger conversation drive (n = 22). Only one target was missed during the control drive. The missed target data was significantly skewed so a nonparametric Friedman's test was used to compare conditions. The number of misses differed significantly across the four conditions {chi-square = 21.6, $p < 0.001$}. Post-hoc comparisons showed significant differences between the control drive and other drives. There were no significant differences among the other conditions.

4.2.2 Subjective Workload Ratings

A one-way repeated measures ANOVA was calculated for the subjective mental effort ratings across the four conditions (see figure 17). There was a significant main effect by condition for mental effort {$F(3, 84) = 23.49$, $p < 0.001$, MSE = 0.46}. Post hoc tests were run to compare the mean mental effort ratings by condition. Mental effort was rated highest for the hands-free drive and lowest for the control drive. The control drive required significantly less mental effort than hands-free ($p < 0.001$), passenger conversation ($p = 0.001$) or in-vehicle task drives ($p < 0.001$). Hands-free was significantly more demanding than either the passenger conversation ($p < 0.001$) or in-vehicle task drives ($p < 0.001$). There was no significant difference in the mental effort ratings between the passenger conversation and in-vehicle task drives.

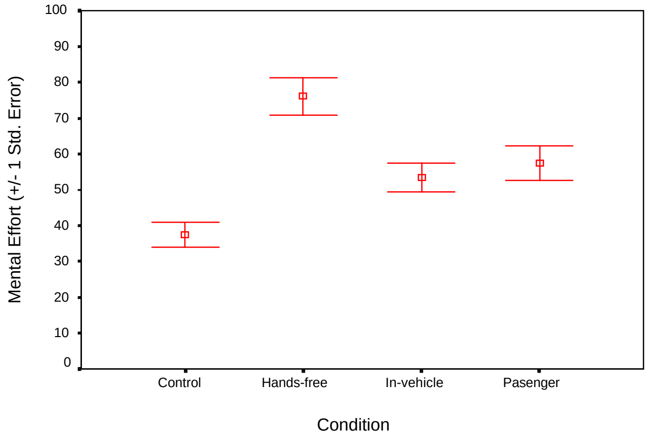

Figure 17 – Mental effort ratings

4.2.3 Questionnaire

All of the 30 participants owned mobile phones and used them regularly. 17 used their phones daily with 13 using them less often. 24 of participants used their phones mainly for personal calls. Only 6 used them mainly for business calls.

23 participants felt that hand-held phones should be banned from use while driving. No participants believed there should not be a ban. Opinions of the penalties for using a hand-held phone varied: fine (n = 7), points on license (n = 11), caution (n = 12) and one did not know. 18 participants felt there should not be a ban on hands-free phoning in cars, 4 said there should be a ban, 5 said it depends on circumstances and 3 did not know.

When asked if they would make a phone call while driving, 13 said yes, 7 said it depends, while 10 would not, or had their phones switched off.

When asked how frequently they would use a mobile phone while driving. 6 used it every time they drove, 20 used their phones occasionally and 4 said they never used their phones.

When asked if drivers should pull over and stop driving when using the phone: 18 said ‘yes’; 10 said that it ‘depends’ on the situation; 2 said ‘no’. 17 drivers did not have a hands-free phone kit in their cars, 3 had professionally fitted hands-free phones and 10 used an earpiece attached to the phone.

When asked if they would answer a phone while driving, 12 said yes, 10 said it depends on the caller or traffic situation and 8 would not.

When they did use the phone while driving, 7 would have business conversations, 11 would have simple short conversations and 10 would give brief messages. Typical these conversations lasted around 1 minute (n = 13), or between 1 and 10 minutes (n = 11) and up to 20 minutes (n = 2). As a percentage of driving time, 18 said that they spent around 1% of their time on the phone. 5 used their phones between 5 and 20% of the time and 2 used their phones for 50% of the time.

When asked if there were any driving conditions or situations when they would not use their phones. Bad weather, motorways and urban driving were mentioned most frequently (n = 23). 2 drivers said they would use their phones irrespective of the driving conditions or situation.

When asked if they would send a text message while driving. 21 would never, 2 would regularly and 7 would occasionally.

Participants were asked to describe from their own observations the type of driver most likely to use their phones whilst driving. The most common answer was ‘business people’ (n = 19) and younger drivers (n = 10).

A repeated measures ANOVA was calculated on the eight different driver distraction ratings (see figure 18). There was a significant main effect for type of distraction {$F(5, 127) = 48.17$, $p < 0.001$, MSE = 0.67}. There was a significant problem of sphericity with the data so a Huynh-Feldt correction was used. Post hoc tests were run to compare the distraction ratings by condition. Sending a text message was considered to be the most distracting activity to perform while driving. From the list, the least distracting activity was having a conversation with a passenger. The subjects rated talking with a passenger as being significantly less distracting than talking on a hands-free phone (p = 0.001). There was no difference between tuning a radio and hands-free phone. Talking hand-held was rated as being significantly more difficult than the other tasks with the exception of text messaging and reading a map (see figure 18).

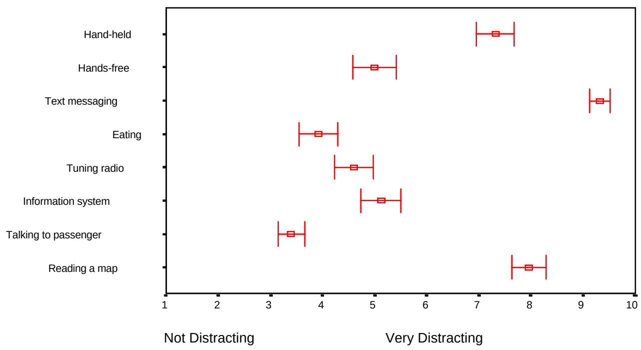

Figure 18 – Perceived distraction of various tasks while driving (Mean +/- 1 SD)

4.2.4 *Conversation Measures*

A number of measures were used to examine the quality of conversations in each condition. These measures make the comparison between the two conversation conditions, passenger and hands-free, and the conversation control where the participant is not driving. The measures are as follows:

1. Errors in sentence repetition
2. Correct sentence repetition
3. Pauses in monologue
4. Rate of talking in monologue
5. Correct answers to verbal and numerical reasoning questions
6. Question response times

4.2.4.1 Mean rate of talking during monologue in each condition

The rate of talking was calculated for the conversations by counting the number of words spoken and dividing it by the duration of the monologue. A one way repeated measures ANOVA was calculated for the rate of talking across the three conversation conditions. There was a significant main effect of condition on the mean rate of talking {F (2,56) = 48.28, p < 0.001, MSE = 0.63}. Post Hoc tests were run to identify the differences. The rate of talking was significantly faster during the control conditions than either the passenger (p < 0.001) or hands-free. There was also a significant difference between the passenger conversations and the hands-free conversations (see figure 19).

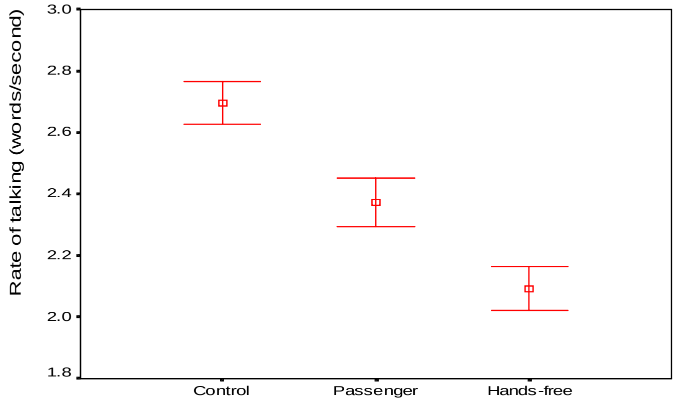

Figure 19 – Mean rate of talking (+/- 1 SD)

4.2.4.2 Mean number of pauses in monologue

The number of pauses during the monologue section was calculated. A one way repeated measures ANOVA was calculated for the number of pauses across the three conversation conditions. There was a significant main effect for the number of pauses by condition {F (1.6,47.8) = 22.67, p < 0.001, MSE = 0.45}. Post hoc tests were run to compare the conditions. The number of pauses was significantly less in the control condition than in the hands-free condition (p < 0.001). There were also significantly fewer pauses during the passenger conversation than the hands-free conversation. There was no significant difference between the number of pauses during the control condition and the passenger condition (See figure 20).

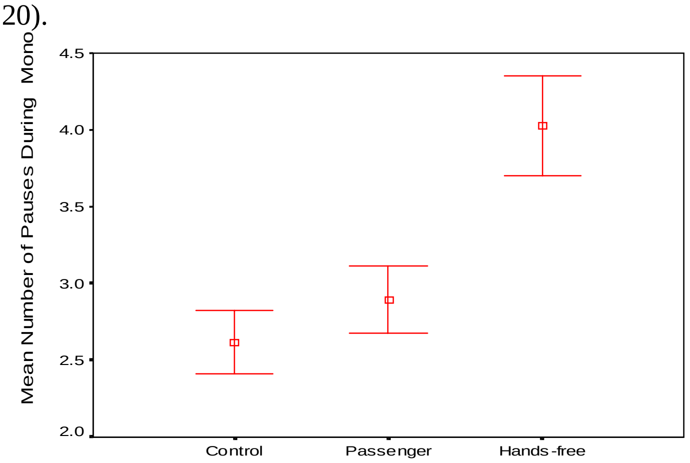

Figure 20 – Number of pauses in monologue (+/- 1 SD)

4.2.4.3 Mean total number of correct answers

A one-way repeated measures ANOVA was calculated for the mean total number of questions answered correctly for the three different conditions. There was a significant main affect for the total number of questions answered correctly by condition {$F(1.9, 53.8) = 3.74$, $p < 0.05$, $MSE = 0.12$}. The number of correct answers was significantly higher in the control condition than in the hands-free condition ($p < 0.001$). There was no significant difference between the number of correct answers in the control condition and the passenger condition, or between passenger and hands-free. (see figure 21) though the trend in the results to show hands free conversations at a disadvantage is repeated.

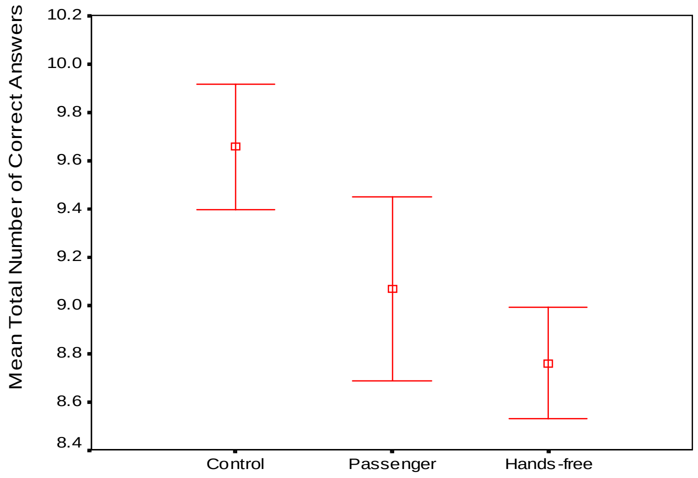

Figure 21 – Total number of correct answers (+/- 1 SD)

4.2.4.4 Mean question response time

A one-way repeated measures ANOVA was calculated for the mean question response time for the three different conditions. There was a significant main affect for the mean response time for the questions answered {$F(2,56) = 6.74$, $p < 0.05$, $MSE = 0.19$}. The question response time was significantly lower for the control condition than either the passenger or the hands-free condition. There was no significant difference between the response times of the passenger and the hands-free conditions (see figure 22).

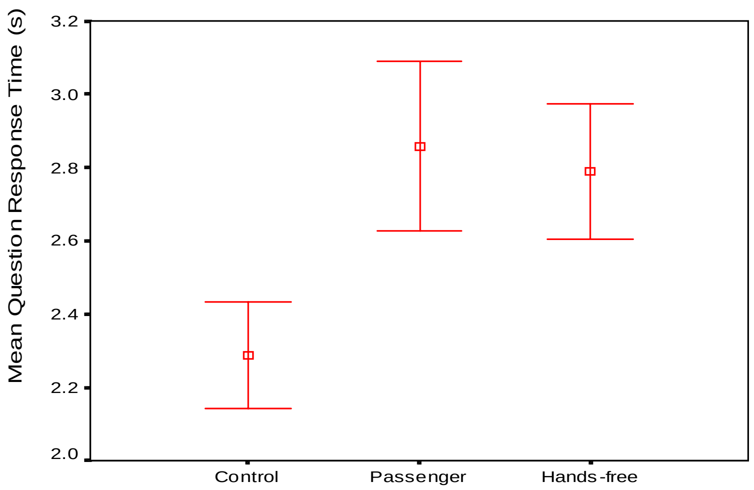

Figure 22 – Question response time (+/- 1 SD)

4.2.4.5 *Mean number of sentences repeated correctly*

A one-way repeated measures ANOVA was calculated for the mean number of sentences repeated correctly for the three different conditions. There was a significant main affect for the total number of sentences repeated correctly by condition {F (1.9,53.3) = 68.14, p < 0.001, MSE = 0.71}. There was no significant difference between the mean number of correctly repeated sentences in the control and the passenger conditions. There was a significant difference between the number of sentences answered correctly in the control condition and the hands-free condition (p < 0.001) and between the passenger condition and the hands-free condition (p < 0.001) (See figure 23).

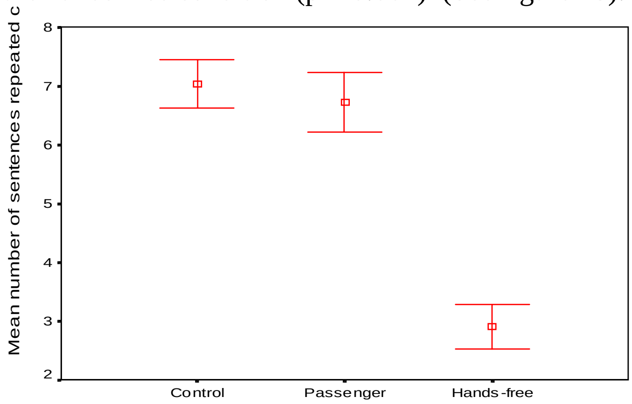

Figure 23 – Mean number of sentences repeated correctly (+/- 1 SD)

4.2.4.6 *Mean response time for sentence repetition*

A one-way repeated measures ANOVA was calculated for the mean response time for sentences repeated for the three different conditions. There was a significant main effect for time by condition {F (1.6,44.3) = 88.87, p < 0.001, MSE = 0.76}. The time taken to repeat back sentences was significantly less during the control condition than either the passenger (p = 0.05) or the hands-free condition (p = 0.001). There was also a significant difference between the passenger condition and the hands-free condition (p = 0.001) (see figure 24).

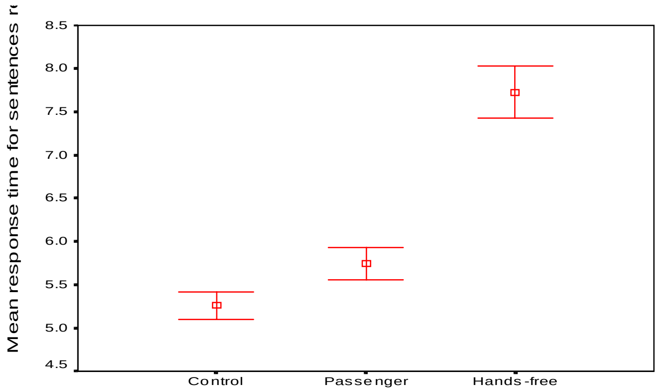

Figure 24 – Mean response time for sentence repetition (+/- 1 SD)

4.2.5 *Visual Behaviour*

Visual behaviour of the drivers was sampled across the whole test route in each driving condition. For each of the four elements of the drive a one-kilometre section was identified and analysed in detail. All glances to the mirrors, speedometer, climate and entertainment controls, or to any ‘other’ region inside the vehicle were recorded. Glances were defined as occupying the period that starts with eye movement away from the road ahead, and includes the dwell time in one of the zones of interest. The glance finished at the point the eye started to move to another location. To aid data scoring and analysis, glances were categorised in 0.5 second intervals. Results from each of the four elements of the drive were aggregated to provide a single composite score for each participant and task condition.

4.2.5.1 *Glances away from road ahead*

Glances to mirrors
There were no significant differences between conditions in either the number of glances towards the mirrors, or in the average duration of those glances.

Glances to speedometer
There was an overall effect of task condition on the average duration of a glance to the speedometer $F(3,78)=2.989$, $p<.05$ (see table 2).

Task	Mean	SD
Control	0.505	0.018
Passenger	0.503	0.009
In-vehicle	0.517	0.031
Carphone	0.507	0.018

Table 2 - Task related duration of glances to the speedometer

A post-hoc Fisher test revealed that there was a significant difference between the duration of glances to the speedometer when participants were involved in completing in-vehicle tasks when compared to any of the other conversation or control conditions. There was no difference between the other conditions (see table 3).

Comparison	Mean Difference	Critical Difference	p Value
Control and passenger	.003	.026	.8461
Control and In-vehicle	-.031	.026	.0205
Control and carphone	-.002	.026	.8943
Passenger and in-vehicle	-.034	.026	.0115
Passenger and carphone	-.004	.026	.7428
In-vehicle and carphone	.029	.026	.0287

Table 3

There was also a significant effect of task condition on the number of glances made to the speedometer during the trials ($F(3,78) = 24.944$, $p<.0001$) (see table 4).

Task	Mean	SD
Control	12.185	7.545
Passenger	6.111	4.602
In-vehicle	11.333	5.152
Carphone	5.519	4.108

Table 4 - Number of glances made to the speedometer

A post-hoc Fisher test revealed that there was no significant difference between the control and in-vehicle tasks, or between the carphone and the passenger tasks, but there was for all other comparisons (see table 5).

Comparison	Mean Difference	Critical Difference	p Value
Control and passenger	5.926	2.916	.0001
Control and In-vehicle	1.057	2.892	.4704
Control and carphone	6.464	2.942	<.0001
Passenger and in-vehicle	-4.869	2.866	.0010
Passenger and carphone	.538	2.916	.7153
In-vehicle and carphone	5.407	2.892	.0003

Table 5

The conversation conducted both with the passenger and over the carphone resulted in significantly fewer glances to the speedometer.

Other regions

Other regions included glances to the carphone, the passenger, the radio or climate controls, or any other target of interest inside the vehicle. There was no significant difference in either frequency or duration of glances to these other regions as a function of task condition.

4.2.5.2 Total percentage time looking off road ahead

There was a significant difference in the percentage of time spent looking away from the road ahead in the different task conditions ($F(3,87) = 90.865$, $p<.0001$) (see table 6)

Task	Mean	SD
Control	6.459	3.091
Passenger	4.355	2.437
In-vehicle	10.235	2.993
Carphone	3.612	1.772

Table 6 - Task related time looking away from the road ahead

A post hoc Fisher test revealed an interesting set of comparisons. There was no significant difference between the conversation conditions, but both these were significantly lower than the control condition, whilst the in-vehicle condition was significantly higher (see table 7).

Comparison	Mean Difference	Critical Difference	p Value
Control and passenger	2.028	1.387	.0045
Control and In-vehicle	-3.755	1.387	<.0001
Control and carphone	2.639	1.399	.0003
Passenger and in-vehicle	-5.784	1.387	<.0001
Passenger and carphone	.611	1.399	.3888
In-vehicle and carphone	6.394	1.399	<.0001

Table 7

4.3 Summary of Results

4.3.1 Driving Performance

Following performance was better in the control condition than in the other conditions. There was less variability in the time headway on the following task indicating more accurate driving. Performance on this task was worse in the passenger, in-vehicle and hands-free conditions, although there was no difference in performance between these conditions.

There were also differences in **speed control and speed selection** across the conditions. Drivers selected a generally higher speed on the curved section of the route in the control condition. Selecting a slower speed is usually an indication that the driver finds the task more demanding, so the result is consistent with the assumption that the control drive was the least demanding. There was no difference in the average speed in the passenger, in-vehicle and hands-free conditions. This suggests that the drivers did not compensate by reducing their speed differentially for the different task demands.

The **variability of speed** on the dual carriageway was also affected by condition. The pattern of results for speed deviation is similar to that of speed selection. The speed deviation was lower in the control condition than in the passenger, in-vehicle and hands free conditions but there was no difference between these other task conditions. There were also less speed errors on the curved section in the control condition than the passenger, in-vehicle and hands-free conditions but no difference between these conditions. In general, the pattern was the same for all speed measures. Performance was better in the control condition than all the other conditions and there were no differences between the passenger, in-vehicle and hands-free conditions.

The pattern of results for the **lane keeping** measures was interesting. The results suggested that lane keeping was better in the two conversation conditions, passenger and hands-free, than in the control and in-vehicle conditions. This result is not consistent with the patterns of results observed for other measures. This could perhaps be partly explained by the slower speeds adopted by the drivers engaged in conversations leading to easier control of the vehicle. The slower speed also associated with the in-vehicle tasks was, however, also accompanied by increased time looking away from the road ahead, and so the benefit may be outweighed by the physical distraction effect.

Reaction times to selected road signs were faster in the control condition than all the other task conditions. Reaction times in the hands free condition were slower than the other conditions and there was no difference in reaction times for the passenger and in-vehicle conditions. In general, reactions were slower while driving and performing a simultaneous task, and talking on a hands-free phone had the greatest effect on performance. The number of missed target signs was also affected by condition. The greatest number of missed targets occurred in the hands-free condition, followed by the in-vehicle and then passenger conditions.

4.3.2 Subjective Workload

The pattern of results for subjective workload is similar to that of reaction time. The control condition was rated as requiring the least mental effort. The hands-free condition was rated as requiring the most mental effort and there was no difference in the ratings for the passenger and in-vehicle conditions.

4.3.3 Visual Behaviour Measures

The analysis of visual behaviour revealed an interesting and consistent picture. The presence of conversation tasks, whether presented by the front seat passenger or over the hands-free carphone, had an impact on visual scanning. The number and duration of glances to mirrors were low during this experiment due to the low volume of traffic in the test scenarios. Glances to other regions of interest in the analysis were also low and there was no significant effect of task condition evident. However, glances to the speedometer region were affected differently depending on the concurrent task. Around half as many glances were made when the participant was having a conversation when compared to both in-vehicle tasks and control conditions. It appears that the act of talking and thinking in the structured conversations reduces the capability of the driver to monitor the vehicle’s displays as effectively as normal.

When considering total percentage of time spent looking away from the road ahead, there was the expected result that engagement in tasks, such as adjusting the radio or climate controls, diverted the eyes from the road ahead, and the total percentage of time spent looking away from the road ahead increased. In the scenarios adopted in this study the figures increased from 6.5 to 10.2 percent. What is equally interesting is the result that the conversation tasks reduced the time looking off road to 4.3 percent when talking to a passenger, and to 3.6 percent when talking on the carphone. So here the distraction is operating in a different way. The in-vehicle tasks provoked a physical interference that diverted gaze from the road ahead. The conversation tasks appeared to produce an additional mental load that interferes with normal vehicle monitoring functions.

4.3.4 Conversation Measures

In general conversation performance was worse in the driving conditions, both with a passenger or using a hands-free phone. The worst performance was observed when talking on a hands-free phone. For some of the performance measures there was no difference between talking to a passenger and talking when not driving.

There were three main conversation tasks: monologue, verbal puzzles and sentence repetition. Performance on the monologue task was significantly adversely affected only in the hands-free condition. The overall rate of talking in the monologue was slower when driving than when not driving. The slowest rate of talking was observed when using the hands-free kit. There were also a greater number of pauses in the monologue when driving and using the hands-free kit. The number of pauses was slightly higher when a passenger was in the car but this was not significantly different from the control condition.

In the hands-free and passenger conditions less verbal puzzle questions were answered correctly than in the control condition. Mean question response times were also higher in the hands-free and passenger conditions than in the control condition. There was no difference between the number of correct answers or response times in the passenger and hands-free conditions. Overall this indicates much worse performance on verbal puzzles when driving than when not driving.

Fewer sentences were repeated correctly in the hands-free condition than in either the passenger or the control condition. Finally, the mean response time for sentence repetition was higher in the hands free condition than the passenger and control conditions. The response times for sentence repetition in the passenger condition were also significantly higher than the control condition.

4.3.5 Questionnaire

The questionnaire examined various factors relating to the participants' phone use and attitudes. The questionnaire revealed a variety of levels of phone use and different attitudes. All of the participants were regular users and the majority stated that they would use their phone while driving. Despite this the majority of participants also felt that use of hand-held phones should be banned and suggested penalties ranging from fines to police cautions. Only three of the participants had professionally fitted hands-free systems. None of these were significant factors in the performance of the drivers. The drivers also rated different tasks for perceived distraction. Writing text messages and reading maps were considered to be the most distracting in-car tasks. Talking to a passenger was rated as the least distracting task. Talking on a hands-free phone and adjusting the radio were both rated as more distracting than talking to a passenger.

5 Analysis of Objectives met

The objectives expressed in section 2 have been met in full.

5.1 Driving Performance

The general pattern of the driving measures indicates that performance suffers when the driver is performing a simultaneous task. The deterioration of performance can be interpreted as an indicator of additional workload. In the control task the participants' attention was focused fully on driving the vehicle. In the passenger, in-vehicle and hands-free conditions a portion of their attention was focused on completing the secondary task.

It was predicted that driver performance would be affected differentially for the different experimental conditions. For measures of speed control and following accuracy there was no difference between the passenger, in-vehicle and hands-free conditions. This suggests initially that the tasks are equally distracting. If this were to be the case then driving while talking on a hands-free phone would be no more distracting than talking to a passenger or adjusting the radio and climate controls.

The results for other measures indicate that the conclusion is not so simple. The observation that conversations conducted while driving appear to improve lane keeping is intriguing. The conversation tasks in this study have been shown to adversely effect performance on speed control and following, and it is unlikely that the relationship between distraction and driving performance is reversed for lane keeping only. It is possible that the improvement in lane keeping is simply a result of the general reduction in speed in these conditions. But there are some other candidate explanations. An alternative may be that drivers realise the effect that conversation has on their performance and compensate by concentrating more than they would normally. It is impossible to distinguish between these explanations on the basis of this study. However, the results do highlight the fact that different aspects of driving are affected differently by simultaneous tasks and that other factors such as driver concentration have a role.

The implications of these findings in terms of safety can be difficult to interpret. Speed control and following accuracy are two important measures of driver safety. The results of this study show no difference between performance while talking on a hands-free phone and two activities that are generally accepted as safe. From these results alone there is no basis for the conclusion that hands-free phones are unsafe when driving. However, reaction times are more seriously affected by talking on a hands-free phone than performing other tasks. It can be argued that reactions govern most aspects of driving. Reaction has an even greater role to play in more complex road situations such as navigating junctions and responding to hazards. In these situations the performance deficit caused by hands-free conversations is likely to be further emphasised. If it can be reliably demonstrated that hands-free voice activated systems are distracting to use while driving, as in the case of hand-held phones, then this has important policy implications.

5.2 Subjective workload

The subjective workload measures are consistent with the driving performance results. Participants rated the control condition as requiring the least mental effort and the hands-free condition as requiring the most. There was no difference in ratings for the passenger and in-vehicle conditions. The ratings for mental effort support the explanation for the driving results that using a hands-free system requires more attention than talking to a passenger or adjusting in-vehicle systems, therefore, affecting performance to a greater extent in more challenging situations.

5.3 Visual Behaviour Measures

The measures of visual behaviour produced results that need careful interpretation. There was the clear and intuitive result that performing in-vehicle tasks such as operation of the entertainment or climate controls drew visual attention away from the road ahead, as drivers needed to look at the device as they manipulated it. When compared with the control condition, it is clear that having a conversation demands a level of concentration (given the complexity of task in the structured conversations used here) that disrupts normal scanning of vehicle functions on the dashboard display. The results show that the drivers spent more time than usual looking at the road ahead, because they adjusted their normal monitoring behaviour. We found that the increased time spent looking forward is not reflected in a benefit to respond quickly or accurately to traffic signals. It appears that although the drivers look forward at the road scene, they do not actively search it in the way that they do when not engaged in a conversation at the same time. This result is entirely consistent with other work (Parkes and Hooijmeijer, 2000) that has shown a reduction in Situation Awareness produced by both hand held and hands-free carphone conversations.

5.4 Conversation performance

The fact that conversation performance is generally worse while driving and talking either to a passenger or on a hands free kit suggests that the two tasks interfere with each other. This is supported by the fact that all drivers rated the conversation tasks as more difficult when driving than when not driving. This is not a surprising result given the fact that conversation and driving are both cognitively demanding tasks.

The most interesting findings are those that demonstrate the relationship between the passenger and the hands-free conditions. Both of these tasks allow the driver to retain full physical control of the vehicle, unlike when using a hand-held phone, and the conversation tasks were the same in both conditions. Therefore, it must be some aspect of the situation, apart from the driving and performance of a verbal task, which affects conversation performance.

There are several differences between the hands-free condition and the passenger conditions that may affect conversation performance. Affective response to the hands-free system (e.g. unfamiliarity, embarrassment and attitudes about phones and driving) could be an important factor. Adjustments to the conversation by the passenger in response to the driving situation may also have an effect on the quality of the conversation. From a theoretical viewpoint a support comes from the *intimacy* model of Argyle and Dean (1965). Though alternatives have developed, notably the *formality* model (Morley and Stephenson, 1969), the *social presence* model (Short et al, 1976) and the *cuelessness* model (Rutter et al,1981). These models make similar assumptions about the way that a conversation may be influenced by the medium in which it is conducted. The thrust of the argument being that a lack of natural cues when the participants are separated visually, leads to a more impersonal style of conversation. Lastly, the pressure to respond may be qualitatively different with a passenger than when talking on the phone. *Social impact theory* states that the magnitude of social influence is a function of the strength, immediacy and number of sources of influence (Latané, 1981). According to this theory the passenger would exert more social influence than the hands-free conversation and this would have an impact on the demand characteristics of the task. A combination of these reasons accounts for the finding that talking on hands-free equipment is more difficult than talking to a passenger.

An association between response time and accuracy was observed for both the sentence repetition and verbal puzzle tasks. Greater average response time was associated with decreased accuracy of response. However, the relationship between the control, passenger and hands-free conditions was different for each task. Conversation performance was worse in the passenger and the hands-free conditions for verbal puzzles but it was worse only in the hands-free condition for sentence repetition. This finding is likely to be due to the greater complexity of the verbal puzzles combined with the greater difficulty of talking using a hands-free system.

The results for performance on the monologue task can also be attributed to the cognitive demands of the simultaneous tasks. The control condition was the least demanding and therefore yielded the best conversation performance and the hands-free condition was the most demanding producing the worst performance.

One clear implication is that using a mobile phone via hands-free kit while driving is not equivalent to talking to a passenger. It is a much more difficult task. The obvious conclusion is that it is not worth the increased potential risk of using a hands-free carphone while driving because the quality of the information exchange is compromised. It is also of importance in situations where complex information must be exchanged verbally while driving. This research may be particularly relevant to companies where employees use phones for work, and may wish to develop policies regarding phone use.

5.5 Strengths and Weaknesses

The repeated measured design of the study lends strength to the conclusions by allowing a direct comparison of conditions that cannot be affected by factors such as individual differences in levels of phone use and driving experience. The differences in driving performance across conditions can only be due to the particular simultaneous task in that condition.

However, it is not possible from the results of this study to see the full impact of the tasks on driver performance. The study only examines certain types of driving scenarios and some of the most common driving tasks such as navigating junctions, are omitted.

The most important aspect of the study is the support to the proposition that driving while talking on a hands-free system is more distracting than talking to a passenger. The comparison between the conversation conditions is strengthened by the use of a standardised conversation script. The Rosenbaum Verbal Cognitive Test Battery provides test items that are matched for difficulty. This means that differences in conversation performance between conditions can be attributed to factors other than the test material. The major drawback is that the verbal cognitive test battery may not be equivalent to normal conversation.

The strength of the comparison between conditions is limited by several other factors. The most obvious weakness is that several extraneous variables are not held constant between the conversation control condition and the passenger condition and between the conversation control condition and the hands-free condition. The passenger and the hands-free conditions are fairly comparable. The only difference between these conditions is the method by which the conversation was conducted, which is the independent variable. Several other factors were altered in the control condition. The conversation took place in a different environment to the driving conditions. The conversation was also conducted face to face rather than in fashion similar to the passenger or hands-free conversations. In spite of these limitations it is clear that the major influence of performance is the presence of the dual task element.

6 Future Priorities

Future research should attempt to address some of the methodological weaknesses of this study. Most importantly, the driving scenario should be extended to include more complex driving tasks, especially those that are common, such as junction navigation, decision making and reaction to realistic hazards. The results for driving performance in the different conditions will then paint a more accurate picture of the safety implications of using hands-free systems, in-vehicle systems and talking to a passenger.

The aim of this study was to compare the effect the distraction caused by using a hands-free system to other in-car tasks. The comparison tasks in this study were both activities that are generally accepted as reasonable to do while driving. In order to judge accurately how dangerous using a hands-free device is, it needs to be compared to tasks that are proven to be dangerous as well as those that are accepted as safe. If it is not compared to known dangerous activities then we can conclude that it is less safe than the proven safe tasks but we cannot conclude exactly how unsafe it is. Therefore, future research should aim to compare hands-free conversations to both “safe” and “unsafe” activities in order to quantify the level of risk associated with the activity.

The drivers in this study identified several other in-car tasks, such as text messaging, that were considered dangerous but are still practised by some drivers. It would be interesting to examine the relative risks of some of these activities in future research.

The conversation scripts used in this study were highly appropriate from an experimental point of view. Nevertheless, they may not be representative of realistic conversation. Future research could attempt to examine the effect of driving on different types of natural conversation. Potential studies could look at different types of natural exchange that vary in complexity and importance. For example, a study could compare general idle conversation, making arrangements, discussing business and having a debate or argument.

6.1 Conclusions

Driving performance clearly suffers when the driver is performing a simultaneous task. The results for reaction time suggest that talking on a hands-free phone is more distracting than talking to a passenger or other in-vehicle tasks. An extension of the driving scenario to include a greater and more complex range of driving tasks is likely to reveal the full effect of hands-free conversations on driver performance.

If hands-free systems are proven to be a factor leading to dangerous driving then there are obvious implications. As a result of research, the use of hand-held phones is already considered dangerous and drivers can be prosecuted for failing to maintain proper control of their vehicle under the road traffic act (1988) sections 2 and 3. Currently the use of hands-free phones while driving is not likely to result in prosecution although the Highway Code states that all mobile phones are distracting and use should be avoided. It is likely that all hands-free systems, or perhaps just some particular types, would also need to be considered in future legislation if they were proven to be significant.

This study shows that talking to a passenger and operating in-vehicle systems results in poorer driving performance. This change in performance has been demonstrated in terms of vehicle control and traffic interaction, and in terms of responses to signals from the roadscene. Visual behaviour is changed, and the level of active concentration on the surrounding road scene is reduced. This finding could have policy implication if it were proven that the levels of distraction are dangerous.

There has been much research relating to using a mobile phone and driving. This study demonstrates that driving and talking is cognitively demanding, and results in poorer driving performance, supporting the conclusion of other research that this activity is likely to reduce safety.

In addition, by examining this relationship from a different perspective, the present study reveals doubts about the benefits of taking that risk. Talking on a hands-free phone while driving can result in an unsatisfactory information exchange. The results of this study clearly indicate that the conversation itself is impaired when driving. This impairment affects not only the time taken to respond in a conversation but also the quality of the information exchange.

If these findings can be substantiated by other similar research then they have implications in a variety of areas, such as the design of hands-free systems, the policies of companies regarding phone use and the use of in-car communications equipment in emergency vehicles.

7 Publications

Three publications are planned

1. A short paper at the International Ergonomics Association Technical meeting in Korea 2003
2. A paper focused on conversation style and performance for *Behaviour and Information Technology*
3. A paper focused on the main results of the study for *Traffic Injury and Prevention*

8 Financial Summary

Salary, NI, Superannuation	22,169
Rented Equipment	31,024
Travel expenses	242
Other expenses	202
Overheads (46% of staff)	10,198
TOTAL COSTS (exc VAT)	**63,835**
VAT	11,171
TOTAL COST	**75,006**

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