Changes in Driver Behaviour as a Function of Handsfree Mobile Telephones

A Simulator Study

Håkan Alm, Lena Nilsson

Reprint from Drive Project V 1017 (Bertie), October 1990
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PREFACE

The study reported here was performed within the DRIVE Project V1017 'Changes in Driver Behaviour due to the Introduction of RTI Systems' (or BERTIE for short). The BERTIE project has brought together five research teams with a multi-disciplinary range of skills to address the problem of analysing the impact of new RTI applications upon driver behaviour.

The five teams are:

<table>
<thead>
<tr>
<th>Code</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUSAT</td>
<td>HUSAT Research Centre, Loughborough, England</td>
</tr>
<tr>
<td>VTI</td>
<td>Swedish Road and Traffic Research Institute, Linköping, Sweden</td>
</tr>
<tr>
<td>TUB</td>
<td>Technische Universität, Berlin, Germany</td>
</tr>
<tr>
<td>BMW</td>
<td>Bayerische Motoren Werke AG, München, Germany</td>
</tr>
<tr>
<td>AFT</td>
<td>Association pour le développement de la Formation professionnelle dans les Transports, Monchy Saint Eloi, France</td>
</tr>
</tbody>
</table>

The BERTIE project has concentrated on behaviour at the micro-level. The aim has been to refine methods of data collection in a variety of test environments, and to present a picture of behaviour change as a function of certain applications. The findings will be of use to future RTI designers and legislators. It is also hoped that the results obtained by this research group will provide valuable information to other projects within as well as outside the DRIVE programme, and also clarify thinking towards the needs for future investigation in the addressed area of research.
Changes in Driver Behaviour as a Function of Handsfree Mobile Telephones: A Simulator Study

H Alm & L Nilsson

Swedish Road and Traffic Research Institute (VTI)

October 1990
ABSTRACT


The effects of a mobile telephone conversation on drivers reaction time, lane position, speed level, and workload in two driving conditions (easy versus hard driving task) were studied in an advanced driving simulator. 40 subjects, experienced drivers in the ages 23 to 61 years, were randomly assigned to four experimental conditions. It was found that a mobile telephone conversation had a negative effect on drivers reaction time, when the driving task was easy. It led to a reduction of speed, when the driving task was easy. It had a negative effect on drivers’ lane position, most pronounced when the tracking component of the driving task was hard. Finally, it led to an increase in workload for both the easy and hard driving task. The effects were discussed in terms of what subtask, car driving or telephone conversation, the drivers gave the highest priority. Some implications for information systems in future cars were discussed.
BACKGROUND

The number of mobile telephone users is steadily increasing in many European countries. This increase has made researchers and authorities worry about the effects of mobile telephone use on traffic safety. A driver using a telephone while driving may be tempted to have the eyes directed at something else but the traffic situation, or to have the eyes directed at the traffic situation but be mentally absent from it. In the worst case this may cause (directly or indirectly) an accident.

Some earlier studies have raised the question about the effects of mobile telephones on traffic safety. In an early study Brown, Simmonds, and Tickner (1969) investigated the effects of divided attention resulting from the use of mobile telephones. They found that when drivers were engaged in a conversation using a headset, thus using something functionally similar to a "hands-free" telephone, they were driving slower, and made more judgmental mistakes compared to a situation where they were not engaged in a conversation. A conclusion from the Brown et al. study was that overlearned tasks of car driving were not affected by the use of a mobile telephone, but that some perceptual and decision-making tasks were negatively affected. Zwahlen, Adams, and Schwartz (1988) investigated lateral path deviations when drivers were dialing a long distance telephone number. They found that 2-12 per cent of the drivers made lateral deviations of a dangerous nature.

In a study performed by California Highway Patrol (1987) both negative and positive results were found. As in the study performed by Zwahlen et al. (1988) it was found that dialing a telephone number had a negative effect on drivers’ lane position. That effect was found to be more severe than when drivers were tuning the car radio. They concluded that when the telephone was mounted on the dashboard the probability for an accident was lower compared to when it was mounted on the console. On the positive side it was found that mobile telephones were used to report accidents, and fires. In some instances this
probably led to the saving of human lives. Stein, Parseghian, and Allen (1987) used a driving simulator to study the effects of mobile telephone use on drivers' traffic safety related performance. It was found that the drivers' lane position was severely affected when a telephone call was initiated manually. This effect was especially pronounced when the telephone was mounted on the console, and not so severe when it was mounted on the dashboard. The effect was also more pronounced for old than for young drivers. The probability of striking an obstacle was increased if the telephone was mounted on the console, and if the driver was middle-aged or older.

In a recent questionnaire study, Alm and Nilsson (1989), found that many mobile telephone users had the telephone mounted in an "incorrect" way (for instance on the console) and that not all users had the "short number facility". Of those who had the facility, few reported that they actually used it. In line with the California Highway Patrol study it was found that mobile telephones were used to report accidents and to help and warn other drivers.

The purpose of the following study was to continue the line of research initiated in the above mentioned studies, and to introduce some variables of interest. Earlier studies have not included variations in driving task complexity. On theoretical grounds it seems reasonable to assume that a mobile telephone conversation will have different effects upon driver behaviour if the driving task is easy or complex. When driving a car a driver must perform some information processing tasks. A driver must, for instance, be able to: a) detect objects in the traffic scene, b) identify objects, c) make judgments of attributes of different objects (speed, direction, intention), d) make judgments of suitable actions to perform in response to other road users and other relevant objects or events, e) make judgments of own ability to perform suitable actions, f) implement planned actions into actual behaviour, g) evaluate the effects of actions performed by himself/herself and other road users. The
driver must also constantly monitor the performance of his/her vehicle, and correct deviations from intended level.

These subtasks can be more or less demanding, depending for instance upon the number of objects in a driving task, their predictability, and so on. The more demanding these subtasks are, the less capacity will be left for a secondary task. Thus it seems reasonable to assume that the nature of the driving task will influence the effects a secondary task will have upon driver behaviour. It was also of interest to introduce subjective measures concerning the effects of a mobile telephone conversation, since earlier studies mainly have focused upon more "objective" measures.

Problem

The purposes of the study were to address the following questions. First, is there an effect of a mobile telephone conversation on drivers' ability to quickly detect an object in a traffic environment? Second, is there an effect of a mobile telephone conversation on drivers' ability to monitor and adjust the performance of the vehicle? Third, is there an effect of a mobile telephone conversation on drivers' workload. Fourth, is there an effect of the difficulty of the driving task on drivers' ability to perform telephone conversations?

Hypotheses

To make predictions about the effects of mobile telephone calls on drivers' ability to quickly detect an object, it is necessary to analyze the components of a mobile telephone conversation. To make the analysis simpler we will restrict it to the situation where a driver receives a telephone call, and uses the handsfree function of the telephone. The driver must: a) activate the handsfree function by performing some manual action, b) divide his or her attention between the contents of the telephone call and the task of car driving. In both of these situations the driver will be either physically or, to some degree, mentally.
absent from the road scene. In both cases it seems likely that the driver’s ability to quickly detect an unexpected object will be negatively affected. On the other hand both of these effects may be compensated for. It is sometimes possible for a driver to increase the level of attention to the driving task when the mobile telephone is ringing. It is also possible for a driver to decrease the demands of the driving task by, for instance, reducing the speed, or stopping at the road side. We must also take into account that learning effects will occur. Still it seems reasonable to predict a delay in reaction time when something unexpected occurs in connection to the activation of the handsfree function, and in connection with the driver’s concentration on the content of the telephone call. These effects are predicted to be stronger when the demands of the driving task increase.

The second question had to do with the effects of mobile telephone calls on drivers’ ability to monitor and adjust the performance of the vehicle. It is predicted that there will be such an effect, and that this will be manifested in drivers’ ability to keep a consistent lateral position. The effect is predicted to be stronger when the tracking demands of the driving task increase.

The third question had to do with the effects of mobile telephone calls on drivers’ workload. It is predicted that workload will increase due to the telephone call, and that the addition in workload will be higher in proportion to the complexity of the driving task. The increase in workload is predicted to lead to a reduction of speed.

Finally, the fourth question had to do with the effects of driving task complexity on the subjects’ ability to perform a telephone conversation. It is predicted that increased complexity of the driving task will have a negative impact on the subjects’ ability to perform a telephone conversation successfully.
Subjects

Forty subjects, 20 men and 20 women, aged 23 to 61 years (mean age 32.4, std. 9.5 years) participated in the study. They all had a driving license, and were experienced drivers meaning that they had had their driving license for at least 5 years, and that they were driving at least 10,000 km per year. The subjects were recruited via advertisements at various public places, like the university and the hospital in Linköping. They were paid (250 SEK) for their participation in the experiment. The subjects were randomly assigned to four experimental conditions.

Apparatus

The VTI driving simulator was used for the study. It is an advanced simulator which consists of a moving base system, a wide angle visual system, a vibration-generating system, a sound system, and a temperature-regulating system (Nordmark, Jansson, Lidström, Palmkvist, 1986, 1988, Nilsson, 1989). These five subsystems can be controlled to operate in a way that gives the driver an impression which is very much alike real driving. The time delay introduced by the simulator is approximately 40 ms, divided into 20 ms computer cycling time, and 20 ms delay in each of the parallelly working moving base and visual systems. With this fairly fast dynamic response the VTI simulator fulfills the crucial requirement that simulator time lags must be short compared to lags of an ordinary vehicle (100-250 ms).

Moving base system. The moving base system has three main degrees of freedom. Thus it can simulate accelerations in different directions through rotations (roll, pitch) and linear motion (lateral) of the cabin. Lateral inertia forces are simulated by combinations of linear motion and roll according to a control strategy, while longitudinal accelerations are simulated simply by tilting the cabin a certain pitch angle. Pitch and roll motions are generated by using hydraulic motors.
The linear motion of a wagon, on which the cabin is mounted, takes place along rails. The wagon is chain-driven from another hydraulic motor.

**Visual system.** In the visual system an image is generated in real time in a specially designed and fast image processor, controlled from a main computer. The image is transformed to standard video signals, which are updated every 20 ms. The video pictures are (via three TV-projectors) presented to the driver as a continuously varying scenery on a screen. The screen is mounted 2.5 m in front of the driver, a distance corresponding to a 120° field of vision. In the visual system a realistic road surface can be generated, simulating a variety of road conditions. Also, the horizontal and vertical curvature can be varied continuously, with a maximum road sight distance of 3.000 m. Different kinds of road details (lines, wheel tracks, macro-texture) as well as road types (asphalt highway, narrow gravel road) can be simulated. Sight conditions can also be varied (clear day, fog, darkness).

**Vibration system.** For the vibration system, producing road vibrations, the cabin itself is mounted on three hydraulic actuators. Any vibration spectrum can be generated as long as it falls within the capabilities of the actuators.

**Sound system.** The sound system provides the driver with information that is important for, for instance, speed control. The system consists of six sound-channels. For noise generation two treble speakers are placed on the dashboard in front of the driver, and two bassmidrange speakers are placed on the wheel housings. Besides, two pairs of large loud-speakers are placed behind the driver in the cabin, and allow generation of high-level (>112 dB(G1)) low-frequency sound (infrasound). The noise pattern generated usually consists of sound spectra recorded during real driving, which has been sampled and stored in digital form. It is, also, possible to create any desired sound spectrum.

**Temperature system.** The temperature system consists of a closed system, where temperature-controlled water is circulated. In a computer-controlled feedback loop the air temperature in the cabin is recorded and fed back to a control unit, which sets
the water temperature to an appropriate value. The cabin temperature can be set to any value from 18°C to 32°C with an accuracy of ±0.5°C.

Driving tasks

The road type that was presented to the subjects in the simulator was a two-lane, seven meter wide asphalt road. It contained both horizontal and vertical curves. The road surface was characterized by high friction corresponding to dry summer roads, and the visibility condition was similar to a cloudy summer day.

Three different routes, one practice route and two test routes were used in the experiment. All three routes had the same general characteristics as described above, but differed in length and in the number and radius of the curves. The practice route was 20 km long, rather straight and easy to drive. It was used to make the subjects familiar with simulator driving, in order to avoid learning effects during the real experiment. The two test routes were both 80 km long. The easy one was rather straight, and was not expected to cause the subjects any problems with the choice of speed and steering strategy. The workload imposed upon the driver was thus supposed to be very low. The hard route was very curvy, which forced the subjects to monitor the road continuously and make decisions about a suitable speed level and steering strategy. These requirements were supposed to impose a high level of workload upon the driver.

Vehicle. The car body used in the experiment was an ordinary Volvo 740 with an automatic gearbox. The simulated physical environment in the "car" corresponded to that in modern passenger cars. Thus, the noise level, the infrasound level, and the vibration level were all within the respective intervals for modern passenger cars during driving in real traffic. The thermal environment was according to normal indoor climate.
**Visual stimulus.** A red square, with the size four by four cm, was used as a visual stimulus. It always appeared in the same position on the left shoulder of the road at a rather long distance in front of the "car". As the position was fixed relative to the road, the sight angle perceived from the driver’s position varied a little according to the road curvature.

**Mobile telephone.** The mobile telephone used was an Ericsson Hot Line device with handsfree facility (Ericsson Radio Systems AB, Sweden). It was mounted at the height of the steering wheel, over the ventilation controls, on the instrument panel to the right of the steering wheel. The telephone communication was simulated with the help of a micro controller and two tape recorders with remote controls.

Via the serial channel of the telephone system, the micro controller activated the telephone, generated the ring signal, and detected when a button was pressed on the telephone. The micro controller communicated with the main simulator computer, which controlled where, along the routes, the telephone calls occurred.

When a subject answered the telephone by pressing a button, one of the tape recorders was activated and "read" the telephone task to the subject. Tasks for eight telephone calls were consecutively prerecorded on one of the tape recorder channels. On the other channel a signal with constant frequency and amplitude was recorded. This signal had the same duration as the presented telephone calls and was used by the micro controller to start and stop the tape at correct positions.

The presented telephone tasks were, together with the subjects’ answers recorded on the second tape recorder.

**Telephone task.** The Working Memory Span Test (Baddeley, Logie, Nimmo-Smith and Brerefon, 1985) was chosen for the telephone (communication) task. This test contains a working memory part and a decision part. The subjects in the experimental groups were exposed to a number of sentences. Each sentence had the form "X does Y", and contained three to five words. For instance: "The boy brushed his teeth" and "The train bought a newspaper". After each sentence a subject was supposed
to answer "yes" if the sentence was seen as sensible, and "no" if it was perceived as nonsense. The test contains 50% sensible and 50% nonsense sentences. When five sentences had been presented the subjects were required to recall the last word in each sentence, in the order they were presented. This completed the task of each telephone call. During the experiment this procedure was repeated eight times (eight telephone calls), for the experimental groups, with different sentences.

The Working Memory Span Test was chosen because it fulfilled the demands we had on the telephone task. Thus it was possible to repeat this test several times without strong learning effects. It was also possible to keep the presentation time for each telephone call constant, and to evaluate how well the subjects managed to solve the task.

**Presentation of the telephone task.** The Working Memory Span Test sentences were prerecorded on a tape. Each call started with an instruction, telling the subjects that the person reading (one of the authors) would present a number of sentences to them. The subjects were informed that they, after each sentence, had to answer "yes" if the sentence was sensible and "no" if it was nonsense. They were also told that they had to answer within three seconds, and that a new sentence would be read after these three seconds. Finally the subjects were informed that they, after all sentences had been read, would receive the command: "Repeat" and that they were then supposed to repeat the last word in each sentence, in the order the sentences were presented. Each presentation took roughly 60 seconds.

**Position of telephone call and visual stimulus along the route.** Eight telephone calls were presented to the subjects in the experimental groups during the experiment. Therefore, eight specific positions (distances between 0 and 80,000 m) along each of the two test routes were randomly selected (Table 1). When the "car" passed these fixed points a telephone call was initiated. At four of these eight positions, also randomly chosen, the visual stimulus appeared in connection to the telephone calls. For two of these four occasions, again randomly chosen, the visual stimulus, simulating an unexpected event in
the traffic outside the car, appeared shortly after the telephone had rung, while for the remaining two occasions the visual stimulus appeared later, when the driver concentrated on solving the telephone (communication) task. The random procedure was used to make it impossible for the subjects to correctly anticipate when the telephone should ring, if the visual stimulus should appear in connection to the telephone call and in case it did, what the temporal relation between them should be. Table 1 summarizes the positions and timing of the telephone calls and the visual stimulus.

Table 1. Positions for telephone calls and occurrence of visual stimuli along the test routes.

<table>
<thead>
<tr>
<th>Telephone call</th>
<th>Distance (m)</th>
<th>Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 079</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>23 316</td>
<td>Yes, after 35 seconds</td>
</tr>
<tr>
<td>3</td>
<td>27 703</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>41 389</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>55 114</td>
<td>Yes, after 1 second</td>
</tr>
<tr>
<td>6</td>
<td>61 516</td>
<td>Yes, after 1 second</td>
</tr>
<tr>
<td>7</td>
<td>67 731</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>76 892</td>
<td>Yes, after 35 seconds</td>
</tr>
</tbody>
</table>

Driving performance measures

Speed, lateral position and reaction time were used as performance measures. Both measurements and stimulations were controlled by the main computer controlling the simulator.

Speed (km/h) was sampled at a rate of two Hz.
Lateral position (m) on the road was measured in relation to a zero-position, defined as the position where the central line of the road coincides with the central line through the driver's body. Also the lateral position was sampled at a rate of two Hz.

Brake reaction time (s) was calculated as the time elapsing from the onset of the red square until the brake pedal was depressed ten mm or more. The resolution was 20 ms. If no driver reaction (sufficiently hard braking) had been detected within five s the stimulus was regarded as unanswered and put out.

Subjective measures. To measure the subjects' workload the NASA-TLX rating scale (Hart & Staveland, 1988) was used. The subjects had to rate six different workload factors, namely mental demand, physical demand, time pressure, performance, effort and frustration level, on a continuous scale ranging from very low to very high. They also had to rate the relative weights of the different factors.

Communication measures. The number of correct sentence judgments (sensible/nonsense) was used as a measure of the decision part of the telephone task. For the working memory part of the telephone task the number of correctly recalled last words in the order they were presented was used as a measure.

Design

The study was performed as a two by two factorial design, where one factor concerned the type of route driven (easy versus hard), and the other factor the RTI system used (telephone versus control).

Procedure

The subjects had to fill in a questionnaire about background variables (sex, age, driver license, distance driven each year, experience of car driving, and of mobile telephone). After that each subject was randomly assigned to one of the four experimental conditions, and given a written instruction, describing
the experimental task. The subjects in the experimental groups were told that they were supposed to drive an 80 km long route in the simulator. They were asked to "drive" the simulator in the way they normally drive a car, and avoid to "play" with it. They were told to brake with their right foot. They were also told that when they were driving, two things would happen. The mobile telephone would ring, and a red square would appear on the screen. When the telephone was ringing, the subject was instructed to answer by pushing the button for the handsfree function. After doing so they should listen to the instructions that followed, and solve the task presented over the telephone. When the read square appeared they were told to brake as fast as possible. After reading and asking questions about the instructions the subjects in the experimental groups had some training on the telephone task. They practiced on three tasks of varying difficulty (two, three, and four sentences respectively) sitting at a table. The subjects in the control group were exposed to an identical instruction, but without the part containing the mobile telephone.

In the next training phase, all subjects were introduced to the driving simulator. For the experimental groups the handling aspects of the mobile telephone were repeated, and they could practice to locate and push the button for the handsfree function. Thereafter all subjects drove a 20 km long practice route. For all subjects the red square appeared three times, (at the same location for all subjects) and the subjects could practice to brake as fast as possible.

For the subjects in the experimental groups the mobile telephone also rang three times, and the subjects could solve the same problems as they did before, but now via the telephone and while driving. When the training phase was over, all subjects had a short brake during which they were offered coffee, tea, or juice.

After the brake, the testphase began. During the testphase the subjects performed the driving, reaction, and telephone (only experimental groups) tasks. For the experimental groups the
subjects' answers to the prerecorded telephone tasks were recorded on tape. The driving performance measures were recorded via the main computer under the test. After completing the 80 km long testroute each subject had to complete the NASA TLX. Finally the subjects were thanked for their participation in the study, and paid 250 SEK. The running of a subject took 2-2.5 hours in total.

RESULTS

The following results will be presented. The subjects' reaction time to the simulated danger situation (the red square), the subjects' lateral position in connection to the telephone call, the subjects' workload and speed, followed by the effects of driving task complexity on subjects' performance on the telephone task.

Reaction time

It was predicted that the subjects in the experimental (telephone) conditions would react slower compared to the subjects in the control (no telephone) conditions. A two-way ANOVA showed a significant interaction between route and RTI system, $F(1,36)=6.40$, $p=.0124$. Figure 1 shows the nature of this interaction.
Figure 1 indicates that there is a difference in the predicted direction for the easy route. A mobile telephone conversation seems to have affected the subjects' reaction time towards longer ones. The difference in reaction time between the two groups in the easy driving task is also rather large (0.385 seconds). For the hard route the situation is different. No significant effect of mobile telephone conversation on the subjects' reaction time could be shown. Thus, the hypothesis is supported for the easy, but not for the hard route.

**Lateral position**

To check the hypothesis about an increased variation in lateral position due to the mobile telephone calls we measured the lateral position of each subject in the experimental groups for a distance of 500 and 2,500 meters from the onset of each telephone call. During the first distance (0-500 m) the subjects must initiate the hands-free function of the mobile telephone, and it is therefore of interest to inspect that distance...
closer. It is also of interest to analyze the entire period during which the telephone conversation is run in parallel with car driving. The second distance (0-2500 m) covers that period. For the control groups corresponding measures were made. If the hypothesis is correct we should expect a greater variation in lateral position for the experimental groups, and the effect should be more pronounced when the tracking component of the driving task is demanding. Figure 2 and 3 shows the results for the 500 meter distance after each call, for the respective driving task.

![Figure 2](image-url)

Figure 2. Lateral position 0-500 m after each telephone call for experimental and control groups in the easy condition.

Figure 2 shows that the difference between experimental and control groups for the easy driving condition is very small. The difference was tested with a two-way ANOVA, and did not reach statistical significance, $F(1,144)=2.32$, $p=.1302$. 
Figure 3. Lateral position 0–500 m after each telephone call for experimental and control groups in the hard condition.

Figure 3 shows that the difference between experimental and control groups was larger for the hard driving condition. There was a significant main effect of RTI system, $F(1,144)=10.97$, $p=.0012$, and a significant interaction between RTI system and calls, $F(7,144)=19.89$, $p=.0001$. This interaction had to do with the fact that the position of the telephone calls were randomly generated, and some calls occurred on straight sections of the road. Thus the hypothesis was confirmed for the hard route, but not for the easy.

Figure 4 and 5 shows the corresponding results for the 2.500 meter distance after each call.
Figure 4. Lateral position 0-2500 m after each telephone call for experimental and control groups in the easy condition.

Figure 4 shows that for the entire 2.500 meter period there exists a difference between experimental and control groups for the easy driving task. A significant main effect of RTI system was found, $F(1,144)=5.67$, $p=.0185$.

Figure 5 shows the corresponding results for the hard driving task.
Figure 5. Lateral position 0-2500 m after each telephone call for experimental and control groups in the hard condition.

There is a significant main effect of RTI system $F(1,144)=22.95; p= .0001$, and a significant interaction between calls and RTI systems $F(7,144)=6.78; p=.0001$. So, the hypothesis is fully supported when we look at the entire distance where the telephone conversation was performed.

**Workload.** The use of NASA-TLX rating scales give scale values, weights, and the combination "scale values*weights" for six different factors. These factors are: Mental demand, physical demand, time pressure, operator performance, operator effort, and frustration level. The rating value of each factor multiplied by the weight for the respective factor was used for further analysis. A two way ANOVA was performed on each factor. Table 2 shows the results from ANOVAs performed on each factor.
Table 2. Results of ANOVAs performed on the subscales in the NASA-TLX rating scales.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental demand</td>
<td>RTI</td>
<td>1,36</td>
<td>30.40</td>
<td>.0001</td>
</tr>
<tr>
<td>Physical demand</td>
<td>RTI</td>
<td>1,36</td>
<td>5.18</td>
<td>.0289</td>
</tr>
<tr>
<td>Time pressure</td>
<td>RTI</td>
<td>1,36</td>
<td>6.72</td>
<td>.0137</td>
</tr>
<tr>
<td>Operator performance</td>
<td>RTI</td>
<td>1,36</td>
<td>7.01</td>
<td>.0119</td>
</tr>
<tr>
<td>Operator effort</td>
<td>RTI</td>
<td>1,36</td>
<td>5.05</td>
<td>.0308</td>
</tr>
<tr>
<td>Frustration level</td>
<td>RTI</td>
<td>1,36</td>
<td>6.62</td>
<td>.0143</td>
</tr>
<tr>
<td>Frustration level</td>
<td>RTI*ROU</td>
<td>1,36</td>
<td>5.95</td>
<td>.0198</td>
</tr>
</tbody>
</table>

Table 2 shows that there is a significant main effect of RTI system on the factor "mental demand" ($F(1,36)=30.40; p=.0001$). Thus the telephone conversation had a significant effect upon the subjects' estimation of the mental demands in their task. The same main effect was found for every factor. It should also be emphasized that the factor "physical demands" also showed a significant main effect of RTI system ($F(1,36)=5.18; p=.0289$). So the introduction of the physical demands associated with the activation of the handsfree function seems to have produced a higher subjective rating of physical demand. Finally for the factor "frustration level" there was a significant main effect of RTI system ($F(1,36)=6.62; p=.0143$), and a significant interaction between RTI system and route ($F(1,36)=5.95; p=.0198$). The subjects were more frustrated during mobile telephone use, and this effect was influenced by route difficulty. In summary, the hypothesis about higher workload due to the use of mobile telephone was supported, but the hypothesis that workload should increase with the complexity of the driving task was refuted.

**Speed level.** For the experimental groups the subjects' speed was measured from the onset of each mobile telephone call and 80 seconds forward. This covered the entire telephone conversation for all subjects. For the control groups corresponding measures
were taken. According to our hypothesis the subjects in the experimental groups should have a lower speed due to the extra workload introduced by the telephone task. Figure 6 shows the speed levels relevant for this hypothesis.

As can be seen from Figure 6 a difference in speed exists between experimental and control groups for both routes. As predicted the speed is lower for the experimental groups. The difference is rather large and also statistically significant ($F (1,144)=14.65, p=.0002$) for the subjects driving the easy route, thus supporting the hypothesis.

The difference for the subjects in the hard route is very small, and did not reach statistical significance ($F(1,144)=1.36, p=.2453$). In this case the hypothesis is rejected.

Effects of driving task complexity on achievement in telephone task. To investigate if the complexity of the driving task had any effect upon the subjects' performance in the telephone task, the number of correct judgments, and correctly recalled last
words in correct order for the respective driving conditions were counted.

Table 3. Performance in the telephone task as a function of driving task complexity.

<table>
<thead>
<tr>
<th></th>
<th>Correct judgments</th>
<th>Correct recall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easy</td>
<td>Hard</td>
</tr>
<tr>
<td>38</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>39</td>
<td>39</td>
<td>16</td>
</tr>
<tr>
<td>38</td>
<td>38</td>
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<td>Mean</td>
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Table 3 shows that there is practically no difference between the tasks when considering the number of correct judgments of the sentence sensibility. There is a small difference in the number of correct recall of the last words (in the correct order) in each sentence. That difference is however very small, and does not reach statistical significance. Consequently, the hypothesis was not supported.
DISCUSSION

Reaction time

It was predicted that the physical and mental distraction due to a mobile telephone conversation should have a negative impact upon drivers' ability to react quickly to an unexpected event in the driving environment. This effect was predicted to be stronger when the complexity of the driving task increased. It was, however, found that when the driving task was easy a mobile telephone conversation had a negative impact on drivers' ability to react quickly, but when the driving task was complex no negative impact was found. These results are somewhat surprising. A rather common assumption is that non driving related information can be given to a driver when his or her workload is low. The results from this study do not support that assumption.

One possible way to explain these results is to consider how the subjects may have made their priorities between the task of driving, and the task of coping with the telephone conversation. The task demands of the hard driving task may have forced the subjects to concentrate on the tracking task. This involves attention to, and judgments of the road geometry, and judgments of how to adapt the speed and steering strategy to the road geometry. In other words, the task demands may have forced the subjects to regard the tracking task as their primary task. Consequently, the telephone task may have been given the status of a secondary task, and was therefore not allowed to influence the drivers' maneuvering behaviour to any greater extent. This could explain the lack of difference between experimental and control groups in the hard driving task condition.

In the easy driving task the subjects did not have to allocate much attention to the tracking component, and this may have led the subjects to give the telephone task the highest priority. Consequently, the task demands of the telephone task may have influenced the drivers' maneuvering behaviour to a much larger
extent. This could explain the large difference in reaction time between experimental and control groups in the easy task condition. If this explanation is correct, then the introduction of a non-driving task can have different effects depending upon what priority the drivers give the non-driving task. This in turn depends upon the drivers' judgment of the complexity of the driving task, and their own ability to cope with that complexity. If the driving task is perceived as very easy the non-driving task may be treated as the primary task, and this may have negative effects upon the drivers' ability to react quickly to some emergency event. On the other hand, if the driving task is perceived as hard it will presumably still remain the primary task even if a secondary, non-driving task, is introduced. If this line of reasoning is correct it means that RTI systems for non-driving information should not give their information when the driver's driving task is extremely simple. Instead it seems better to provide the driver with information when the driving task has a medium complexity.

Other explanations of the reaction time results fail in one way or another. For instance, another possible way to understand these results is to take a closer look at the task demands of the respective driving tasks. Common for both tasks is that the subjects must detect the "brake stimuli", and perform a braking maneuver. To detect the "brake stimuli" they must direct their attention to the field where it occurs, and to brake quickly they must shift their foot from the accelerator to the brake pedal.

In the easy driving task the tracking component was fairly easy, which probably led the subjects to have their visual attention focused straight ahead most of the time, that is in the area where the "brake stimuli" occurred. In the hard driving task the subjects drove a rather curvy road which most likely led them to sometimes focus their visual attention on areas where the "brake stimuli" did not occur. Thus it seems reasonable to assume that the subjects' detection of the brake stimuli was somewhat faster in the easy (straight), compared to the hard (curvy) driving
task. Another aspect also speaks for this conclusion. It seems reasonable to assume that the subjects' stress level was somewhat higher in the hard driving task, due to the more complex tracking component. The results from the NASA-TLX also speak for this conclusion since the subjects in the hard driving task were more frustrated than the subjects in the easy driving task. When the stress level goes up this normally leads to a narrowing of attention, in extreme cases to "tunnel vision". This presumed narrowing of attention could have made it somewhat harder for the subjects in the hard driving task to detect the "brake stimuli".

The next phase in the reaction time measurement involves the action of moving the foot from the accelerator to the brake pedal. Since the mean speed for the easy versus hard route was different, we should also expect a time difference between the groups due to the differences in relative position between accelerator and brake pedals. Earlier studies, for instance Davies and Watts (1969), have indicated such a difference. Since the subjects in the easy condition were driving faster, and thus had a somewhat longer relative distance between accelerator and brake pedal, it seems reasonable to assume that they needed a somewhat longer time to initiate the brake maneuver.

Consequently, the subjects in the easy condition may detect the "brake stimuli" quicker, but should need a somewhat longer time to initiate the brake maneuver. The subjects in the hard condition may detect the "brake stimuli" somewhat slower, but may be slightly quicker to initiate the brake maneuver. If the detection time is the largest component then these two components can be used to explain the results for the control groups in both driving tasks. But, to apply the same logic to explain the opposite results for the experimental groups is not possible.

Another possible way to explain the results would be in terms of arousal level. It would be possible to assume that the subjects in the easy driving condition had a very low level of arousal caused by the rather boring task of driving straight ahead. This
could have explained their relatively slow reaction to the "brake stimuli" in the experimental group. In the hard driving condition the subjects' level of arousal may have been higher due to the rather complex tracking component. This could explain their somewhat quicker reaction to the "brake stimuli" in the experimental group. The problem is, however, that this cannot explain the opposite results for the control groups.

**Lateral position**

It was predicted that a mobile telephone call would negatively affect drivers' ability to monitor and adjust the vehicle's position on the road. The effect was predicted to be stronger when the demands of the driving task increased. The results from this study mainly confirm the hypothesis. It seems that the physical and mental distraction imposed by the telephone task actually had an effect upon drivers' ability to maintain a steady course on the road, and that this effect was more pronounced when the tracking task was complex. This is probably caused by the pressure on the driver to time-share between the monitoring of the vehicle, and the telephone conversation.

**Workload**

The prediction was that workload would be increased due to the mobile telephone call. Also this prediction was confirmed. A somewhat surprising finding was that even physical workload was increased, despite the fact that the only physical maneuver the subjects had to do was to activate the handsfree button. This may mean that the activation of the handsfree button should be improved. A first improvement could be to make it larger, more distinct, or both. Another possible improvement would be to change its position to, for instance the steering wheel. A third possible improvement would be to make the function voice activated. It was also predicted that workload would be more increased when the driving task was complex. This hypothesis was not supported, with the exception of a higher frustration level. This can be interpreted to mean that the subjects in the hard
driving task gave the task of "driving" the car the highest priority, and that the demands from the secondary task (the telephone calls) were not allowed to interfere with the driving task. When workload is increasing and threatens to be higher than drivers capacity, one strategy is to concentrate the efforts on the most important task. This will result in an increased frustration level, since the driver must pay secondary attention to some tasks, and partly ignore other tasks.

**Speedlevel**

It was predicted that increased workload should lead to decreased speed, and that the decrease in speed should be proportional to the increase in workload. It was found that there was a significant difference in the predicted direction for the subjects in the easy, but not for those in the hard driving task. Again, these results are somewhat surprising, but can be explained in the same way as the results concerning the subjects' reaction time. That is, the subjects in the easy driving task may have turned the telephone task into their primary task. Because of the high workload devoted to the telephone task this may have led to a decrease in speed. The subjects in the hard driving task may, according to this hypothetical explanation, have devoted most of their workload to the task of driving, and less to the task of solving the telephone task. Consequently, the decrease in speed was not made to the same extent.

However, it is also possible to explain these results in a completely different way. The decrease in speed may simply have been an attempt to reduce the noise level in the car, in order to hear the message better. Since the drivers in the easy condition were driving faster, they also had to reduce the speed more than the subjects in the hard condition. From this study it is not possible to determine if any or both of these explanations are valid. However, the low noise level in modern cars which was simulated here, makes this explanation less plausible.
Effects of driving task complexity on achievement in the telephone task

The prediction was that the complexity of the driving task should have an effect upon drivers' ability to successfully perform the mobile telephone task. Analysis of the decision and memory component in the telephone task did not reveal any significant differences due to the complexity of the driving task. It was also noted that the subjects performance on the decision aspect of the task was close to perfect. In other words we had a ceiling effect, meaning that this part of the test may have been too simple. On the short term memory aspect there was a tendency for the subjects in the easy task to perform better, but this tendency was not significant. Consequently, the prediction was not supported. This can be interpreted in many ways. One possible interpretation is that the test used is not sensitive enough to detect any difference in performance. Another possible interpretation is that the difference in driving task complexity was too small. Manipulation of the tracking component can be the wrong way to increase task complexity since the tracking task of driving should be one of the most overlearned tasks. It would be of interest for future studies to vary driving task complexity in other ways, and to investigate the effect(s) on a secondary task.

CONCLUSIONS

In contrast to the conclusions drawn by Brown et al., 1969, we found that even very simple tasks of car driving can be affected by a secondary task like a mobile telephone conversation. New is also the finding that the most severe effect on reaction time was found when the driving task was very simple. If this finding can be replicated it has implications for when RTI systems for non driving information should offer information to a driver.

It must be emphasized that the effect on simple reaction time, and all other effects were obtained on a sample of skilled
drivers. This probably means that the effects can be much more pronounced for other categories of drivers.

Implications for traffic safety. Under some circumstances the increase of brake reaction time may cause problems. A driver on a straight and lonely road who is engaged in a tricky telephone conversation may react too slowly when some animal suddenly crosses the road. These kind of accidents are common in some European countries.

A sudden decrease in speed for some drivers may or may not increase the risk of accidents. It can be argued that anything that increases the variation in speed in a traffic stream has the potential to increase the risk of an accident. Increased variation in speed will make the predictability of the traffic stream lower, which in turn will make it harder for drivers to make judgments of a correct distance to other drivers. It is also easy to imagine situations where the risk would be increased, and also not increased. For instance, a driver driving in fog on a motorway, and being the first car in a platoon of cars may be one cause of a series of collisions, if the driver suddenly slows down. If the driver is the last one in a platoon of cars, nothing dangerous will happen.

Variations in lateral position can contribute to an accident if the variations are so large that the driver is leaving the correct lane. In this context it must be noted that the increased variation in lateral position found in this study was rather small, and hardly can be regarded as dangerous.

Implications for future research. The subjects used in this study were all skilled drivers. It is therefore of interest to investigate other groups of drivers, for instance less skilled and old drivers. Especially the category old drivers is of special interest, since the proportion of old drivers is increasing in Europe.
It is also of interest to proceed systematically in the study of the effects of mobile telephones on driver behaviour. A next step would be to make the drivers' reaction time task somewhat harder. In this study the subjects' task was simply to detect when a visual stimuli appeared on the screen, and thereafter perform a pretrained and overlearned action. In real driving the situation is seldom that simple. A driver must certainly detect an object or event, but also sometimes identify it, and decide what to do when confronted with it. A next step towards a more complex situation would therefore be to introduce visual stimuli that must be identified, for instance different stimuli with different implications for the drivers' actions.

Another interesting questions for future research is what effect(s) different types of telephone conversations have on driver behaviour. The task used in this study is rather abstract, and loads the drivers' decision-making and memory capacity. Of interest would be to investigate the effects of telephone conversations loading drivers' spatial abilities. Consider for instance the situation where a driver receives navigation information via the mobile telephone. The spatial character of this information may or may not interfere with the spatial character of car driving.

When discussing the traffic safety effects of mobile telephones it is also necessary to take a view from an aggregated level, and look at the system effects on traffic safety. With the help of simulation models it should be possible to investigate what will happen in terms of traffic flow, traffic conflicts, potential accidents, when different proportions of drivers are engaged in telephone conversation.
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