Behavioural effects of mobile telephone use during simulated driving

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The effects on driving performance of using a hands-free, mobile telephone were investigated in a pursuit-tracking task that simulated driving. Twenty subjects in two age groups, 19–26 years (median = 21 years) and 40–51 years (median 45-5 years), participated, with five males and five females in each group. The primary task was driving safely. The subjects drove for 20 min in each of three secondary task blocks with (i) a simple telephone conversation about a familiar topic, (ii) a difficult telephone conversation, incorporating a test of working memory, and (iii) car radio tuning and listening. Half of the driving was done on a simulated firm road surface and half on a slippery road surface. The subjects’ behaviour was subsequently observed and classified in four activity categories, two without and two with a secondary task, with driving (i) on a clear road, and (ii) with obstacles, and with driving involving the secondary task components of (iii) communication, and (iv) instrument manipulation. The results show different patterns of driving performance on the two road surfaces. For driving on the slippery road, a deterioration was especially marked during manipulation of the instruments, in particular the radio, which required more prolonged manipulation than the hands-free telephone. Driving during an easy telephone conversation was associated with the least performance decrement, and could, in some cases, be seen as facilitatory. The female subjects tended to perform less well than the male subjects while driving on a slippery road. Some of this difference could be attributed to less previous driving experience. In general, the male drivers exhibited better control while driving under difficult conditions. There was no difference in driving proficiency between the age groups. It is concluded that simply conversing over a hands-free telephone while driving does not in itself impair performance. However, a difficult conversation may affect the driving adversely, and any prolonged manipulation of the telephone is liable to produce a performance decrement, particularly under conditions that put heavy demands on the driver’s attention and skill.

1. Introduction

Mobile telephones have come into increased use by businessmen and others who travel a lot by car during working hours. This application offers an opportunity to utilize more effectively the time while sitting in the car for planning and job-coordination. However, it seems doubtful that such a complex task as driving can be carried out sufficiently well at the same time as another task that places additional demands on the driver’s attention. This is particularly important with a view to the traffic safety of both the driver and other road users.

In an early study of the effects of mobile telephone use on driving performance, carried out before the advent of cellular telephones in cars, Brown et al. (1969) found a reduction in speed and an increased number of judgmental mistakes to be the result
of conversing by means of a head-set telephone while driving. They concluded that the divided attention resulting from the communication task led to decrements in perception and decision making during driving. In a more recent study (California Highway Patrol 1987), it was found that dialling telephone numbers while driving had a negative effect on drivers' lane positioning. Also, Stein *et al.* (1989), who carried out a driving simulator study of drivers' performance while using a cellular mobile telephone, found a negative effect of dialling while driving, and Zwahlen *et al.* (1988), found that more than 10% of the drivers in their study made dangerous, lateral path deviations while dialling long distance telephone numbers.

In the California Highway Patrol study (1987), the telephones were mounted on the console of the car, instead of on the dashboard as is more usual. This probably increased the risk factor associated with the telephone use, which in this study was greater than that of tuning the car radio. This conclusion is supported by results by Stein *et al.* (1989) who compared the two mountings, and found that the negative effect of telephone use on lane position was appreciably greater when the telephones were mounted on the console of the simulator than on the dashboard.

In a recent study of mobile telephone use during actual driving, Brookhuis *et al.* (1991) found that telephoning resulted in an increased effort, both as rated by the subjects themselves and as measured through their heart-rate, and that the increased effort was reflected in driving performance. They also found that making a telephone call that required dialling the number manually was associated with a significantly greater increase in steering wheel movements than occurred when only receiving a call.

Researchers at the Swedish Road Transport Institute, VTI, have also carried out a series of driving-simulator studies of people's use of a hands-free, mobile telephone while driving (Alm and Nilsson 1992, 1994, Nilsson and Alm 1991, cf. also Nilsson 1989). The results from the first of these (Alm and Nilsson 1994) indicate that the use of the telephone leads to (a) an increase in drivers' simple reaction times, (b) a reduction in speed when the driving task is easy, (c) a deviation from correct lane position when the task is hard, and (d) an increased subjective work-load for the driver under all conditions. Alm and Nilsson (1992) also found longer choice reaction times in response to rare events during the simulated driving.

Stein *et al.* (1989) had found that the negative effect of telephone use on lane positioning was more pronounced for older than for younger drivers. Nilsson and Alm (1991) attempted to verify this finding by extending their previous simulator study to encompass a comparison of the performance of young and elderly drivers. Their main findings were that, during telephone conversations, the variation in the elderly drivers' lateral positioning on the road was greater than that of the younger drivers, and the absolute positioning of the older drivers on the road was less optimal than that of the younger drivers. They were also able to demonstrate an increase in choice reaction time with age.

On the basis of these studies it may be supposed that mobile telephone use results in diminished traffic safety. However, it is necessary to explore the possible reasons for the results obtained in these investigations.

Research on people's ability to carry out two or more tasks simultaneously is of particular relevance in this context, and the idea that an individual can be regarded as an information processing system with a limited capacity for signal detection and task performance is central here. For instance, Shiffrin and Schneider (1977) proposed that the performance of a given task may be carried out in two different ways. First, task performance may be under conscious and voluntary control of the individual, in which
case it is characterized by flexibility and adaptability. However, performance is, in this case, relatively slow, as the task takes up a large proportion of the individual's limited cognitive processing capacity. New situations and problems require this kind of processing. Second, task performance may be automatic, as happens when the task has received a lot of training over a long period of time, and functioning is here characterized by effectiveness and speed. In the latter case, the performance requires relatively little processing capacity, but is rigid and capable of only limited voluntary correction.

Learning to drive a car is often used to illustrate these different ways of functioning. As the inexperienced driver learns to control the vehicle with the help of an accelerator, clutch, and gear lever, he/she employs a conscious and voluntary mode of control, which is demanding on such resources as attention and decision making, and leaves little space for the execution of other tasks, such as discovering obstacles and other dangers on the road. In contrast, the experienced driver is capable of performing the basic control tasks automatically and without appreciable voluntary effort, and at the same time do other tasks, such as carrying on a conversation.

While a limited capacity does not imply an inability to do two or more tasks simultaneously, it means that several demanding tasks cannot be carried out at the same time without negative interference. An important factor in this connection is the degree of similarity between the tasks, e.g. as has been proposed by Wickens (1984) in his ‘multiple resource theory’ of human performance. Thus, it is easier to perform simultaneously dissimilar sensory and motor tasks than it is to perform tasks that require the use of the same modalities. For instance, it is easier to attend to one visual and another auditory message simultaneously than attend to two spoken messages binaurally. In this context, one task (the primary task) is usually regarded as having priority over other tasks (the secondary tasks). According to this paradigm, telephoning-while-driving can be regarded as a dual task in which attention has to be divided between the primary task of handling the vehicle, and the secondary task of telephoning. The consequences of this would seem to be that all activities connected with the use of a mobile telephone and other extra equipment potentially encroach upon the driving and make it more difficult and dangerous. These effects could be expected to be particularly marked in situations where extreme care and precision of control is required.

Wickens (1984) proposed a three-dimensional model for the structure of processing resources, where the dimensions are stages, modalities, and codes with associated responses. In the present context, it is particularly the last dimension that is of interest. The codes proposed by Wickens and spatial and verbal, and the associated responses are manual and vocal. This has the consequence that, if we consider driving to be a primarily spatial/manual task, and telephoning to be a verbal/vocal task, the resources required for the two are well separated on the dichotomous codes/responses dimension. There should, therefore, be very little or no interference with the driving task from the telephone communication.

‘Car driving’ has, elsewhere, been defined as a complex task, composed of ‘a mixture of automatic and control processes, possibly organized in a systematic network, with many of the automatic processes operating in parallel’ (Schneider et al. 1984). Thus, from a psychological point of view, car driving is not a unitary activity. According to Michon (1985) the driving task may be seen as being organized on three levels: the lowest level includes automatic, sensory-motor sequences, such as steering, changing gears and so on. The next level is tactical, and includes such operations as attending to traffic signs, pedestrians, and other vehicles. The highest level is strategic, where such
processes as choice of route and temporal planning are situated. Michon's model is similar to the general, SRK-model proposed by Rasmussen (1980, 1986) to explain the control of human actions in human–system interaction, in which Rasmussen distinguishes three levels of human performance, skill-, rule-, and knowledge-based behaviour. Performance at the skill level is based on the processing of automated sensory-motor patterns, at the rule level, on handling familiar task problems, and at the knowledge level, on dealing with novel problems that crop up at times during the execution of the task. All three levels are operational simultaneously, but the locus of control is at one of the levels at any time.

Owing to the considerable practical difficulties involved in studying the various aspects of drivers' performance in the field, the majority of the available studies of mobile telephone use during driving have employed simulated driving in some form (Drory 1985, Stein et al. 1989, Alm and Nilsson 1992, 1994, Nilsson and Alm 1991). Furthermore, these and other, more realistic studies (Brown et al. 1969, California Highway Patrol 1987, Brookhuis et al. 1991) have concentrated on explicating the effects of telephoning on performance at the skill and rule levels, and do not treat the knowledge level of the driving task to any significant extent. However, function at the three levels (SRK) cannot be separated, and it is, therefore, necessary to examine the relative effects on performance of the various components of the driving and communication tasks instead.

The present study was designed to obtain a fuller and more realistic picture of how hands-free mobile telephone and radio communication influences driving performance at different levels of driving task difficulty. In order to be able to assess the effects on skill- and rule-based performance in situations requiring a high degree of control, it was decided to carry out a laboratory simulation rather than a field study. A low-fidelity driving simulation was subsequently used, where a pursuit-tracking task modelled actual driving. Furthermore, two components of the telephoning task were distinguished here, namely, the manipulation of the device and the communication itself.

The following hypotheses were put forward regarding the eventual results.

(a) All secondary tasks make the primary task of driving more difficult.
(b) The higher attentional demands that the secondary task places on the driver, the greater the deviations from correct performance of the driving task. Thus, a complicated communication task during driving should lead to a greater deterioration.
(c) The more similar the secondary task is to the driving, both with regard to perceptual modality and motor control, the greater its negative effect on the driving task. This implies that the motor parts of the secondary communication tasks should interfere more than the verbal communication, and that those parts of the secondary task that require visual control should disrupt the driving more than the auditory aspects.
(d) In comparison to the secondary task effects, effects of the drivers' age (within reasonable limits of youth and old age) and gender are negligible, other things being equal.

2. Method

2.1. Subjects
There were twenty subjects, 10 in each of two age ranges, approximately 19–26 years (median = 21 years) and 40–51 years (median = 45.5 years), half the subjects in each
group were male, and half were female. The subjects in the younger group were all first year psychology undergraduates at the University of Lund, while nine of the older group were engineers and office staff from the Radio Division of Swedish Telecom in Malmö, and one was a lecturer in biology at the University of Lund. All the subjects were experienced drivers, and had held a driving licence from one to 26 years. All had normal hearing and normal eye-sight, corrected or uncorrected.

2.2. Design
The study was built up around simulated driving, which was the primary task of the subjects. The study had a factorial design with three task levels, where each subject served in six \((3 \times 2)\) driving conditions on the first two levels. Task level 1 contained three secondary task blocks, each lasting for 20 min of simulated driving. In two of these the subjects communicated with one of the experimenters by means of a hands-free telephone. The interchanges involved two levels of difficulty: simple conversation about a familiar topic included in one task block, and a difficult conversation with a test of working memory span included in the other task block. The third block was concerned with manipulating and listening to a car radio, defined here as one-way communication. On task level 2, within each of these three secondary task blocks, the subject drove in two road surface conditions of varying difficulty, firm and slippery.

![Figure 1. The structure of the simulated driving task, showing the 24 basic 'driving' conditions employed in the study.](image)
These conditions were of a 5 min duration, and alternated twice within each of the 20 min blocks. This design is illustrated in figure 1.

Within each of these six task levels, a third one was included. Thus, on task level 3, the subjects spent half of the time in each 5 min road surface condition performing a secondary task of communication (Radio, Telephone I, and Telephone II, each in a separate task block). The other half of the time, they drove either without any particular disturbance ('only driving') or with obstacles that had to be avoided (cf. figure 2(b) below). On a behavioural level, the subjects were classified as being engaged in one of four kinds of activity at all times during the simulated driving. Two of these (communication and manipulation) involved driving with a secondary task, and two (only driving and obstacles) involved driving without a secondary task. The activities, although restricted to definite positions in the design, were not of fixed lengths, and, therefore, not directly a part of a fixed blocked design, but were extracted afterwards through observation of the subjects' recorded behaviour. Thus, there were altogether 24 combinations of factors on the three tasks levels shown in figure 1.

2.3. Apparatus

2.3.1. Simulator apparatus and driving task: The simulator apparatus was situated in a cubicle 2.5 × 2.5 m, and placed on a low, steady table, around a black console representing the dashboard. Basically, this apparatus consisted of a 14 in. colour
Figure 2. The apparatus: (a) set-up (schematic): (i) back view; (ii) side view. 1, 14-inch colour monitor; 2, steering wheel; 3, accelerator pedal; 4, mobile telephone; 5, car radio; 6, dashboard; 7, Sony loudspeakers; 8, car radio loudspeaker; and 9, video cameras. (b) A typical screen view. (c) The six signs shown on the screen during the simulated driving.

monitor, a steering wheel, a pedal, two loudspeakers, a hands-free mobile telephone, and a car radio. The subject sat in a comfortable chair in front of the screen, which was mounted on the console at the level of his/her eyes. The steering wheel was clamped to the table and fixed to the console. The telephone was mounted on the console 10 cm to the right of the steering wheel, and the radio was fixed on the table in front of the console 30 cm to the right of the steering wheel. The accelerator, a general-purpose foot-pedal, was placed in a hardboard cradle on the floor in a position similar to that in a motor car, but it could be adjusted to suit the subject. The stereo loudspeakers were situated on the table on each side of the monitor approximately 1 m from the subject. An additional loudspeaker for the car radio was placed under the table. This set-up is shown in figure 2(a).

The simulation was controlled from a computer. The ‘road’ (a curved line) and the ‘car’ (a triangle) were rendered in white on a blue field in a ‘window’ on the upper half of the screen. An analogue speedometer in yellow on a black field was shown below the window. At the beginning and end of each 5 min road surface condition, four obstacles (‘road-works’) in the form of red, horizontal bars (length: 25 and 50 pixels)
appeared next to the road (left, right, left, right). The subjects were instructed to avoid allowing the car to collide with these bars. The essential screen set-up is shown schematically in figure 2(b).

During the simulated driving sessions, a composite noise signal, produced by a noise generator, was delivered through the two loudspeakers. The noise signal was so composed as to resemble the road noise that car drivers normally experience.

Six different signs in red, yellow, and black (diameter: 50 pixels) could be made to appear to the right in the upper field of the screen at various points during the driving: two speed signs, signalling 50 and 70 km/h (round), a ‘slippery road’ and an ‘end of slippery road’ signs (triangular), a ‘phone-now’ message (round, with a picture of a telephone receiver), and ‘tune-radio-now’ message (round, with the letter R). The six road signs used are shown in figure 2(c).

The firm and slippery road surfaces were simulated by using velocity and acceleration control dynamics, respectively, to translate the steering wheel movements into changes in the lateral position of the car on the screen. The 50 km/h sign appeared before the beginning of the 5-min periods of acceleration control, and the ‘end of slippery road’ sign followed by the 70 km/h sign appeared immediately before the periods of velocity control.

The driving conditions were pre-programmed for every session, and were initiated by the subject. The driving task consisted basically in controlling with a steering wheel the lateral movements of a triangle, representing the car, on the screen so that it followed as closely as possible a line traced out by a complex sine wave, which in its turn represented the centre of the road that the car was being driven along. Extra feedback about road positioning was given by having the pointer change colour from white to green when it deviated by more than 23 pixels (approximately 1 cm) from the road on either side, and from green to red when the deviation was greater than 50 pixels (approximately 2 cm). While the colour of the pointer was green, a continuous sound (360 Hz) was delivered through the loudspeakers, and while it was red, another continuous sound (180 Hz) was delivered.

The subject controlled the speed of the driving (the speed of the generation of the sine wave) by depressing a pedal, which represented the accelerator. The speed, \( S \) (km/h), shown on the speedometer on the screen (figure 2) was related to the update rate, \( U \) (ms), of the sine wave by the function, \( U = 130 - S \). On the firm road the speed limit was always 70 km/h, and on the slippery road the speed limit was 50 km/h. If the speed deviated by more than 10 km above or below the given limit, the speedometer needle turned red, otherwise it was yellow. Everything that appeared in the blue, upper field of the screen progressed downwards at the same rate as the road was generated, which in turn was determined by the depression of the pedal. The lateral position of the car relative to the road, as well as the movements of the wheel and the pedal, were sampled continually (every 60 ms) and the data stored in a log file in the computer in relation to other information about the pre-programmed task.

2.3.2. Apparatus for behaviour recordings: While the subject performed the driving task his/her overt behaviour was recorded by two video cameras, placed at oblique angles relative to the subject: The first camera was placed at a high, front angle, and afforded a view of the subject’s fact and upper part of the body, as well as the steering wheel, telephone, and (part of) the radio; the second camera was placed at a low, rear angle, and gave a view of the lower part of the subject’s body, the screen, and the equipment to be controlled. These camera angles were selected so as to pick up
maximally the relevant aspects of the subjects' behaviour. The signals the cameras were combined in a video mixer, with the second inserted into the top right corner of the first, and the composite picture was recorded on videotape together with a time code.

2.4. **Secondary communication tasks within the task blocks**

2.4.1. **Simple telephone conversations:** The first 30 s of the (approximately) 2-5 min communication periods were allotted to dialling and being connected. The conversations themselves were 2 min conversations about four current topics: (a) The war in Bosnia, (b) President Clinton's economic policies in the USA, (c) Children's prostitution in Thailand, and (d) The unemployment situation in Sweden. These conversations followed a normal, standardized conversation pattern, and contained the following components: greetings, small-talk, down-to-business, conclusions, and farewells.

2.4.2. **Difficult telephone conversations:** As with the simple conversations, altogether 2-5 min were allotted to the communication phase. The conversations followed a similar pattern, but were centred on a test of working memory span, similar to that used by Alm and Nilsson (1992). A similar test had previously been employed by Baddeley et al. (1985). In the present, adapted version, the test consists of 12 sets of four sentences, half of which were logical (e.g. Grandmother baked bread) and half of which were illogical (e.g. The driver ate a car). The subject was required to do two things, (a) indicate after each sentence whether it was logical or illogical, and (b) repeat over the telephone the first words of the four sentences in a set after the last one had been presented. No ambiguous or unclear sentences were included.

2.4.3. **Radio communication:** This was considered to be a one-way communication task, and consisted basically of normal radio use. The subjects were required to turn on the radio when the appropriate sign came up on the monitor, tune into and listen to at least four local radio stations, using a quick-tuning facility, but not pre-tuned stations, and lastly turn off the radio again at a signal from the experimenter.

2.5. **Procedure**

Each of the 20 subjects participated individually in a 4-h long session, of which about 2 h was spent in simulated driving and related activity within the design presented above. Only aspects of direct relevance to the simulated driving performance are reported in this paper. Each session was divided into instructions, practice and testing phases, with the actual simulated driving task being performed in three blocks of 20 min each. In two of the blocks, the subject made and received telephone calls with the car radio off, and in the third, the subject attended to the car radio with no telephone conversations.

The sessions began with a 10 min introduction, during which time the subject provided basic information about him/herself. The following items were included: (1) name, (2) age, (3) occupation, (4) number of years of holding a driving licence, (5) number of km/year driven, (6) traffic incidents while driving: (i) number involved in, (ii) whose responsibility, (7) mobile telephone: (i) possession (owned or borrowed), (ii) frequency of use, (iii) when and where.

The subject was then informed of the details of the study, especially that the object of the driving task was to follow the simulated road as closely as possible at all times.
He/she was allowed to select his/her own speed, but urged to keep as close to the given speed limit as possible, while at the same time 'keeping the car on the road'. Then came an instruction period of about 10 min, which included a short demonstration (2.7 min) of all the aspects of the simulated driving task. After that, the subject had six, 5-5 min practice blocks, with 2 runs through the firm road surface conditions and 4 through the slippery road surface conditions. The subject then rested for approximately 15 min, during which time further instructions were given, and the subject practised using the telephone and radio. The subject then participated in the three, 20 min driving blocks, with about 10 min rest in between blocks.

Each subject began with either one of the two telephone conversation task blocks, simple or difficult, then the radio task, and finished with the other telephone task. Half the subjects began the first block with a firm road surface, and half with a slippery road surface, and then continued with the other blocks according to a balanced design. Within these conditions, half the subjects began the telephoning by calling up the experimenter, and half with answering a call on the mobile telephone. Four periods of telephone communication within the telephone block were initiated either by the driver himself after prompts on the simulator display or by another caller, with each communication period lasting about 2.5 min. This is shown in figure 3.

2.6. Variables included in the design
2.6.1. Independent variables: The simulated driving of the subjects during each of the three driving blocks was examined in relation to the three independent, within-subjects, variables, road surface, secondary task, and activity. In relation to these three independent variables, information was extracted from the driving log files on eight dependent variables. The principal data gathered were related, in the first instance, to the four activity categories: (a) only driving on a clear road, (b) driving with obstacles present, (c) driving with communication over the telephone (two-way) or the radio (one-way), and (d) driving with manipulation of the radio or telephone. These categories were defined by their temporal positions in the driving blocks. The time...
intervals from which to gather the data on the behaviour variables was determined by subsequent behaviour observation of the video recordings of each of these driving sessions.

Other independent, between-subjects, variables examined here were the subjects' gender and age group, the number of kilometres per year that they drove normally (km/year), and the number of previous incidents that they had been involved in while driving.

2.6.2. **Dependent variables:** During the simulated driving sessions, data were continuously recorded and stored in log files, from where the following eight performance variables, grouped under three major headings, were extracted:

1. **Road position** (pointer position) relative to the road on the screen, measured in screen pixels. The 14 in. monitor has a screen image 640 pixels wide, and thus the width of each pixel is approximately 0.4 mm. The position is directly related to the movement of the steering wheel. Three variables were derived from this measure in relation to the road: (a) Position deviation: average amount of deviation from the correct path (measured as the Root Mean Square Error (RMS) of the left/right deviations), (b) Error 1: Per cent of the time that the car was 'on the shoulder of the road' (25–50 pixels from the road, green pointer), and (c) Error 2: Per cent of the time in a given interval that the car was 'off the road' (> 50 pixels from the road, red pointer). The position deviation Errors 1 and 2 are also referred to below as 'minor and major deviations', respectively. Related to road position is also another variable, (d) the number of corrective steering wheel movements that the driver performed during various periods of driving.

2. The number of **collisions** with the obstacles that appeared twice in every 5 min sub-block.

3. **Speed of driving** along the path set out in the simulation, recorded as km/h. The absolute speed was directly related to the depression of the accelerator (pedal). Three variables were derived from this measure: (a) Mean driving speed relative to the given speed limit, (b) the mean RMS (absolute) deviations from the speed limit, and (c) fast and slow violations, the former defined as the number of times that the subjects speed went more than 10 km/h above the speed limit, and the latter as the number of times that the subject's speed went more than 10 km/h below the speed limit.

3. **Results**

Of the information originally provided by the subjects, the following was analysed: (i) number of years that the subject had held a driving licence, (ii) distance driven per year (in km), (iii) number of previous traffic incidents that the subject had been involved in as a driver, and (iv) whether or not the subject used a mobile telephone regularly while in the car. To begin with, the first three were correlated to each other and to the subject's age, and the resulting matrix is shown in table 1. The almost perfect correlation between age and number of license years shows that almost all of the subjects had obtained a driving licence as soon as their age allowed. In fact, only two of the subjects had received their licenses after the age of 20, both at 23 (male in the younger group, female in the older group). As age and distance driven per year are also positively correlated, there is bound to be such correlation also between distance driven per year and license years.
Table 1. Correlation matrix for four background variables: (i) the subject’s age, (ii) number of years holding a driving licence, (iii) distance driven (km/year), (iv) number of previous traffic incidents involved in as a driver.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Licence years</th>
<th>Distance driven (km/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Licence years</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance driven</td>
<td>0.78</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Number of incidents</td>
<td>0.38</td>
<td>0.42</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Table 2. Distance driven per year (km/year) by the male and female subjects in the two age groups.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age group</th>
<th>Younger</th>
<th>Older</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>7000</td>
<td>24000</td>
<td>15500</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1900</td>
<td>11200</td>
<td>6550</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4450</td>
<td>17600</td>
<td>11025</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Number of previous incidents reported by the subjects.

<table>
<thead>
<tr>
<th>Reported incidents</th>
<th>Number of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11 (55%)</td>
</tr>
<tr>
<td>1</td>
<td>6 (30%)</td>
</tr>
<tr>
<td>2</td>
<td>2 (10%)</td>
</tr>
<tr>
<td>3</td>
<td>1 (5%)</td>
</tr>
</tbody>
</table>

However, the relation with regard to distance driven per year is not entirely clear-cut, and a 2-way ANOVA with gender and age group as independent variables shows significant main effects \(F(1, 16) = 16.6\) and \(36.0; p < 0.01\), respectively], but no interaction between the factors (table 2).

There was no clear correlation between previous incidents and the other factors, as shown in table 1. Table 3 shows that the previous incidents were quite few in number, three reported incidents in the younger group and ten in the older group. Only two of the subjects, both male, one in each age group, claimed responsibility for an incident.

All the mobile telephone users were in the older age group, where eight of the subjects, four male and four female, reported using a mobile telephone regularly, privately or in their work.

The size of the effects of the various driving performance factors and their combinations was examined in a series of mixed model (subjects random) repeated measures ANCOVAs with three within-subjects (nested) variables. Preliminary analyses revealed a consistent non-significance of the independent variables of age group and previous incidents for determining the subjects’ performance, either as individual factors or in combinations with other factors. Subsequently, these two variables were not included in the ANCOVAs, and only gender was used as a
between-subjects, independent variable. However, as the distance driven per year was closely related to both gender and age group, it was used as a correlate in the ANCOVAs of the driving performance. It turned out that distance driven per year accounted for a substantial proportion of the variation in the data, particularly that connected with the gender variable. Thus, the significance of some of the interactions depending on fairly extreme values contributed by a few of the subjects failed to appear with the distance driven per year correlate present. This correlate is incorporated in all the ANCOVAs reported below.

3.1. Road position

3.1.1. Position deviation: Secondary task, road surface, activity, and gender were all shown to have a clear effect on the driving performance of the subjects, as shown in figure 4. Driving on a slippery road surface was the single most difficult condition, with a mean deviation of 31.5 (screen pixels), while driving on a firm surface was associated with a mean deviation of 10.5 \((F(1,17) = 20.4; p < 0.01)\). This is shown in figure 4(a). Of the secondary task conditions, performance was most affected by driving in the radio block (mean deviation = 21.2), while simply conversing over the telephone while driving had the least effect (mean deviation = 19.7), with the difficult conversation task being in between \([F(2,34) = 4.0; p < 0.05]\), as shown in figure 4(b). The activity during driving was also a highly significant factor, with easy driving and driving with communication affecting performance least (mean deviations = 17.7 and 18.7, respectively), and manipulation of the equipment during driving affecting performance most (mean deviation = 25.2), with driving with obstacles being in between \([F(3,51) = 7.2; p < 0.01]\). This is shown in figure 4(c). Figure 4(d) shows that the female subjects' mean deviation was 27.9, as compared to 14.1 for the male subjects \([F(1,17) = 13.3; p < 0.01]\).

There were also significant interactions between the factors. Much of the different in deviation in the slippery road condition may be found during the activities of communication and manipulation \([F(3,51) = 6.1; p < 0.01]\). However, this effect is to some extent also dependent on the difference in performance in the secondary task blocks, as shown in figure 5 in the interaction between these three factors \([F(6,102) = 2.4; p < 0.05]\).

3.1.2. Errors 1 and 2: The results are for the most part analogous to those for the position deviation, as these variables also measure aspects of the lateral deviation from the central path during driving. Thus, the main error effects for all three within-subject variables and the one between-subject variable are shown in figure 4. As before, road surface was the most salient factor, and the main effects for both Error 1 (E1) and Error 2 (E2) were significant here \([F_{E1}(1,17) = 5.7; p < 0.01; F_{E2}(1,17) = 5.2; p < 0.05]\). For secondary task, only the main effect for E2 was significant \([F_{E2}(2,34) = 5.1; p < 0.01]\). Similarly, only the E2 main effect for activity was significant \([F_{E2}(3,51) = 3.7; p < 0.05]\), whereas for gender only the main effect for E1 was significant \([F_{E1}(1,17) = 3.4; p < 0.01]\). However, several of the interactions between factors were significant: For E1, these are road surface \(\times\) gender \([F_{E1}(1,17) = 10.8; p < 0.01]\), activity \(\times\) gender \([F_{E1}(3,51) = 4.1; p < 0.05]\), and road surface \(\times\) activity \(\times\) gender \([F_{E1}(3,51) = 2.9; p < 0.05]\). These effects are shown in figure 6. For E2, the interactions secondary task \(\times\) road surface and road surface \(\times\) activity were significant \([F_{E2}(2,34) = 3.4; p < 0.05; F_{E2}(3,51) = 4.2; p < 0.05]\), and the effects are shown in figures 6 and 7, respectively. (For the 3-way interaction effect, road surface \(\times\) secondary
task × activity: \(F_{EI}(6,102) = 2.1; \text{NS})\). Thus, most of the minor deviations were made by the female subjects on slippery road, and the major position deviations were made by both the male and female subjects on slippery road in equivalent measures (allowing for driving experience), and almost exclusively during manipulation.

3.1.3. Steering wheel movements: No significant driving performance effects were discovered for this dependent variable in relation to any of the independent variables in the design.

3.2. Collisions
None of the main factors were significant, but a significant effect was found for the interaction road surface × gender \(F(1,17) = 6.5; p < 0.05\). The effect consists in the male drivers having approximately 0.3 collisions on average on both firm and
Figure 4. The road positioning aspect of the simulated driving, shown as mean position deviation (columns) with standard error bars, and percentage errors 1 and 2 (circles): (a) position deviation and percentage errors on firm and slippery road surface. (b) Position deviation and percentage errors in the three secondary task blocks, radio, and simple and difficult telephone conversations. (c) Position deviation and percentage errors during the four activities of communication, easy driving, obstacles, and manipulation. (d) Position deviation and percentage errors in relation to the drivers' gender.
slippery road surfaces, but the female drivers having on average 0.07 and 0.73 collisions on firm and slippery road surfaces, respectively. This is shown in figure 8.

3.3. Speed

3.3.1. Mean relative speed: This was measured relative to the speed limit at the time of driving (70 km/h on firm road and 50 km/h on slippery road). The overall mean relative speed was 6.6 km/h above the speed limit. The only significant effect here was for road surface \[ F(1,17) = 5.1; \ p < 0.05 \], where the speed on firm road was 2 km/h lower than on slippery road. This is shown in figure 9.

3.3.2. Speed deviation: Two main factors, road surface and secondary task, were significant here \[ F(1,17) = 6.7; \ p < 0.05 \], and \[ F(2,34) = 5.7; \ p < 0.01 \], but none of the interactions between factors. The mean speed deviation on the firm surface was 5.25 km/h, and 7.52 km/h on the slippery surface, i.e. both were positive and analogous to the mean relative speed. For secondary task, the mean speed deviations were 4.31, 3.42, and 4.62 km/h, respectively, for radio and simple and difficult conversation, with only the difference between the latter two being significant. The effects are shown in figures 9 and 10.

3.3.3. Fast and slow violations: Fast violations occurred every time the speed went more than 10 km/h above the current limit. This occurred to a significant extent only in connection with the activity main factor \[ F(3,51) = 6.3; \ p < 0.01 \], with a significant difference between communication and only driving, on the one hand (mean: 1.27 violations) and obstacles and manipulation, on the other (mean: 0.65 violations), as shown in figure 11. Slow violations occurred when the speed went below the current limit less 10 km/h, which happened to a significant extent for the two road surfaces (1.88 and 2.64 violations on average, for firm and slippery, respectively; cf. figure 9).
Figure 6. Position deviation percentage errors 1 (deviation = 25–50 pixels) and percentage errors 2 (deviation > 50 pixels) during the four activities on firm and slippery road surface. Percentage error 1 is shown in relation to the drivers' genders. Error bars: Up for percentage error 1, and down for percentage error 2.

Figure 7. Position deviation percentage error 2 (deviation > 50 pixels) on firm and slippery road surface within the three secondary task blocks.
Figure 8. Mean number of collisions with obstacles on firm and slippery road surfaces in relation to the drivers' gender.

Figure 9. Mean relative speed (actual speed — speed limit: dark columns, error bars up), mean speed deviation (mean of positive and negative deviations: light columns, error bars down), and mean number of fast and slow speed violations (circles) and firm and slippery road surface.

The numbers for fast violations on firm and slippery surfaces, shown in figure 9, were not significantly different. The interaction effects for secondary task × activity and secondary task × activity × gender \([F(6,102) = 2.9; p < 0.05, \text{ and } F(6,102) = 2.4; p < 0.05]\), were statistically significant, and these effects are also shown in figure 11. The interaction effects were, in this case, fairly complex, but may chiefly be attributed to more slow violations occurring during communication and only driving than obstacles and manipulation (mean: 2.14 and 1.29, respectively). A notable exception here was that the female drivers committed on average 3.40 slow violations during
Figure 10. Mean speed deviation in the three secondary task blocks.

Figure 11. Mean number of speed violations (≥ ± 10 km relative to speed limit) during the four activities. Slow speed violations (narrow columns, error bars up) are shown for driving in the three secondary task blocks (2-way interaction), and fast violations (wide columns, error bars down) are shown as the main factor. The significant aspect of slow violations in relation to the drivers’ gender (in a 3-way interaction) is represented in the figure by the inclusion of one datapoint (female, radio).
manipulation of the radio, as compared to a mean of only 0.83 during manipulation of
the telephone (figure 11).

4. Discussion
For half a century researchers have attempted to relate traffic accident involvement to
various aspects of everyday driving. In spite of this, reliable, predictive evidence
regarding important relationships between aspects of driving performance and
accidents is still lacking (Evans 1991). One reason for this may be an overemphasis in
studies of driving performance on driver skills (what the driver can do) rather than actual
driver behaviour (what the driver in fact does), the latter probably being a more
important factor in traffic violations and accidents. For example, the ability to judge
the speed of a vehicle, maintain that speed, and react appropriately to obstacles and other
hazards are all a part of a driver’s skill. Steering, head and eye movements for observing
the controls and the surrounding traffic, as well as the speed chosen by the driver under
various driving conditions, are aspects of a driver’s behaviour. Doubtless, the quality
and timing of the driver’s behaviour are influenced by his/her skill, but the actual
behaviour carried out depends also on other factors inherent in the immediate driving
situation and the driver him/himself, such as attention and decision processes.

Driver skill focuses on capabilities, and it has been investigated by many methods,
including laboratory tests, simulator experiments and observations of actual traffic.
While what happens in actual traffic situations cannot be studied in a simulator, many
types of driver behaviour can profitably be studied in laboratory simulations, and the
results generalized to and tested in real traffic situations. The results of the present study
fall into this category.

Incorporating a behaviour observation in the design made it possible to determine
exactly when the different activities began and ended. Such exactness would not be
possible otherwise, owing, among other things, to practical difficulties inherent in
telephoning over the mobile phone, such as delays in being connected, or being
disconnected temporarily or permanently during a conversation. Interruptions of the
planned procedure, such as the subject being late in starting to dial or forgetting to dial,
or carrying on talking or listening longer than planned, also make the temporal
placement of events difficult. Using behaviour observation gave the design an added
strength, as it was possible to assign the activities during driving to their rightful
categories with a considerably greater accuracy than if a rigidly blocked design had been
employed.

All of the independent (within-subjects) variables included in the design, as well
as the variable gender, affected the simulated driving performance. The more important
of these effects still remain when the not inconsiderable variation due to differences
in driving experience has been removed.

4.1. Road positioning
On the firm road, without a secondary task, the drivers in the study were generally able
to keep close to the centre line, but deviated appreciably more when driving round
obstacles. This was to be expected, considering the task requirements. However, in this
road condition, overall performance did not deteriorate with the addition of the
secondary task, as we had expected, but instead improved slightly.

In the more difficult driving condition on the slippery road a different pattern
emerged, where the amount and degree of deviation from the correct path was, on
average, about three times greater than on the firm surface. Differential effects of the
various secondary task components on driving performance had been predicted, and this prediction was borne out in that the additional task of manipulating the equipment made for greater deviations from correct road positioning. However, driving together with the auditory communication itself led to no greater position deviations than did driving on a clear road without a secondary task! This was, generally, true for both one-way and two-way communication. In fact, driving with simple communication was associated with the least position deviations on the slippery road surface. Deviation from the correct road positioning was especially marked when the driver had to manipulate the equipment, in particular the car radio. Manipulation of the telephone in the slippery road condition also led to increased position deviations, mainly in association with the difficult communication task, even though the manipulation was essentially the same for both kinds of communication. This indicates a significant influence of the content of the on-going telephone conversation of the drivers’ ability to position the vehicle correctly on the road, such that a more difficult telephone conversation tended to lead to greater deviations than the easier one.

A further aspect of the road positioning is afforded by the degree of deviation from the road (minor and major deviations: Errors 1 and 2). The pattern for these errors is similar to that observed for the mean position deviation, but some further, interesting aspects emerged when the degree of deviation was analysed separately. Both types of error were rare during driving on a firm road, but occurred more frequently on the slippery road. It can be seen that minor deviations from the correct path during manipulation are almost exclusively contributed by the female subjects, while, taking into account previous driving experience, major deviations from the correct path during manipulation were contributed in equivalent amounts by the subjects of both sexes. On closer examination, different, and, sometimes, surprising deviation patterns emerged for the two road conditions.

Considering first the minor deviations (Error 1) on the firm road, both male and female drivers had (i) the highest error frequency when only driving, and (ii) the lowest when in communication, but (iii) the female drivers showed nearly as high an error frequency when driving with obstacles and when manipulating the equipment as when only driving. As for the minor deviations on the slippery road, it was observed that (iv) the female drivers constantly exhibit a greater error frequency than the male drivers, and (v) have the lowest frequency when only driving and highest when manipulating the equipment, with the other activities in between, whereas (vi) the male drivers have by far the lowest frequency when in communication, and (vii) about an equal frequency for the other activities. Thus, the male drivers showed a similar pattern of minor errors on both the firm and the slippery road, whereas the pattern was different for the less experienced female drivers, indicating that they did not, generally, have the same degree of control under the difficult road conditions as the male drivers.

Looking at the major deviations (Error 2), it can be seen that (i) there are no differences in either pattern or frequency, specifically attributable to the drivers’ gender, (ii) this degree of deviation almost never occurs on the firm road, and (iii) on the slippery road, the frequency is considerably greater during equipment manipulation, and is about equally distributed among the other activities. Generally, (iv) these (major) deviations occur to a lesser extent in the simple telephone conversation block.

Not surprisingly, these results seem to indicate, more than anything else, that it is more dangerous to drive on a slippery road than on a firm road. The reason for including in the design two conditions so markedly different in road holding difficulty was, of course, not to underline this fact, but to make it possible to compare patterns
of performance in various primary and secondary task combinations. Generally, during an easy drive on a firm road, it is less likely that dangerous situations will arise in conjunction with the hands-free, mobile telephone communication. The results show conclusively that when the driving became more difficult, such as on a slippery road, not only the driving difficulty, shown in errors and deviations, but also the pattern of driving was different, and varied also between the male and female drivers. For example, we found that the frequency of occurrence of minor deviations for male drivers in communication on a slippery surface was less than that for the comparable firm driving. This was not an isolated finding, but one which accords with several of the other results.

Three main results stand out, specifically, when the road positioning results on the slippery surface are examined, namely that (i) the use of a hands-free telephone does not, in itself, increase the risk of an incident, but (ii) all manipulation increases the risk, while (iii) a simple, manipulation-free conversation may, actually, contribute to a decrease in the deviation from the correct path for drivers of both sexes.

4.2. Collisions
Collisions, which, of necessity, occurred only during the activity of obstacle driving, were rare, and no relation to the secondary task components was discovered. On the other hand, an interesting result here was that, while there was no overall difference in collision frequency between the drivers of the two sexes, a difference between the male and female drivers appeared in connection with the road surface. Thus, when driving under easy road conditions, the female drivers seldom collided with an obstacle, whereas the male drivers collided here about four times as often as the female drivers, and about as often under easy as under difficult conditions. However, the female drivers collided with an obstacle about ten times as often when driving on a slippery as on a firm road, and about twice as often on the slippery surface as the male drivers on either road surface.

On the whole, the results with respect to mean deviation, degree of position error, and number of collisions show that one of the main differences in performance between male and female drivers is related to the ability to keep control of the car under difficult driving conditions.

4.3. Speed
Speed is another important aspect of driving performance examined here. One relevant aspect is that the largest proportion of slow (> 10 km/h) violations during only driving occurred in the easy telephone conversation block (statistically significant). This may be compared to the large proportion of the slow violations during the activity of communicating in the difficult telephone conversations block (not statistically significant).

As a rule, the subjects drove slightly too fast in relation to the given speed limits, and it is known that drivers tend to behave in a similar fashion in real life (Thompson et al. 1985). However, the speed was somewhat lower on the firm than the slippery road, a finding that is in accordance with that of Alm and Nilsson (1994). It was observed that driving on the slippery road was far more difficult than on the firm road, and resulted occasionally is loss of control over the driving. This may have caused the drivers to, possibly inadvertently, let the speed race up above the speed limit on the slippery road,
and, thereby, contributed to the higher mean speed. A concomitant effect might be the excess of extreme (< 10 km/h) corrections towards a lower speed that were observed on the slippery road, as a means of compensation for the loss of speed control.

The speed deviations were generally towards higher speed, and this is, ultimately, also reflected in the higher mean speed. However, by far the greatest number of deviations were within 10 km/h of the speed limits, possibly indicating that only in extreme cases did the drivers lose control. The greatest number of the fast speed (> 10 km/h) violations were within the activities of communication and only driving, i.e. the conditions in which it was observed that it was normally easiest for the driver to keep control over the position of the car. Thus, it is obvious that speeding is not always a function of loss of control. Moderate speeding may, indeed, be a sign of the driver feeling in full control, and, therefore, more inclined to exceed the safety limits and break the rules slightly.

Another, interesting finding was that a majority of the slow speed violations was encountered during the same activities (communication and only driving) as the fast speed violations. A notable exception to this was that the number of slow violations during manipulation of the radio far exceeded that in manipulation of the telephone. On closer examination it became apparent that the effect was primarily owing to the female drivers’ tending to drop their speed and commit significantly more slow violations when manipulating the radio than when manipulating the telephone or engaging in any other activity. The reasons here are probably different from those applicable for the fast violations. For one thing, female drivers may have less ambition to show their skill and competence, which would result in more easy-going driving performance in general. Also, it is clear from the other results that the female drivers generally had more difficulty controlling the position of the car under slippery road conditions, and that this was especially marked during manipulation of the radio. This would probably lead to a greater number of corrections towards a lower speed.

4.4. **Communication tasks**

Some distinct patterns stand out in the results for the communication tasks. First, within all the communication tasks, manipulation by itself resulted in considerably greater errors and deviations than communication without the manipulation component. Second, it emerged that the radio communication (one-way), which generally required more prolonged manipulation, was the most difficult of the secondary tasks. Third, the difficult telephone conversation task tended to be associated with greater deviations and errors than the simple conversation.

The negative effects of the equipment manipulation on driving performance found here are analogous to those found by previous investigations (California Highway Patrol 1987, Stein et al. 1989, Zwahlen et al. 1988, Brookhuis et al. 1991). The particular difficulty associated with the manipulation of the radio may be related to the fact that the radio was located slightly farther from and below the monitor screen than the telephone, which required the driver to remove his/her gaze from the road slightly farther from and for longer when manipulating the radio than the telephone. The actual, temporal difference would normally only be a split second, but this may be long enough to generate a deterioration in performance under difficult driving conditions. This supposition is corroborated by the finding of Stein et al. (1989) of the negative effect on lane positioning of mounting the phone on the console of the car as compared to the dashboard. In the present study, it was observed also that the female
drivers sometimes had a greater difficulty than the male drivers in finding the right buttons on the radio and turning into audible stations, which then required them to look at the radio more often and keep their gaze off the road for longer periods. Under those circumstances, it would seem natural to correct for the concomitant loss of control, both over speed and road position, by lowering the absolute speed, which is what the female drivers tended to do more often than the male drivers.

The simulated driving employed here may be characterized as a pursuit-tracking task. Wickens (1984) proposed that, if two tasks both demand the use of common resources on any particular dimension of processing or modality of input, performance decrements will result. Accordingly, if driving is characterized as primarily a sensory-motor task, interference would be expected in this task from other tasks of the same kind. Such interference should not occur to a significant extent from simultaneous activities that include mainly verbal processes associated with memory and judgement. The first of these assumptions is borne out by the present results, where the greatest negative effect on the driving performance is from manipulation of the telephone and radio, which was the most exclusively motor, secondary task-component included in the design. However, the results also show that the introduction of communicatory, auditory/visual, secondary task-components led to changes in performance, and that this was related to the level of difficulty of the conversation carried out while driving. Thus, driving performance under difficult road conditions deteriorated when the driver listened to the radio or engaged in difficult conversation. On the other hand, simple conversation was associated with about the same amount of, or even less, position deviation as the activity of only driving without any added tasks. Thus, it was found that there was a relatively big interference from manipulation, and a moderate interference from the difficult conversation, while simple conversation actually appears to be facilitatory.

The effect on driving performance of both the verbal/cognitive and the motor components of the communication tasks is probably owing to the activation of different information systems, or resources. According to Wickens’s theory, the effects with respect to those resources should be diametrically different, but these results show no such clear-cut effects. Wickens’s multiple resource theory is partly based on the fact of the existence of different information systems. However, the possibility of equivalent effects of any two systems of performance under certain conditions, or different effects under other conditions must not be precluded. Thus, the motor skill required for equipment manipulation would be expected to interfere with driving performance in the simulation, which is largely a motor task. However, a high degree of attention to different task components is also required throughout the driving. Attention can be seen as a shared resource for motor, perceptual, and logical tasks, and the interaction with respect to these different components is, for example, shown in the differential driving performance associated with the logical (conversation) tasks. In the difficult conversation, a great deal of attention is required, and relatively little can be allotted to the motor components, whereas relatively little attention is required to carry on the simple conversation, which is based on largely automatic, verbal skills and memorized information. This may explain why the simple conversation appears to free, rather than tie up resources.

While Wickens’ model of performance concentrates more on skill and automatic processes, Rasmussen’s model incorporates such cognitive aspects as the operator’s previous knowledge and reasoning. Applying Rasmussen’s model to the results makes it easier to explain some of the other effects obtained. Also, by relaxing the restrictions
imposed on the particular outcomes that we may expect, the latter model allows us to look more freely for alternative explanations of the observed phenomena. To begin with, it may throw some light on the gender differences in driving performance that have been observed. Thus, owing to their generally less driving experience, the female drivers seem to operate more at the knowledge level of performance, making more conscious choices and having slower performance (Shiffrin and Schneider 1977), while the male drivers operate more at the skill and rule levels. The effects of this are more marked under difficult driving conditions.

In addition to this, there is some evidence that indicates that personality traits may also play a part in the driving performance (Hedman and Briem, in preparation). Basically, it appears that the female drivers are more careful to avoid direct incidents than their male counterparts. In general, they appear to avoid incidents by setting a lower driving speed and giving a wider berth when encountering obstacles, but on the slippery road surface, when required to keep the car on the road, while at the same time avoiding collisions, their control in both of these tasks tended to deteriorate.

The differential performance of the two sexes was highly correlated with the amount of time that the two groups reported spending behind the steering wheel. This emphasizes that driving is not a skill that, once established, is retained undiminished in the absence of practice. Instead, regular driving appears to be necessary for the driver to be able to cope with difficult situations. Infrequent drivers may never actually get to practice some of the more difficult aspects of car control, as the little driving they do only serves to maintain their basis skills.

As regards the age of the drivers in the study, the authors failed to find any association between this factor and performance, apart from the fact that all those who used a mobile telephone regularly were in the older group. The failure here of any age-related functional decrement is in disagreement with the findings of Stein et al. (1989) and Alm and Nilsson (1994) who compared the driving performance of older and younger drivers, among other things. While it is reasonable to suppose that a deterioration in driving performance does take place as a person gets older, evidently it does not happen until after middle age.

5. Conclusions

The results of the present study show that communication, in the form of conversing over a hands-free mobile telephone or listening to a car radio, during a simulated driving task affects driving performance in various ways. The effects were shown to be dependent on, first, the difficulty of the driving task, second, the amount of attention that the driver has to devote to the communication, and third, the experience of the driver. Obviously, many different factors, individual, situational and technological, determine the risk associated with using mobile telephones while driving. One way to minimize some of the negative effects of mobile communication is to develop good ergonomic design for new equipment (Kames 1978). For example, using speech controlled mobile telephones would be one way of reducing the potential hazard of communication while driving. However, given the current state of the art, serious restraint in the use of mobile communication while driving is to be recommended under all circumstances. Under difficult driving conditions, such as in town traffic, on an unstable road surface, or with reduced visibility, the driver is well advised to park the car before attempting to initiate telephone calls. Generally, the present findings are highly relevant to driver behaviour in everyday driving situations, but the extent to
which they are to be generalized should be determined more closely in field studies of driving while using hands-free and hands-on mobile telephones.

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References
CALIFORNIA HIGHWAY PATROL 1987, A special report to the legislature on the findings of the mobile telephone safety study, Department of the California Highway Patrol, Senate Concurrent Resolution No. 8, Los Angeles.
DRORY, A. 1985, Effects of rest and secondary task on simulated truck-driving task performance, Human Factors, 27, 201–207.
HEEDMAN, L. R. and BRIEM, V. Personality traits and sex as determinants of simulated driving performance (in preparation).
NILSSON, L. 1989, The VTT driving simulator, VTI särtryck, 175 (Swedish Road and Traffic Research Institute, Linköping, Sweden).
NILSSON, L. and ALM, H. 1991, Effects of mobile telephone use on elderly drivers’ behaviour—including comparisons to young drivers’ behaviour, VTI särtryck, 176 (Swedish Road and Traffic Research Institute, Linköping, Sweden).