Use of mobile phones while driving – effects on road safety

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A literature review

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Summary

Driver distraction and inattention in its various forms is thought to play a role in 20-30% of all road crashes (Wang, Knipling & Goodman, 1996). Distraction is caused by a competing activity, event or object from inside or outside the vehicle. Safety problems related to driver distraction are expected to escalate in the near future as more technologies become available for use in motorized vehicles. A relatively new technology, already widely available and accepted, is the mobile phone. While it is clear that mobile phones enhance business communication and increase personal convenience, use of mobile phones while driving has become a road safety concern.

The vast majority of drivers (60 to 70%) report using their mobile phone at least sometimes while driving, and it is estimated that at any given moment during the day, 1 to 4% of the drivers is using a mobile phone.

The mobile phone distracts drivers in two ways: it causes physical distraction and cognitive distraction. Physical distraction occurs when drivers have to simultaneously operate their mobile phone (i.e. reach, dial, hold) and operate their vehicle. Cognitive distraction occurs when a driver has to divert part of his/her attention from driving to the telephone conversation. However, the ability to divide one's attention between two simultaneous tasks is limited. Mobile phone use while driving could therefore negatively affect driving performance. The results of epidemiological studies strongly suggest that using a mobile phone while driving can increase the risk of being involved in a road crash up to four times.

The possible 'impairment potential' of mobile phone use while driving has been the focus of various behavioural studies. This review only includes studies published from 1999, because studies published prior to 1999 have already been analysed in a previous SWOV report (see Oei, 1998). For the purpose of this review, based on the research methodology (degree of realism and closeness to real-world driving), the analysed studies are grouped in:

1. Simulator studies
2. Closed-track studies (test-track studies)
3. Studies on the real road

The distractive effects of mobile phone use depend on the momentary context of driving. Phone use during undemanding driving periods may not seem to be a problem. However, both the demands of the driving context and the content and demands of the mobile phone conversation play a role in this process. The level of complexity of the phone conversation (its cognitive demands) is the important factor that also determines the extent of the effect of the phone conversation on driving performance.
Although studies differ with regard to the extent of behavioural changes found, most of them confirmed the fact that using a mobile phone while driving negatively affects various aspects of driver performance.

The following effects have been demonstrated:
- Slower reactions to traffic signals and more frequently missed signals
- Slower braking reactions with more intensive braking and shorter stopping distances
- Reduced general awareness of other traffic
- More risks in decision making,
- Compensatory behaviour

Hands-free versus handheld use of the mobile phone remains one of the most commonly investigated features. The vast majority of studies report that hands-free phoning does not have a significant safety advantage over handheld phoning. Although handheld units add to the driving task due to the need for manipulation, the most important negative factor of mobile phone use is the same for both types of phone – the diversion of attention from driving to the conversation itself.

Different countries have introduced various kinds of legislation aimed at restricting the use of mobile phones. The most common legislative measure is the ban on handheld mobile phones in vehicles. Other measures include prohibiting the use of the mobile phone for drivers in some special driver categories, such as drivers with special responsibilities (e.g. school bus drivers) or young drivers who only have a learner's licence. There is still very little data on the effectiveness of these legislative measures. There are indications that although the short-term effects could be a 50% reduction in mobile phone use, the long-term effects (after one year) are far less positive. It has been recognised that the effectiveness of legislation could be increased if supported by publicity campaigns and a broadly based educational campaign to promote responsible use of mobile phones while driving.

In order to better determine, control and reduce the effects of mobile phone use on road safety, this report concludes with the following recommendations:
- Identify the extent of drivers' use of mobile phones more precisely in order to generate more exact data on the risk of mobile phone use while driving.
- Record mobile phone use in accident reports in order to produce a truer estimate of the number of mobile phone crashes in the total number of crashes.
- Make drivers more aware of the dangers of mobile phone use and other various distracting activities.
- Design the Human-Machine Interface as ergonomically as possible.
- Develop precise criteria and methodologies for assessing the safety implications of in-vehicle information systems (IVIS), including mobile phones.
- Base the legislation of mobile phone use on scientific evidence.
- Support company policies like those imposing a complete ban on the use of mobile phones while driving and other kinds of policies contributing to the corporate safety culture.
- Use the 'technology against technology' principle: technology could also provide the answer, at least partly, to solving the problem of driver distraction.

Contents

List of abbreviations used

BVOM	Bureau Traffic Enforcement of the Public Prosecution Service
CBS	Statistics Netherlands
CDS	Crashworthiness Data System
DBI	Driving Behaviour Inventory
FARS	Fatality Analysis Reporting System
HASTE	Human machine interface And the Safety of Traffic in Europe
IVIS	in-vehicle information systems
MMS	multimedia messaging service
MRT	modified rhyme test
NASA-TLX	NASA-task loaded index
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
NOPUS	National Occupant Protection Use Survey
PDA	Personal Digital Assistant
PDT	Peripheral Detection Task
PROV	Periodical Regional Road Safety Survey
SMS	short message service
TRL	Transport Research Laboratory
TTC	time to collision

1. Introduction

In recent years, there has been an increasing focus on issues relating to drivers' inattention and the role of driver distraction in road safety. The reason for this increased interest is largely due to new in-vehicle technologies (e.g. various in-vehicle information systems, advanced driver support systems, entertainment systems) whose popularity is rising but whose implementation is also accompanied by the rising fear of their distraction potential and related effects on road safety.

However, despite the recognised and increasing importance of driver distraction for road safety, the scope of the driver distraction problem is not yet really known. The National Highway Traffic Safety Administration (NHTSA) estimates that driver distraction and inattention in its various forms contributes to 20-30% of all road crashes (Wang, Knipling & Goodman, 1996). These NHTSA estimates are based on the statistical analysis of data from the 1995 Crashworthiness Data System (CDS). However, the CDS was not originally intended to collect crash causation data. Furthermore, the crash investigation is always a retrospective, reconstruction process.

The AAA Foundation for Traffic Safety defines driver distraction as a situation “when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver’s shifting attention away from the driving task”. What distinguishes distraction from inattention is the presence of a triggering event. Factors that cause driver distraction can come from inside or outside the vehicle. Potential in-vehicle distracters could include eating, drinking or smoking in the vehicle; adjusting radio, cassette or CD; adjusting climate controls or other objects/controls integral to the vehicle; talking to a passenger or talking on a mobile phone, the latter being the subject of this report.

This report focuses on the effects of mobile phones on driving performance and traffic safety. As such, it follows up the 1998 SWOV report (Oei, 1998) and therefore only includes significant literature published after 1998.

The second chapter reports on the general trends and level of use of mobile phones in various countries, followed by estimates of the level of mobile phone use by drivers while driving. The latest developments on the mobile phone market, such as the availability of a whole new range of services and new trends in the design of mobile phones, as well as increased mobile phone use by younger users, are discussed as being especially relevant for the potential road safety effects of mobile phone use in vehicles.

While it is clear that mobile phones enhance business communication and increase personal convenience, use of mobile phones whilst driving has become a concern in the field of traffic safety. However, data regarding the contribution of mobile phones to road crashes are far from exhaustive. The third chapter reports on available data on the involvement of mobile phones in road crashes as well as estimates of crash risk associated with the use of mobile phones while driving, obtained in epidemiological studies.

The fourth chapter presents the results of various simulator, closed-track and on-real road studies on the effects of mobile phone use on driving performance. An overall conclusion is that this increasing body of behavioural research strongly suggests that mobile phone use can potentially reduce driving performance and can therefore have a negative impact on traffic safety. Effects of mobile phone use are also compared with the effects of alcohol, talking to a passenger and listening to a radio on driving performance.

The fifth chapter discusses the attitudes of the general public and also those of the drivers themselves towards the use of mobile phones while driving. It also provides an overview of existing legislation regarding the use of mobile phones and its short and long-term effectiveness.

The sixth and last chapter presents a general summary of the conclusions on the effects of mobile phone use on driving performance. In order to better determine, control and diminish the effects of mobile phone use on road safety, several recommendations are also given.

2. The use of mobile phones

2.1. General trends in possession and use of mobile phones

Mobile phones were introduced on the market in the United States in the mid-1980s. By 1985, there were 91,600 mobile phones subscribers in the United States. Since then, the number of American subscribers has risen dramatically to 197,680,004 (www.ctia.org, on 25 October 2005).

The trend of increased ownership and use of the mobile phone is evident all over the world. In 2000 the mobile phone ownership rate in Finland was 70%, which at the time was the highest ownership rate in the world (Lamble, Rajalin & Summala, 2002). Today, according to an Ericsson survey (www.mobiletechnews.com), Sweden has the highest ownership rate, with 93% of its population possessing a mobile phone. In the UK, by the end of 1980s, less than 1% of the population had a mobile phone. By April 2000, there were approximately 25 million phone subscribers, making up 40% of the potential market. The number is expected to grow to 45 million by 2005, representing 75% of the potential UK market.

In the Netherlands, the number of mobile phone subscribers and the use of the mobile phone have increased significantly in recent years. The number of mobile phones now exceeds the number of fixed phones. At the start of 2002, more than 12 million people in the Netherlands had a mobile phone. In 1998, they spent approximately 8.5 minutes a day on mobile communication; today this has risen to 30 minutes a day (www.monet-info.nl).

For years, annual growth rates in the number of mobile phone subscribers have been between 30 and 50%. By the end of 2004, the number of wireless subscribers worldwide is expected to exceed 1.5 billion. Although some of the oldest mobile phone markets (e.g. Europe, United States and Japan) seem close to saturation point, new, fast growing markets like those in China, India or Brazil support the projection of more than 2.5 billion mobile subscribers worldwide in 2009.

2.2. Reasons for the popularity of mobile phones

What are the reasons for the popularity of mobile phones?

Communication
Mobile phones facilitate communication and give people greater flexibility. Compared with traditional phones, mobile phones are more successful in reaching the person required. Only one in five 'office to office' calls reaches the desired person, compared with four in every five calls using a mobile phone. With mobile phones, there is no need to be based in a particular location, e.g. office or home. It is possible to have direct contact with whoever you need, whenever you need them and to use your time more efficiently.

Safety
Besides communication, for many people safety is another important reason for having a mobile phone. Personal safety could be improved by being able

to make all kinds of emergency calls: call help-services and report vehicle breakdowns, report accidents, dangers on the road, medical emergencies or crime in progress. In the US, 140,000 emergency calls are made every day (www.ctia.org). In Finland, more than 50% of drivers report using their mobile phone for safety purposes (Lamble, Rajalin & Summala, 2002). Such 'safety' activities include: drivers calling to tell someone they will be late, allowing them to continue driving safely rather than driving too fast; drivers reporting dangerous situations or slippery roads; calling for help due to a breakdown or accident; even keeping themselves awake by talking to someone when there was a risk of falling asleep at the wheel.

2.3. Estimates of level of mobile phone use while driving

Although data about the precise number of mobile phone subscribers does exist, data about the number of drivers using their mobile phone while driving are not so precise. There are three major sources for estimating these numbers:

- Self-reports about the use of mobile phones while driving
- Observational studies
- Police accident records

However, each of these sources has certain limitations. Consequently, only approximate and rather biased estimates of exposure are available.

The next sections discuss data regarding the percentage of drivers using mobile phones while driving and the percentage of drivers engaged in mobile phone conversations at any given time, based on self-reports and observational studies. Data about crashes with mobile phones as a contributing factor are discussed separately in the following chapter.

2.3.1. *USA*

It is estimated that between 70 to 90% of drivers in the US use their mobile phones while driving at least some of the time (Sundeen 2001; Lissy et al. 2000). However, although the vast majority of drivers use mobile phones in their vehicle, the extent of phone use varies substantially.

In the NHTSA survey, the National Occupant Protection Use Survey (NOPUS) data collection protocols were expanded to include observation of driver handheld mobile phone use (Utter, 2001). In October and November 2000, trained data collectors observed the use of handheld mobile phones by drivers at 640 sites. These sites consisted of intersections controlled by a stop sign or traffic light. Observers spent 45 minutes at each observational site, covering every day of the week and all daylight hours. The results showed that in the US, at any moment, 3% of drivers were using mobile phones. Converting this percentage into real numbers, this means that at any given time during daylight hours, approximately half a million drivers used mobile phones on US roads in 2000. Several other American observational studies performed in Washington State, North Carolina, Texas and Michigan support this NHTSA result with observed rates ranging from 3 to 5%.

Two subsequent NOPUS surveys performed in 2002 and 2004 revealed an increase in the use of handheld mobile phones in vehicles. Compared with

3% of drivers in 2000, in 2002 4% of drivers were using a handheld mobile phone at any daylight moment. In 2004 this percentage rose to 5%. In terms of the number of vehicles, that means that at any daylight moment in 2004, there were 800,000 vehicles on the road driven by someone holding a phone. By combining the NOPUS data on the use of handheld mobile phones with data from the National Household Travel Survey and other research studies, the total percentage of drivers using some form of mobile phone at any daylight moment in their vehicles in 2004 is 8% (Glassbrenner, 2005).

2.3.2. *Australia*

In Perth, Australia, Horberry et al. (2001) observed an average 1.5 % of drivers using handheld mobile phones during the daytime. The observed users were predominantly male (78%) and under the age of 40 (64%). This percentage of observed users remained stable for December 1998 and December 1999 despite the 10-15% increase in the mobile phone market in that period. A possible explanation for this result could be the local media education campaign that ran from January 1999 and the increase in the number of hands-free phones that were not subject of this study.

2.3.3. *New Zealand*

The results of the Sullman and Baas (2004) survey showed that 65% of New Zealand's population own a mobile phone and that 57.3% of those surveyed use a mobile phone while driving at least occasionally. Of those who reported using a mobile phone while driving, 17.2% reported having a hands-free kit while the majority of drivers (82.8%) did not. Drivers who use a hands-free kit tend to use mobile phones more frequently, report a much higher annual mileage and have a new car with larger engines. More than half of the drivers (57%) reported believing that using a mobile phone while driving is 'very' or 'extremely' hazardous. Those who reported using a mobile phone quite frequently whilst driving tended to be male, reside in a main urban area, report a higher annual mileage, drive a newer car with a larger engine, prefer to drive faster, have less driving experience (in years) and be younger.

2.3.4. *Europe*

2.3.4.1. UK

In 2000 the survey of 1000 UK drivers (Green Flag, 2000) showed that 37% of drivers use a mobile phone while driving, one third of whom did so 'often'. Young, male and high mileage drivers were more likely to use a mobile phone while driving.

Between October 2000 and April 2002, Traffic Research Laboratory (TRL) carried out regular surveys of mobile phone use by car occupants (TRL, 2002). Although the sites in this survey were mainly located at junctions controlled by traffic signals and mobile phone use at junctions may differ from that at other parts of the road network, TRL’s results provide a useful insight into the increasing national trend of mobile phone use in the UK see *Table 2.1*).

Phone type	October 2000	April 2001	October 2001	April 2002
Handheld (%)	1.1	1.3	1.5	1.7
Hands-free (%)	0.3	0.3	0.3	0.4
Either (%)	1.3	1.7	1.9	2.1

Table 2.1. *Observed percentage of car drivers using a mobile phone in the UK, by phone type (TRL, 2002).*

The proportion of drivers using mobile phones has been consistently higher among men than women and higher on rural than on urban roads.

In October 2002, September 2003, April 2004 and September 2004, TRL carried out four more surveys at sites in the south east of England (TRL, 2004). The sites were chosen to represent the full range of conditions on British roads. Observers were equipped with an electronic device that detects the microwave radiation emitted by both handheld and hands-free mobile phones so that visual and electronic detection could be combined. Bearing in mind that the period between September 2003 and September 2004 coincided with the introduction of the ban on using handheld mobile phones in cars (effective since December 2003), it is not surprising that the use of handheld phones among car drivers dropped by approximately 30% (see *Table 2.2*). Drivers under the age of 30 were almost twice as likely to use a mobile phone as drivers over 30.

Driver type	Phone type	October 2002	September 2003	April 2004	September 2004
Car drivers	Handheld (%)	1.8	1.5	1.2	1.1
	Hands-free (%)	1.7	1.7	1.9	1.4
	Overall (%)	3.5	3.2	3.1	2.4
Other drivers	Handheld (%)	2.8	2.3	2.0	2.2
	Hands-free (%)	1.4	1.6	2.5	1.6
	Overall (%)	4.2	3.9	4.5	3.8

Table 2.2. *Percentage of drivers using mobile phones according to TRL surveys in England (TRL, 2004).*

2.3.4.2. Sweden

In Sweden, one third of drivers reported using mobile phones daily while driving. The estimates of Thulin and Ljungblad, 2001 (cited in Kircher et al. 2004) are that mobile phones were used during about 2% of the total driving time in Sweden.

2.3.4.3. Finland

A phone poll conducted by the Central Organisation for Traffic Safety in Finland in May 1997 reported that 38% of drivers had a mobile phone in their car (Lamble et al. 1999). 24% of these drivers used a mobile phone daily while driving. Over the next two years, in autumn 1998 and 1999, data regarding mobile phone use while driving were collected by Gallup home poll. When comparing the results of these two polls, it is evident that after only one year, a significantly larger proportion of drivers were using a mobile phone in their car (67.7% in 1999 as opposed to 55.8% in 1998). A significantly higher proportion of phone-using drivers also experienced risky or dangerous situations (50.2% in 1999 as opposed to 43.5% in 1998). With regard to age, younger drivers (aged 15-24 and 25-34) used mobile phones more frequently than older drivers and a larger proportion of younger drivers also experienced dangerous situations while using a mobile phone.

The continued trend towards increased mobile phone use while driving is revealed in a subsequent Gallup home poll (Poysti, Rajalin & Summala. 2005). This poll showed that 81% of drivers used their phones in the car at least sometimes, with 9% using it over 15 minutes a day. Again, young drivers and males used their phones more often than older drivers or women; again it was the youngest age group (18-24) who reported experiencing hazards while using a phone eight times more often than the oldest age group (64+ years). In general, almost half of phone-using drivers (44%) admitted having experienced hazardous situations while using a mobile phone in the last 6 months. Also, people in top positions (managers, executives, etc.) reported experiencing hazards very often and even three times more often than pensioners.

2.3.4.4. The Netherlands

Regarding the use of mobile phone while driving, the results of the Periodical Regional Road Safety Survey (PROV) in 2001 conducted by the Dutch Ministry of Transport, Public Works and Water Management (Feenstra et al. 2002) showed that 4% of drivers used handheld phones in the car often, while 36% of drivers used handheld phones sometimes. The percentage of drivers using hands-free phones (who had them at that time[1]) while driving was significantly higher: of drivers using a hands-free phone in 2001, 43% used hands-free phones often and 48% sometimes while driving.

In 2003, the PROV results showed that drivers used both handheld and hands-free phones less, compared with 2001. However, there is still no data about the actual use of mobile phones by Dutch drivers while driving.

Frequency	Handheld (%)	Hands-free (%)
Often	1	14
Sometimes	22	23
Never	77	63

Table 2.3. *Use of handheld and hands-free mobile phones while driving in the Netherlands (Van der Houwen, Hazevoet & Hendriks, 2004).*

2.3.5. *Summary*

Since the introduction of mobile phones on the market, there has been a continuous, even dramatic increase in the number of mobile phone users. At the same time, the percentage of drivers using mobile phones in their

[1] At the time of this survey (2001), both handheld and hands-free phones were permitted in the car.

vehicles has also increased. At the moment, the vast majority of drivers (60 to 70%) report using their mobile phones while driving at least sometimes. Observational studies from the US, Australia and the UK give comparable results concerning actual road exposure rates in an approximate interval of 1 to 4% of drivers using mobile phones at any given moment during the day. Males and younger people (younger than 30 years) tend to use mobile phones while driving more often.

Similar trends of mobile phone use while driving are noted in the Netherlands. Although there was a small decline in the use of mobile phones in 2003 compared with 2001 (based on self-reported behaviour), the number of fines issued for the use of mobile phones while driving has risen significantly each year (see also *Table 5.2*). It is not clear whether this is the result of an actual increase in mobile phone use while driving or merely the result of more intensive enforcement.

2.4. New trends and developments in mobile phone use

At the moment of its introduction on the market in the 1980s, the price, size and capabilities of mobile phones did not appeal to a large proportion of the population. After just two decades, the status of the mobile phone has completely changed. Today, the mobile phone is attractive - some argue even necessary - and affordable to almost everyone. The mobile phone is no longer a 'miracle of technology' but an inevitable part of everyday life.

It is not just the number of people using mobile phones that has increased. The amount of use of mobile phones and the range of services offered by mobile phones have also increased.

2.4.1. *New mobile phone services - increased attractiveness of mobile phone*

In order to increase the attractiveness of mobile phone use, new services (e.g. travel information services) are becoming available every day. The capabilities of mobile phones seem to be almost unlimited. Drivers can combine their mobile phones with a whole range of computerised devices such as personal organisers, address books, electronic mail or their company’s computer systems (for a full overview of mobile computers in cars, see Braimaister, 2002). Their cars are beginning to resemble an office. The NPD Group reports that consumers who are likely to buy a mobile phone in the next 12 months will be looking for features such as changeable ring tones, colour screen, voice-activated dialling, a built-in still camera, short text messaging and e-mail (www.itfacts.biz). It is estimated that 28% of potential buyers will also want Internet access or web browsing capabilities, while 18% want a built-in PDA organiser. With these new features and services, it is not just dialling and conversations that could interfere with the driving task. A whole range of new activities are being introduced that require increased interaction with the mobile phone by drivers while driving. For almost all of these activities, there are no data about their potential effects on driving behaviour. However, based on experience with similar distractions, these activities could be expected to have negative safety effects. The new trend involving the display of visual information on mobile phones (e.g. reading SMS) would distract drivers’ visual attention away from the road. This could have implications for safety because driving is primarily a visual task.

Developmental trends in the design of mobile phones, such as miniaturization, could also reinforce the problems of mobile phone use while driving.

2.4.2. *Young drivers as heavy mobile phone users*

At the start of the mobile phone era, businessmen and other adults were the main users of mobile phones. Today young people are becoming the prime users. In August 2004, Ericsson conducted a survey in Canada involving one hour-long in-home interviews. The study identified a key mobile phone market group called 'explorative youth'. This group is a segment of tech-savvy, entertainment-oriented young people which is driving the wireless service market forward. The group includes early adopters, between the ages of 15 and 24, who are heavy users of mobile phones and associated services. On average they spend more than an hour every day talking on their mobile phones (according to Ericsson, the global average is 27 minutes). They are driving the SMS market with 49% using text messages on a weekly basis and 10% already using new multimedia messaging services (MMS) every month. They are most interested in downloading games (47%), music (47%), sharing pictures while talking (44%) and sending e-mails via a mobile phone (50%).

As heavy mobile phone users, young people also belong to the group of novice drivers. It is well known that this group is about four times more likely to have a crash compared with drivers in other age categories. Some results suggest that mobile phones could also have more impairment affects on younger drivers. Thus, the heavy use of mobile phones by young drivers could be particularly dangerous and could increase the high crash risk for novice drivers.

2.4.3. *Future design of the mobile phone*

Developments in the design of mobile phones, such as miniaturisation, location of displays and keys, shape, etc. could reinforce the problems of mobile phone use while driving. However, the mobile phone industry could reduce some of the negative effects of mobile phones by taking human factors into account when creating new mobile phone designs.

3. How dangerous is the use of mobile phone while driving?

3.1. Road crashes during mobile phone use

The collection of information about mobile phone involvement in road crashes is neither widespread nor very systematic. This makes it difficult to estimate the danger of mobile phone use in vehicles. In most countries, the presence or use of a mobile phone in a vehicle is not recorded. The lack of systematic data collection gives rise to justified concerns about the obvious underreporting of mobile phone use as a cause of road crashes. Accident reports citing their use only relate to cases whereby the police can definitively attribute the crash to a driver's use of a mobile phone. There is obviously a need for a specific data collection programme that can address the relative risk of mobile phone use while driving.

An additional factor contributing to underreporting is, of course, that drivers who are involved in a crash may be reluctant to report using a mobile phone to police because of the fear of liability.

Because of a general lack of data about mobile phone involvement in crashes, only some data regarding the situation in a few countries have been encountered.

3.1.1. *USA*

In the USA, the Fatality Analysis Reporting System (FARS) used by the NHTSA began recording the presence of mobile phones in vehicles in 1991. In 1995 the National Automotive Sampling System (NASS) began recording mobile phone use as a possible driver-related crash factor. At that time, Oklahoma and Minnesota were the only two states that included a specific data element related to mobile phones in their police accident reports.

Oklahoma had a standardised accident report 'check-box' for police officers to indicate the presence and/or use of a mobile phone. However even though Oklahoma was collecting this data, there were still some problems because only the presence of a visible mobile phone was reported. This allowed underreporting in cases when the phone was in use but not visible to an investigating officer.

Fortunately, increasing numbers of states in the USA are now beginning to record mobile phone use in their accident data systems. In 2001, twelve US states were collecting information about mobile phone involvement in crashes. However, only four of these states have collected sufficient data to issue reports (Gillespie & Kim, 2001).

An analysis of FARS data for 1994 shows that the most common phone-related crash factors are 'inattention', 'driving too fast', 'run off road' and 'failure to yield'. In the majority of cases, mobile phone users were drivers of the colliding vehicle and the crash occurred during the conversation, not the dialling phase. This is in contrast to Japanese data (see *3.1.2*).

3.1.2. *Japan*

In June 1996, the Japanese National Police Agency conducted a study in order to assess the frequency of mobile telephone use as an antecedent to a motor vehicle crash. Of 129 crashes, 76% involved rear-end collisions, 2.3% were single vehicle crashes, 2.3% were pedestrian impacts and 19% were categorized as 'others'. In contrast to US data, most of the crashes were related to handling a phone (32% dialling, 42% answering, 5.4% hanging up) with only 16% of drivers talking on the phone at the time of the crash. For the 42% of drivers who were responding to a call at the moment of the accident, the behaviour was described as looking to the side to try to pick up the telephone, careless driving when hearing the phone ring and dropping the receiver. The majority of drivers involved in an accident were men (82%) and in the 20-29 age range.

3.1.3. *Finland*

Of 2,200 serious injury crashes that occurred in Finland in the period between 1991 and 1998, mobile phone use was found to be a risk factor in 26 crashes (0.9%). The majority of drivers (14 of 26) were talking on the phone at the moment of the crash and the mobile phone was the handheld type in 23 (of 26) cases.

3.1.4. *Summary*

There are evident difficulties and flaws in gathering data regarding mobile phone involvement in crashes. There is therefore no well-established data regarding the proportion of mobile phone crashes in the total number of crashes. Instead it can only be estimated that the crashes caused by the use of a mobile phone in the vehicle represent a couple of percent of the total number of road crashes.

3.2. **Estimates of risk increase due to mobile phone use - epidemiological studies**

Although there is not enough data about crashes involving mobile phone use to reach a conclusion about the real risk related to the use of mobile phone while driving, some epidemiological studies have been dedicated to finding an answer to this question.

These epidemiological studies attempt to find a statistical relationship between mobile phone use and road crashes. The advantage of epidemiological studies is that, unlike experimental studies, they are about real situations. The disadvantage of epidemiological studies is that it is difficult to measure or control various, potentially significant factors.

3.2.1. *Redelmeier and Tibshirani (1997a)*

Probably the most famous and most frequently cited epidemiological study about the risks of mobile phone use while driving is the study of Redelmeier and Tibshirani (1997a). Redelmeier and Tibshirani used the case-crossover design in order to quantify the impact of mobile phone use while driving on crash risk. The study was conducted in Toronto, Canada. It evaluated the mobile phone use of 699 drivers who had mobile phones and who were involved in a road crash resulting in substantial material damage (but not personal injury). When comparing usage during a 10 minute period immediately before the accident[2], to the same period on a comparable preceding day, Redelmeier and Tibshirani found that the risk of a collision when using a mobile phone was four times higher than the risk when a mobile telephone was not being used. Calls close to the time of the collision were particularly hazardous: the relative risk was 4.8 for calls within 5 minutes before the collision, compared with 1.3 for calls more than 15 minutes before collision. The results of this study suggested that hands-free phones offered no safety advantage over handheld units. When analysing only drivers with hands-free phones, Redelmeier and Tibshirani found a relative risk of 5.9. When the study was restricted to analysing drivers who had owned a mobile phone for more than five years, Redelmeier and Tibshirani still obtained a relative risk of 4.1. This suggested that the relationship was not just a reflection of inexperience but might indicate a more basic limitation in driver performance.

Although Redelmeier and Tibshirani used the case cross-over design where each person serves as his/her own control, which enables automatic control for various potential confounders (i.e. age, sex, visual acuity, training, personality, driving record and other fixed characteristics), there could be some limitations in this study. Hahn and Tetlock (1999) noted that two factors might bias Redelmeier and Tibshirani's risk estimate upward. The reported association may not be causal because circumstances (e.g. congestion, poor weather, a delay that motivates the driver to go faster) might contribute to both the exposure (mobile phone use) and the outcome (accident) and it is not clear how great this effect might be. Secondly, Redelmeier and Tibshirani may have misclassified calls made for emergency assistance after the crash as calls that occurred before the crash. Limitation in establishing an exact time of the crash creates uncertainty regarding the precise relationship between talking on a mobile phone and an increase in the number of road crashes. However, Redelmeier and Tibshirani pointed out that in those cases for which the exact collision time was known, the relative risk was similar (RR=4) to the overall risk estimate.

3.2.2. *Violanti & Marshal (1996) and Violanti (1998)*

Violanti and Marshal compared 100 randomly selected drivers involved in crashes in the past two years with a group of 100 randomly selected drivers who had been accident-free for the last ten years. They found that conversations on mobile phones for more than 50 minutes per month were associated with a 5.59 fold increased risk in road crashes. The main limitations of the Violanti and Marshal case-control study is that the study is based on a relatively small sample and there is no control for potentially critical confounders (e.g. distance driven per year). The validity of the study results is therefore limited.

In the subsequent case-control study, Violanti (1998) tried to determine a statistical relationship between traffic fatalities and the use or presence of a mobile phone. Violanti analysed 223,137 reported road crashes in the state of Oklahoma between 1992 and 1995. The results indicated that both the use and presence of a mobile phone in the car were associated with an

[2] Redelmeier and Tibshirani defined 10 minutes before the estimated time of the collision as the hazard interval.

increased statistical risk of a traffic fatality. Drivers who reported using a mobile phone stood an approximate nine-fold risk of a fatality compared with drivers who did not use a phone. The mere presence of a mobile phone in the vehicle was associated with twice the risk of fatality compared with the risk for drivers with no mobile phone in their car. Although this Violanti study also implies a statistical relationship between mobile phones and traffic fatalities, several limitations must be taken in account. One limitation concerns exposure data because there was no information regarding the number of miles driven per year or changes in mobile phone ownership across age and gender. There was no control for other possible confounding factors such as traffic conditions, other potential distractions, psychological, physical conditions and personality of the driver, etc. An additional limitation concerns reliance on data from police accident reports as a source of information and possible reporting bias. It is possible that police officers did not detect possible crash factors and even if they did detect them, they might not report them.

3.2.3. *Laberge-Nadau et al. (2003)*

The objective of the Laberge-Nadau et al. study was to verify the relationship between mobile phone use and road crashes while attempting to overcome some of the problems found in previous epidemiological studies. After mailing 175,000 questionnaires about exposure to risk, driving habits, opinions about activities likely to be detrimental to safe driving, some socio-demographic information, information about potential crashes involvement within the last 24 months and additional questions for mobile phone users about the use of the mobile phone, 36,078 completed questionnaires were received. Data from three data sources were merged: data from files on mobile phone activity provided by phone companies, data from files for 4 years of drivers' records and data from police reports.

The main result of the Laberge-Nadau et al. study is that the relative risk for injury collisions and for all collisions is 38% higher for mobile phone users. When taking into account potentially confounding variables (kilometres driven, driving habits, educational level, listening to and adjusting the radio, CD tapes), the adjusted relative risk for all collisions is lower, i.e. 1.11 for male users and 1.21 for female users compared with non-users.

The most significant finding of this study is a dose-response relationship between the frequency of mobile phone use and crash risks. The adjusted relative risks for heavy users are at least two compared with those making minimal use of mobile phones. These light mobile phone users have similar collision rates as non-users. The final conclusion of the authors of this study is that their results and applied study design and considerations justify causal inference of the frequent use of mobile phone and higher crash risks.

3.2.4. *McEvoy et al. (2005)*

This study was conducted in Perth, Australia on 456 drivers who owned or used mobile phones and had been involved in a road crash between April 2002 and July 2004 resulting in hospitalisation. The study used a case-crossover design where the driver's use of a mobile phone at the estimated time of the crash was compared with the same driver's use during another suitable time period. The hazard interval was defined as the 10 minute period before the crash and was estimated based on several resources (emergency response records, medical records, self-reports, phone-company records).

McEvoy et al. found that drivers using a mobile phone when driving are four times more at risk of having a road crash resulting in hospitalisation. This result is consistent with that of Redelmeier and Tibshirani (1997a). Sex, age or type of mobile phone did not affect the relationship between mobile phone use and the risk of a road crash.

3.3. Summary and discussion

The epidemiological studies estimate that drivers who use a mobile phone while driving have a higher crash risk than those who do not. The estimated increased risk varies from 2 to 9. However, although most of the epidemiological studies found indications of a link between mobile phone use and road crashes, one must be aware that although this link has been found, the epidemiological studies could not establish a causal connection between mobile phone use and road crashes. The problem of establishing the causal relationship is related to two methodological issues:

1. *Exposure assessment*: there are two important issues for defining exposure in order to help establish the possible causal connection. Firstly, the exposure has to be defined in a measurable way. Secondly, the exposure has to be defined narrowly enough to reduce or avoid confounding. There are various ways to define exposure to a mobile phone: ownership of a mobile phone, presence of a mobile phone in the car, hours of phone use per month, use of the phone just prior to an accident, etc. It is obvious that different problems of measurability and relevancy are associated with each of these types of exposure.
2. *Confounding*: the danger of confounding is present when a third factor is associated with both exposure and outcome. In the case of a mobile phone, this would mean that other factors may be related to mobile phone ownership/use (or any other defined exposure) having a higher crash rate. In that case, mobile phone use does not have to be the cause of a road crash. It is also possible that these other factors related to mobile phone ownership/use could be causing higher crash rates for mobile phone users. A higher crash risk for mobile phone users may be caused by their greater acceptance of high-risk behaviour or by their higher annual mileage compared with non-users. For example, the study of Eby and Vivoda (2003) showed that safety belt use for handheld mobile phone users was significantly lower than for non-users. That means that those conversing on mobile phones are not only potentially more likely to be involved in a traffic accident, they are also more likely to sustain greater injury due to not wearing a safety belt. In the Netherlands, the last Periodic Regional Road Safety Survey, i.e. PROV 2003 (Van der Houwen, Hazevoet & Hendriks, 2004) also showed that drivers who still use handheld phones while driving (this type of phone has been banned in the Netherlands since March 2002) wear seat belts less frequently than drivers who never use a handheld mobile phone in the car. They also demonstrate other riskier behaviour, such as driving more often while intoxicated and exceeding the speed limit to a larger extent.

However, it must be concluded that the results of the methodologically sound epidemiological studies strongly suggest that using a mobile phone while driving can increase the risk of being involved in a crash and that this risk is approximately four times higher. In this report, this factor four was also adopted in the estimation of the number of Dutch traffic victims resulting from mobile phone use while driving (see *5.2.2.4*).

4. Effects of mobile phone use on driving performance

What are the reasons for this four-fold increase in the risk of having a road crash when using a mobile phone? What makes a mobile phone so dangerous when used in a vehicle? The simple truth is that the use of a mobile phone while driving distracts the driver and causes various changes in driving behaviour that could negatively affect traffic safety.

Although driving is a complex task, almost everybody can do it. In time, basic activities related to controlling a vehicle become automatic and generally these activities do not require much mental processing. This routine element of driving 'allows' drivers to engage in parallel activities that are not related to driving, such as use of a mobile phone. However despite the automation of driving routines, there is evidence that these parallel activities may distract drivers and negatively affect their driving performance.

Mobile phones potentially distract driver in several ways:

1. Physically: instead of focusing on the physical tasks required by driving (e.g. steering, gear changing), drivers have to use one or both of their hands to manipulate the phone.

2. Visually: mobile phones could visually distract drivers in two ways:
   - Firstly, drivers have to move their eyes from the road and focus on the mobile phone in order to be able to use it.
   - Secondly, while talking on a mobile phone, even if drivers' eyes are focused on the road, they 'look but do not see'.

3. Auditory: the focus of drivers' attention moves from the road environment to the sounds of the mobile phone and the conversation. This particularly applies when the sound quality is poor.

4. Cognitively: instead of focusing their attention and thoughts on driving, drivers divert their attention and focus on the topic of the phone conversation.

There is a significant body of scientific research that addresses the consequences of mobile phone use for driving behaviour. As mentioned in the previous chapter, one of the potential weaknesses of the epidemiological approach is the difficulty controlling variables that are potentially significant for the effects of the mobile phone. However, in experimental studies performed in driving simulators or on closed tracks, researchers can have the required degree of control while the driving environment still remains relatively realistic. Nevertheless, the quality and realism of these types of studies also vary because they differ in the various factors and conditions under which they have been performed:
- Method used (simulator, closed-track, real road testing)
- Type of road (highway, urban, rural road)
- Traffic density (low or high traffic density)
- Age, gender and experience of participants

- Type of mobile phone (handheld or hands-free, different models of phones)
- Type of phone conversation (intense or not, demanding or not, naturalistic conversation or different types of arithmetical or grammatical tasks)

Although all these variables are relevant for the possible effect of mobile phones on driving behaviour, only variables specifically related to the mobile phone and phone conversation will be discussed here in more details.

4.1. Phone and conversation-related variables relevant to driving behaviour research

4.1.1. *Phone–related variables significant for the driving behaviour research*

There are numerous phone design-related factors that could be relevant for the effects of mobile phone on driving performance: handheld versus hands-free, voice activated versus non-voice activated, mounting kit/base versus non mounting kit/base, cord versus non-cord, flip-phone versus non-flip phone, visual display features, keypad size and spacing, etc.

The most famous feature of mobile phones, at least regarding traffic safety research, is the handheld versus hands-free feature. Although initially there seems to be a clear distinction between these two categories of phones, it is sometimes difficult to define the precise borderline between handheld and hands-free phones. The difference between handheld and hands-free phones is most evident during the conversation phase of the call. In general, the term 'handheld' refers to the group of phones where the receiver has to be held against the ear during a conversation. 'Hands-free' refers to phones that enable the user to talk on the phone without having to hold the receiver to their ear. This could be achieved through a separate earpiece and a microphone placed on the driver ('personal hands-free phone') or microphone and speaker mounted in the vehicle ('hands-free speaker mobile phone').

Regarding the dialling phase, handheld and hands-free characteristics do not necessary overlap with those related to the conversation phase. Dialling is a more continuous feature where the level of the phone's hands-free capability could vary considerably with varying degrees of manual action required. Here are the most common dialling methods:

- Manual dialling: an entire telephone number is dialled, followed by pressing on the 'ok' or ‘talk’ key
- Speed dialling: only one key is pressed (i.e. ‘single-digit', 'speed number’)
- Menu dialling: access the menu and scroll through the menu with arrow keys to find desired number and then press the 'ok' or 'talk' key
- Voice-activated dialling: press the ’ok' or 'talk' button and say the name of person you want to call. Then wait for confirmation

All these various types of dialling are available in both handheld and hands-free mobile phones.

The range of features of mobile phones related to complexity of handheld versus hands-free features could be relevant for the effects of mobile phone use while driving. They are also significant for the potential generalisation of research results obtained on a particular type of mobile phone for mobile phones in general. However, these necessary details about the type and model of the mobile phone used in the research are not always reported or taken into consideration.

4.1.2. *Conversation-related factors significant for driving behaviour research*

Variables significant for telephone conversations are call frequency, placing and receiving calls, duration, content, etiquette and the difficulty (complexity) of conversation.

For experimental research into the effects of telephone conversations on driving behaviour, it is important to choose relevant, valid, realistic conversation tasks that would represent a naturalistic mobile phone conversation. Nevertheless, some of the conversation tasks used in research struggle with these demands.

Conversation tasks used in driving behaviour research can generally be divided into two main groups:

1. Naturalistic conversation: conversation about a subject that has been previously determined as interesting to the participant or a conversation in which the participant gives answers to simple or more complex questions.

2. Non-naturalistic (artificial) conversation: these types of conversation tasks include mathematical tests (e.g. computations,) verbal tests or question-answer dialogues based on intelligence test materials (e.g. mental arithmetic, grammatical reasoning tests).
   Some of the frequently used verbal tests include:
   - Shadowing technique: the participant has to repeat the word he has just heard.
   - Word generation task: the participant has to create a word according to some rule (e.g. word should begin with the last letter in the previously stated word).

Although non-naturalistic conversation tasks are easier to quantify than naturalistic ones, whether they represent typical mobile phone conversations is questionable. This is because the relationship between such tasks and the content of normal mobile phone conversations is unknown. Furthermore, non-naturalistic conversation tasks miss some of the key elements of naturalistic conversation such as emotional engagement. Emotionally charged conversations like domestic arguments or tense business deals may have an even greater negative impact on traffic safety than those of cognitively demanding tasks.

This review only includes studies published from 1999 because studies published before 1999 were analysed in the previous SWOV report regarding the relationship between mobile phones and traffic safety (see Oei, 1998). For the purpose of this review, the studies analysed are grouped on the basis of the research methodology (degree of realism and closeness to real-world driving) used in:
- Simulator studies (section *4.2*)
- Closed-track studies (test-track studies; section *4.3*)
- Studies on the real road (section *4.4*).

4.2. Simulator and simulated driving task studies

4.2.1. *Parkes & Hooijmeijer (2000)*

The study investigated the driving performance of 15 young well-educated participants engaged in hands-free phone conversations. When comparing the phone and no-phone condition, significant differences in choice reaction time, responsiveness to a change in speed limit from 80 to 50 km/h and situation awareness (measured by the questionnaire) were found in favour of the no-phone condition. No significant differences were found in the mean lateral position, the standard deviation of the lateral position or speed. The study concludes that although this group of young and educated participants was able to engage in a difficult in-vehicle telephone conversations while at the same time reasonably coping with driving, even this group showed a dramatic fall in situation awareness due to the concentration level demanded by the phone conversation. The applicability of the results of this study tends to be limited to situations of a relatively easy driving task combined with a relatively difficult phone task.

4.2.2. *Haigney, Taylor & Westerman (2000)*

This simulator study investigated the possible influence of the vehicle transmission type (automatic versus manual) and the phone type (handheld versus hands-free) on driving behaviour. Each simulated drive was divided into three 150 second periods: pre-call, during call and post-call period. The effect of the ’period’ was found on driving speed and heart rate. Speed was significantly lower during the mobile phone call period with the heart rate being the highest during this period. Handheld and hands-free phones differed in the number of off-road excursions with more ’offs’ for a handheld phone. There were no differences in heart rate between the two types of phones, indicating that the additional load of concurrent phone use is not related to the physical demands associated with holding the phone. The reduced variability of accelerator pedal travel during the call period and failure to change gear in either call or post-call period suggest reduced driver responsiveness to traffic conditions at the time of the telephone conversation. This reduced responsiveness could make drivers less able to deal with emergency situations or other sudden increases in driving task demands. However such situations were not included in the study.

4.2.3. *Strayer & Johnston (2001)*

In the first experiment in this study, the effects of handheld and hands-free phone conversations on a visual pursuit-tracking task were compared. 48 young participants performed a pursuit-tracking task on a computer display. From time to time, the target would flash red or green to simulate traffic signals. When the red light was detected, participants were to press a ’brake button’ located on the thumb position on top of the joystick as quickly as possible. The naturalistic conversation task was a discussion about two major national events at that time. The results showed that telephone conversations resulted in a significant increase in reaction time to simulated traffic signals. Also during conversation, participants missed twice as many simulated traffic signals. There were no differences between handheld and hands-free phone condition.

In the control condition, participants listened to a radio, e.g. book on tape. In the control condition, there were no differences in performance between single and dual-task conditions. This difference in performance in the control and the phone conversation condition suggests that the active engagement in the mobile-phone conversation could be the significant factor for the reduction in driving performance.

In the second experiment, the mobile phone conversation task varied in difficulty: participants were required to repeat the word they heard (shadowing task) or they had to generate a new word beginning with the last letter of the word read by an experimenter. Tracking errors increased in the more difficult conversation condition where participants had to perform an active, attention-demanding, word-generating task. This was not the case in the easier, shadowing task condition.

4.2.4. *Strayer, Drews, Johnston (2003)*

This study of Strayer, Drews & Johnston was generally designed to replicate and extend the findings of the study of Strayer & Johnston (2001) discussed above. In order to increase the validity of the research results for real driving, this time Strayer, Drews & Johnston (2003) used a high-fidelity simulator (not just the laboratory station like in previous study). Participants were engaged in naturalistic hands-free phone conversation on topics that were of interest to them. The study embraced four experiments where participants performed a simulated driving task in single task (i.e. driving only) and dual-task conditions (driving and talking on a mobile phone). In the first experiment, authors used a car-following paradigm where a number of real-time performance variables were measured in order to determine how participants reacted to a car braking in front of them. The second experiment was designed to examine how telephone conversations affect the driver’s attention to objects encountered while driving. In the third experiment, the effects of telephone conversations on visual attention were further examined by measuring eye fixations, while in the fourth experiment the implicit perceptual memory for words that were presented at fixation was studied during the pursuit-tracking task. Only the relevant and the most important results are reported here.

In general, talking on a hands-free mobile phone impaired driving performance and this impairment became more pronounced as traffic density increased:
1. Driver's reaction to vehicles braking in front of them was slowed down when they were engaged in mobile phone conversations.
2. Drivers continued to press the brake pedal longer when they were driving in dual-task conditions.
3. Drivers increased the following distance when they were talking on a mobile phone in an attempt to compensate for their slow reactions.
4. Talking on a mobile phone impaired the recognition memory for objects presented in the driving scene. This difference in recognition memory performance could not be attributed to alternations in visual scanning of the driving environment. Even when the participant's eyes were focused on objects in the driving environment, they were less likely to remember them if they were talking on a mobile phone.

The authors discussed their results in the light of the inattention-blindness hypothesis according to which "Cell-phone conversation disrupts performance by diverting attention from the external environment associated with the driving task to engaging in internal context associated with the cell phone conversation".

About half of the participants in this study found driving with a mobile phone to be no more difficult than driving without using a mobile phone. Nevertheless, participants reported that they had observed other drivers driving erratically when using a mobile phone. However, participants rarely, if ever, thought that their own driving was impaired when they used the mobile phone. This indicates an obvious disconnection between self-perception of one's driving performance and the objective measurement of their driving performance in the case of mobile phone conversation.

4.2.5. *Consiglio et al. (2003)*

In this study, a laboratory station designed to simulate foot activity in driving was used to compare simple reaction time[3] to the red brake lamp positioned in front of the participants. Reaction time (i.e. braking response) in this study refers to the time interval between the activation of the red lamp and the initial movement of the foot from the accelerator pedal. There were five conditions: control, listening to music played on a radio, conversation with a research assistant, use of a handheld and use of a hands-free mobile phone. Of the four experimental conditions, only in the condition 'listening to music played on radio' did reaction time not significantly differ from the reaction time in the control condition. In all other three 'conversation' conditions, reaction times were significantly increased. The use of the mobile phone caused reaction time to slow down by 19% with a hands-free phone, providing no advantage over a handheld phone. Furthermore, there was no significant difference between conversations conducted in person and conversations on a handheld or hands-free mobile phone.

The results of this study must be viewed with caution due to several limitations. First of all, it is difficult to determine the implications of the results obtained in a laboratory station for real world driving. Secondly, the study focused on young adults only (the average age of the participants was 21 and ages ranged from 18 to 27). The generalisation of these results to older age groups is therefore questionable. Thirdly, there were relatively few trials in this study, which is not a problem if differences are statistically significant.

4.2.6. *Rakauskas, Gugerty & Ward (2004)*

The study of Rakauskas, Gugerty & Ward (2004) investigated the effects of easy and difficult mobile phone conversations on driving performance. They used hands-free mobile phone and naturalistic conversation tasks. The conversation task had two levels of difficulty: easy and difficult. The difficulty of the conversation tasks was validated in the pilot testing. The main hypothesis of this study was that the degree of impairment and effort would be greater when a participant is engaged in the more complex conversation. However, although self-reported mental effort was higher in the presence of

[3] Reaction time (braking response) was the time between activation of the red lamp and the initial movement of the foot from the accelerator pedal.

conversation (in comparison to no conversation), there was no significant difference in reported effort between the two levels of conversation difficulty. The mobile phone conversation significantly changed driving performance in terms of increased accelerator pedal position variability and increased speed variability (both measures of speed maintenance) and reduced average driving speed. The degradation on these driving performance indicators suggests that drivers reduced the performance goals of mobility and controllability in order to lower the task demands. The general conclusion of this study is that the main impairment effect occurs during any conversation, relative to driving without conversation.

The study of Rakauskas, Gugerty & Ward (2004) is one of the rare studies that attempted to address the problem of different complexity levels of naturalistic conversation. However, the issue of quantification of the complexity and dynamics of conversation need to be further investigated in order to be able to further clarify the relationship between complexity of conversation and driving performance.

4.2.7. *Tornros & Bolling (2005)*

In this study, the effects of hands-free and handheld mobile phone dialling and conversation in simulated driving were investigated. 48 participants took part in two experiments (i.e. conversation and dialling experiments) performed in the moving base driving simulator of the Swedish National Road and Transport Research Institute. The phone task in the conversation experiment was a demanding paced serial addition task with a total of ten calls each lasting about 1 minute.

The performance variables included the Peripheral Detection Task, the standard deviation of the lateral position and the mean driving speed.

Peripheral Detection Task (PDT)
The PDT is considered a valid method to measure small changes and short peaks in workload while performing a continuous task such as driving. The PDT requires participants to respond to a light stimulus that would appear in the participant's periphery in respect to the main driving focal point. Compared with other workload measures, the advantage of the PDT is less interference with the task at hand. It is also a very sensitive measure for workload variations induced by traffic, the road environment, driving experience or complexity of the human-machine interface.
The PDT reaction time was impaired by both phone tasks: 159 milliseconds for the conversation and 270 milliseconds for the dialling task. The phone mode (i.e. hands-free and handheld) was not significant. Also, the number of missed PDT signals increased for both phone modes with 12.7% of units for the conversation and 24.3% units for the dialling task.

Deviation of lateral position
The standard deviation of lateral position decreased as an effect of conversation for 1.3 cm, but the phone mode was not significant. On the other hand, the standard deviation of lateral position increased (6.5 cm) as an effect of dialling and again the phone mode was not significant.

Mean driving speed
The phone mode was significant for the mean speed in the conversation experiment. The conversation on hands-free phone had no effect on mean driving speed, while the mean driving speed was reduced for 2.8 km/h when conversing on a handheld phone.
In the dialling experiment, the phone mode was again significant but this time, contrary to the conversation experiment, the effects were greater for the hands-free phone (3.7 km/h compared with 2.0 km/h for the handheld phone).

These effects of reduced speed could be a sign of compensatory behaviour by the drivers in an attempt to reduce the increased workload resulting from mobile phone use. However, the most important conclusion of this study is that hands-free mobile phones do not offer any safety advantages. Conversations seem to be quite similar for both hands-free and handheld mobile phones. Hands-free phones may even be less safe with regard to dialling.

4.3. Closed-track studies

4.3.1. *Cooper et al. (2003)*

Cooper at al. investigated the effect of audio messages on driving performance in three driving situations that varied in the level of complexity. The three increasingly challenging driving tasks were:
1. A traffic light which turned from green through amber to red (low complexity)
2. A series of off-set pop-up targets which required drivers to weave through (medium complexity) and
3. A left-turn decision task (high complexity)

Although the real hands-free phone was not used in this study, the audio messages were used to simulate 'hands-free' operation. The conversation task consisted of a recorded criterion or contextual statement followed by a string of target words separated by a 1.0-1.5 second gap. During this gap, participants were required to state whether or not the word met the criterion defined in the contextual phase.

The results of the study indicate that the effects of audio messages on driving performance appear to be influenced by the complexity of the driving manoeuvre. The audio messages in the traffic light task, i.e. low complexity task, provoked a more conservative response from participants. Drivers were more likely to stop rather than run the light. Also when stopping, they tended to react earlier. Because the traffic signal task represents a common and frequently encountered task in everyday driving, drivers seem to have established workable coping strategies, possibly even risk compensation strategies which in this case enabled successful 'multitasking'.

However, the effect of the audio message on driver performance was different in the other two, less familiar driving tasks. In the weave situation, drivers made significantly less speed adjustment and ended up driving significantly faster through the weave manoeuvre. In the left-turn task, they adopted riskier decision-making by accepting shorter gaps and they failed to adjust their driving to adverse road conditions. The results of this study indicate that the extent of driving impairment is related to the complexity of the driving manoeuvre, i.e. more complex manoeuvres lead to more degradation in driving performance.

4.3.2. *Hancock, Lesch & Simmons (2003)*

In this study, 36 participants drove on the half-mile long, closed-loop test track. Participants were divided into two groups according to age: one group of 19 younger participants (ages 25-36) and one group of 17 older (ages 55-65). Participants were confronted with three tasks:

1. Number memorisation and recall task
2. Mobile phone, i.e. distraction task
3. Stopping task, i.e. critical driving manoeuvre where a traffic signal changed from green to red as the vehicle approached the intersection. Participants were expected to stop the vehicle as quickly and as safely as possible.

Here are the results of four dependent measures of longitudinal control of a vehicle:

Compliance rate to the red light (stopping accuracy)
Without the distraction, the overall compliance rate to the stoplight activation was about 95%. When the phone distraction task was added, the rate dropped to 80%, constituting a highly significant 15% reduction in stopping response. The age of the participants was significant for the reduction in the compliance rate. In the situation without the mobile phone, younger drivers stopped for 93% of the red lights. This decreased to 87% for the mobile phone task. Older drivers stopped for 97% of the red lights compared with only 74% of the red lights for the mobile phone task.

Brake response time
Brake response time was significantly higher where there was a distracting factor (0.71 second versus 0.52 second) with a significant effect of age. For older drivers, brake response times were delayed by approximately one-third of a second compared with about one-tenth of a second for younger drivers. Gender was another significant factor. The presence of a distracting factor had a greater influence on female than male drivers, with a disproportionate disadvantage for older females.

Stopping time
Stopping time is the period between the driver's first activation of the brake after the red light came on and the time at which the vehicle sustained zero velocity.
Drivers also stopped faster in the presence of the mobile phone task (2.23 seconds versus 2.57 seconds in the control condition). This means that drivers brake harder when exposed to distraction. This could represent a kind of risk compensation response by drivers. They recognize their limitation in initial response and try to make up for this by greater braking intensity.

Stopping distance
Although drivers brake more intensely in the mobile phone task, the stopping distance from the line of the red light was still shorter than in the control

condition. On average these drivers ended up 50% closer to the intersection (70% closer for older drivers and 20% closer for younger drivers).
As already mentioned, for all these findings driver characteristics such as age and gender had a significant influence on patterns of response to in-vehicle phone distraction. In all cases, older drivers showed a larger distraction effect than younger drivers. Gender influenced brake response time and stoplight compliance, with female drivers being disadvantaged.

4.4. On-road testing

4.4.1. *Lamble et al. (1999)*

The study of Lamble et al. (1999) investigated the performance of drivers in the safety critical sub-task of detecting a car ahead decelerating while performing mobile phone-related tasks. Dialling was simulated by use of number keypad tasks, while memory and addition tasks were used to simulate a phone conversation. Testing was conducted on a 30km section of a real motorway with a speed limit of 80 km/h.

The detection ability of drivers in a closing headway situation was impaired for both brake reaction time and time-to-collision[4]. While performing a non-visual cognitive task (simulated conversation), there was an increase of about 0.5 second and almost 1 second in brake reaction time and time-to-collision, respectively.[5] Similar impairments were also found for the keypad task (i.e. dialling task).

4.4.2. *Matthews, Legg & Charlton (2003)*

The study of Matthews, Legg & Charlton (2003) investigated differences between different phone types on subjective workload: handheld phone, hands-free phone with an external speaker and microphone, and a personal hands-free phone with a personal single earphone and microphone.

The subjective workload was measured by NASA-task loaded index (NASA-TLX). The NASA-TLX questionnaire is commonly used to assess the subjective workload of operators working with various human-machine systems and it is also frequently used in studies of effects of mobile phones. It is a multidimensional rating procedure that derives an overall workload score based on weighted averages or ratings on six subscales. The six subscales are: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration.

The intelligibility of conversation was assessed by the modified rhyme test (MRT). MRT measures the intelligibility of the front or end consonants of words, where participants have to generate their own response to the word they think is presented to them. The number of correct responses is counted and converted to a percentage.

The study used within subject, repeated measures design where 13 drivers drove on the 6 km rural highway section with a 80 km/h speed limit. All of the

[4] Time to collision (TTC) is the time required for two vehicles to collide if they continue at their present speed on the same path.
[5] These increases in time do not include normal motor response component of about 0.2 s and the brakes latency time (0.2 s).

three mobile phone types induced a significantly increased total subjective workload. Differences in subjective workload between handheld, speaker hands-free and personal hands-free phones were also significant. The personal hands-free phone was associated with the lowest total subjective workload, followed by the handheld phone. The highest subjective workload for the hands-free phone with external speaker could be explained by the lower intelligibility associated with this type of phone compared with the other two types. This leads to higher frustration which then subsequently contributed to the total workload.

4.4.3. *Patten et al. (2004)*

40 professional drivers drove an instrumented vehicle on a 74 km section of the motorway. The chosen route was of low level road complexity regarding vehicle handling and information processing. The effects of the phone type (handheld versus hands-free) and the type of conversation (complex versus simple versus no conversation) were investigated by means of a Peripheral Visual Detection Task (PDT; see also *4.2.7*).

The light stimulus was illuminated for 2 seconds; in this interval participants were required to depress the micro-switch attached to their left index finger. The main result of this study is that while there is a significant effect of the conversation type on the peripheral detection task performance, the phone type is not significant. However, the phone type was significant for the mean driving speed. The mean speed for the handheld phone was significantly lower than the baseline mean speed, while the hands-free mean speed was significantly higher than the baseline mean speed. The authors have no explanation for this finding.

The mean reaction time on the peripheral detection task in the complex conversation condition increased by 45% from the baseline. The PDT correct hit rate dropped from 96% in the baseline to 85% in the telephone task. The results of this study indicate that drivers engaged in a complex conversation are less likely to detect (peripheral visual) changes in their traffic environment than when not subject to distraction by a telephone conversation.

4.4.4. *Liu & Lee (2005)*

After a pre-screening test of 150 participants with the Driving Behaviour Inventory (DBI) to assess aggressive disposition, six aggressive and six non-aggressive drivers were chosen for this experiment. They drove instrumented vehicles on a 7 km section of a four-lane highway in Taipei with a speed limit of 51 km/h with 24 signalised intersections. The phone conversation task consisted of 24 pairs of double-digit additions and the phone was a hands-free, voice-activated Nokia 3310 car phone system.

The results of this study show that both performance on the secondary, i.e., phone conversation task, as well as some driving performance measures were affected. The mean correct rate for the addition test decreased from 90% in the laboratory to 87.5% in city traffic and 75.8% at intersections. At the same time the mean response time for these addition tests increased from 3.8 seconds to 4.5 seconds and 5.6 seconds respectively.

As a result of increased workload, drivers changed their driving behaviour in an attempt to reduce the task demand. When negotiating intersections and simultaneously conversing on a mobile phone, drivers reduced their driving speed, which was 6.4% lower than the mean speed in the control condition. As in Hancock, Lesch & Simmons (2003), both stopping time and stopping distance were affected by the phone conversation. The mean stopping time while conversing on the phone (9.1 seconds) was significantly lower than the stopping time in the control condition (12.6 seconds). Although drivers braked harder in the presence of the distraction, the intersection line was exceeded more frequently compared with normal driving.

With regard to the aggressiveness of drivers, the aggressive drivers tended to drive faster and brake later than non-aggressive drivers, even when using a mobile phone.

4.5. Mobile phone compared with other negative influences on driving performance

In contrast to mobile phone use while driving, clearer social norms do exist for some other activities that could negatively affect driving performance,. Therefore if any activity, including mobile phone use, induces changes in safety-related driving behaviour equal to or greater than those already defined by these existing norms, it is clear that this activity should be at least avoided.

4.5.1. *Comparison of the mobile-phone driver and the drunk driver*

Redelmeier & Tibshiranin (1997b) were among the first to compare alcohol and mobile phone impairment. They suggested "the relative risk of being in a road crash while using a mobile phone is similar to the hazard associated with driving with a blood alcohol level at the legal limit". However in their subsequent article, they concluded that cumulative risks associated with alcohol intoxication are much greater than those associated with using a mobile phone (Redelemeir & Tibshirani, 1997b). According to Redelmeier and Tibshrani, the most important factor for this difference is the short duration of most mobile phone calls compared with the number of hours in which alcohol stays in the blood stream (only relevant during periods where the driver is over the limit).

However, the comparison of mobile phones with alcohol impairment continues to attract researchers because of the already established thresholds and risks for alcohol impairment, which can now be used as a benchmark for distraction caused by mobile phones.

4.5.1.1. Burns et al. (2002)

The aim of the Burns et al. study was to quantify the distraction from hands-free and handheld phone conversations in relation to the impairment of driving performance caused by alcohol. 20 participants drove a 15 km route in a driving simulator in the control, handheld, hands-free and alcohol condition. The mobile phone was a NOKIA 3310, at the time the most popular/widely chosen handset on the UK market. The phone conversation task consisted of questions from the Rosenbaum Verbal Cognitive Test Battery that measures judgement, flexible thinking and response times. The test consists of 30 sentence memory task and 30 verbal puzzle tasks. The quantity of alcohol was individually determined for each participant (depending on age and body mass) so that drivers were moderately impaired according to the UK legal alcohol limit (0.8 g/l). The main result of this study in both phone conditions was that drivers tended to slow down (even when instructed to maintain a set speed), while alcohol had the opposite effect. When using a handheld phone, participants showed significantly more variations of speed as well as a poorer speed-keeping performance. Furthermore, in phone conditions drivers had slower reaction times to road signs as well as missing significantly more target signs. The fact that phone use impaired drivers' abilities to respond to warnings more than alcohol is the critical finding of this study. In general, although driving performance in the alcohol condition was worse than in the control condition, it tended to be better than the driving performance in both phone conditions. The subjective ratings of drivers also show that they found driving under the influence of alcohol easier than driving while using a phone. Although there are various problems involved in comparing impairments of driving performance caused by alcohol and those caused by phone conversations, the study concludes that although driving while intoxicated is clearly impaired, certain aspects of driving performance are even more impaired by mobile phone use.

4.5.1.2. Strayer, Drews & Crouch (2004)

In this simulator study, Strayer, Drews & Crouch compared the driving performances of 41 participants in baseline condition (single-task driving), while conversing on a mobile phone (both handheld and hands-free) and in the alcohol condition with the level of blood alcohol concentration of 0.8 g/l (legally intoxicated).

In both mobile phone conditions, participants were engaged in naturalistic conversations with a research assistant on topics identified earlier as being of interest to them. Results obtained on seven driving performance variables showed that both handheld and hands-free phone conversations impaired driving but that there were no significant differences between these two types of mobile phones.

Both mobile phone and alcohol conditions differed significantly from the baseline. When conversing on the mobile phone, drivers were involved in more rear-end collisions, brake reaction time was reduced by 8.8%, the variability in following distance increased by 24.5% and it took them 14.8% longer to recover the speed lost during braking. When legally intoxicated, participants drove more aggressively with closer following and 23.4% more braking force. Mobile phone and alcohol conditions also differed significantly from each other. The conclusion of this study is that when controlling for driving conditions and time-on-task, mobile-phone drivers may exhibit greater impairments than intoxicated drivers.

4.5.1.3. Summary and discussion

Although impairments caused by mobile phones can be as significant as those associated with driving legally intoxicated, the mechanisms of these two types of impairments are different. The mobile phone impairment is associated with the diversion of attention and is transitory, while impairment from alcohol persists for longer periods of time. With mobile phones, drivers can have some kind of control (e.g. pause in conversation); when drunk, drivers cannot do much to control their performance. Alcohol directly impairs drivers' judgment; phone use might delay or remove judgement, but it does not impair it as such.

4.5.2. *Comparisons with other sources of driver distraction*

4.5.2.1. Conversation with a passenger

One of the most frequently heard arguments against a mobile phone ban is that conversations on a mobile phone are no different from a conversation with a passenger. Nevertheless, opposite opinions also exist.

Conversations with passengers in the real world are self-paced in contrast to phone conversations. Phone conversations are generally deliberately initiated conversations and, compared with a conversation with a passenger, are more purposeful and goal-directed with a faster exchange of information. Because the passenger is present during the whole journey, a conversation with a passenger can be conducted in a less urgent manner.
In the case of a passenger conversation, the passenger himself is also aware of the driving situation and can sometimes even help draw attention to dangerous situations. In the case of a mobile phone conversation, the other person is generally not even aware that his/her conversation partner is driving. In their recent study, Crundall et al. (2005) tested this so-called conversation suppression hypothesis, i.e. in-car conversation can be modified to the demands of the roadway. They compared the number of utterances, words and questions across different types of roads (i.e. dual carriageway, rural, urban and suburban roads) in three conversation conditions: a passenger in a vehicle, a blindfolded passenger in a vehicle and a remote conversation on a mobile phone. The main result of this study is that the normal conversations with a passenger were suppressed on the most demanding urban roads, for both driver and passenger. On the other hand, the mobile phone conversation prevented suppression from occurring in the passengers' conversations and even encouraged drivers to make more utterances that they would normally do in a normal passenger conversation.

However, this does not mean that a conversation with a passenger does not have distraction potential too. The intensity of distraction naturally changes according to the intensity and content of the conversation, the type of passenger (adult, child) and also the type of driver. For example, for young novice drivers, the presence of their peers is particularly dangerous not just because of the conversation itself, but also because young people are often more prepared to take risks in the presence of their peers.

4.5.2.2. Listening to the radio

Although most vehicles are fitted with radios today, little research has been conducted into the distracting effects of a radio. Like a mobile phone, radio also places physical, visual, auditory and cognitive demands on the driver. It is also logical to assume that the distraction effects of different tasks required in the interaction with a radio differ and depend on the nature of these tasks (e.g. turning on/off, finding a station, listening to music or conversation).

Two of the analysed studies compared the effects of a mobile phone conversation and listening to a radio. These two studies suggest that listening to a radio impairs driving performance less than a mobile phone conversation. The study of Consiglio et al. (2003) showed that, although the reaction time in the radio condition was 4% slower than in the control condition, this was not a statistically significant difference. In the same line are the results of Strayer & Johnston (2001), who found no dual-task reduction in the case of listening to a radio broadcast. Nor was this the case in an additional experiment controlled for the listening to the broadcast material. It must be noted that these conclusions refer only to listening and not to the manipulating part of the radio task, which was not considered here. Nevertheless, even if the level of distraction caused by listening to a radio is lower than that caused by a mobile phone conversation, it is still an activity that can place additional demands on the driver’s attention.

4.6. Conclusions about the effects of mobile phones on driving performance

4.6.1. *Overall effects*

Distractions to drivers by secondary tasks or events such as mobile phone conversations can result in general or selective withdrawal of attention. Even if automatic behaviour is maintained, the event detection level can be degraded. The distractive effects of mobile phone use depend on the momentary context of driving. Phone use during undemanding driving periods seems easy; however, not only the driving context demands but also the content and demands of mobile phone conversations play a role in this process. The level of complexity of a phone conversation (its cognitive demands) is the main factor that also determines the extent of the effect of phone conversations on driving performance. The combination of these two factors may have negative consequences on traffic safety as it is impossible to predict both demanding driving situations and demanding mobile phone conversations.

What happens when a driver engages in a mobile phone conversation while driving? Many studies provide a similar answer to this question: using a mobile phone while driving negatively affects various aspects of a driver's performance. Regardless of the method used in these studies (e.g. simulator, closed-track or testing on the real road), the changes found in driving performance are similar. This allows the following summary of the demonstrated effects of mobile phone conversation on driving performance:

- *Slower reactions and more misses*
  The phone conversation results in a significant slow-down in reaction time regarding responses to traffic signals or other relevant traffic events. Mobile phone conversations also increase the probability of missing important traffic signals.

- *Braking*
  Braking reaction time has been found to be slower during a telephone conversation. Different studies found the decrease in reaction time ranged from 0.3 to approximately 0.7 seconds. During concurrent mobile phone use, drivers brake harder (they stop faster). Despite this more

intense braking, the stopping distance (i.e. distance between them and another vehicle, a stopping line or an intersection) is shorter.

– *General awareness of the other traffic*
  Situation awareness shows a significant drop in all its three elements (i.e. perception, comprehension and projection) due to the level of concentration demanded by in-vehicle phone conversation.

– *Riskier decision-making*
  Commonly encountered traffic situations (stopping at red light) tend to provoke conservative decision-making. However during less common or more complicated (difficult) events (e.g. weaving, left turns), a significant negative impact of conversation is detected. Drivers accept shorter gaps, make fewer speed adjustments and less adjustment to potentially dangerous road conditions such as slippery roads.

– *Compensatory behaviour*
  Besides the above changes in driving performance that are negative from a traffic safety point of view, some studies found that drivers engage in risk-compensatory behaviour during mobile phone use. The most obvious example is a slower average speed. The possible explanation for this compensatory behaviour could be the drivers' attempt to reduce performance goals, thus reducing driving task demands and the workload. However, although lowering their performance goals for mobility, drivers still report increased stress and effort. In some cases, a slower mean speed was accompanied by greater variations in speed, which again could be a sign of lowering the performance goal. There is another potential explanation for this behaviour: it could be the result of attention being diverted from driving goals to the phone conversation. Without sufficient attention resources for the primary task of driving, it can be expected that drivers will be less able to cope with emergency situations or other abrupt pressures on driving task demands. Even if drivers are engaged in risk compensation behaviour by lowering their performance standards, the newly accepted standards may still be significantly below the safety requirements of a momentary context of driving.

4.6.2. *Effects of handheld versus hands-free mobile phone*

The handheld versus hands-free feature continues to be one of the most investigated features in most of the studies examining the influence of mobile phone conversations on driving performance. The introduction of the ban on using handheld phones while driving in some countries additionally polarized this dichotomy. Is this type of legislation sending a message that hands-free phoning does not have a negative impact on traffic safety? It seems so. 70% of the public supports a ban on handheld phones, while 72% of the public believes use of hands-free mobile phones while driving should be legal (Gillespie & Kim, 2001). But does this type of legislation correspond with the results of behavioural studies?

The vast majority of studies conclude that hands-free phones do not have significant safety advantages over handheld ones. Although handheld units introduce an additional load on the driving task due to the need for manual manipulation of the phone, the most important negative factor of mobile

phone use remains the same for both types of phone: they divert attention from driving to the conversation itself. The impact of conversations on driving performance is the same for both handheld and hands-free phones. At the same time, not all hands-free phones require the same amount of physical manipulation to operate them. Thus in some models of hands-free phones, physical manipulation still can play important role.
Although hands-free phones solve some of the safety problems associated with dialling, holding, reaching for the phone, dropping the phone and steering the vehicle with one hand, one of the additional dangers of hands-free phones could be that drivers, encouraged by the deceptive eliminations of problems, decide to use hands-free phones more often and for longer than their previous handheld phones. A paradoxical consequence of the use of ’safe’ hands-free phones could then be the increased drivers' exposure to the general hazards of mobile phone use.

4.6.3. *Conversation*

The conversation tasks used in mobile phones studies vary in their nature, duration and difficulty. This is one of the potential sources of variation in the effects of mobile phone conversation found on driving performance. The complexity of a telephone conversation and its cognitive demands are important factors in determining the extent of the effect of a phone conversation on driving performance. The more difficult the conversation, the stronger its effects on driving performance. In order to increase the validity of the research results, the more natural conversation tasks are increasingly used in the research. Unfortunately, for these more naturalistic conversation tasks it is also more difficult to determine the exact level of difficulty.

4.6.4. *Driving context*

As already seen, the distracting effects of mobile phone use depend on the nature of the conversation. At the same time, however, they also depend on a momentary driving context. Phone use during undemanding driving periods seems easy, but with the increasing complexity and difficulty of driving situations, the effects of mobile phone conversation are more pronounced.

5. Effectiveness of countermeasures

Mobile phone use has been the focus of scientific research for years. The overall research results suggest that the use of a mobile phone while driving negatively affects driving performance and therefore increases the crash risk. In terms of victims, in the Netherlands alone the use of mobile phones while driving could have been responsible for almost 600 people injured or dead in traffic crashes in 2004 (see *5.2.2.4*). Numbers like that call for countermeasures, but despite the range of possible countermeasures for coping with the dangers of mobile phone use while driving, there is little data about their effectiveness. This chapter therefore emphasises legislation and enforcement as the most usual countermeasures against mobile phone use while driving. Although the data regarding their effectiveness were the most available, they were also quite limited.

But what are the opinions and attitudes of the public towards mobile phone use in vehicles? Does the public feel that mobile phone use while driving is dangerous and does it feel that legislation concerning mobile phone use in vehicles is needed?

5.1. Attitude and opinion towards mobile phone use and legislation

5.1.1. *Attitude towards mobile phone use*

A study of Lesch & Hancock (2004) focused on drivers' confidence in their ability with regard to mobile phone use and the relationship between their confidence level and the observed actual decrement in their driving performance.
Most participants (67%) reported feeling 'comfortable' dealing with distractions while driving, with younger and female drivers reporting greater confidence.
With regard to the relationship between actual performance and driver perceptions, there was little relationship between the two. Many drivers were relatively unaware of the decrements in their actual driving performance resulting from concurrent mobile phone use. This is especially true for female drivers and even truer for older female drivers. Here the confidence rating did not correlate with any of the examined performance measures. For male drivers, confidence was more related to the actual performance, while the confidence of male drivers decreased with increasing age.
Although the results of this study should be considered as suggestive because they are based on a relatively small number of participants and relatively 'rough' measures of confidence (scale from 1 to 4), it is obvious that there could be a gap between the possible effects of distraction and the consciousness of drivers about their ability to overcome them.
Nevertheless, it is easier for drivers to recognise impaired driving performance of others during concurrent mobile phone use and thus indirectly recognise the dangers of mobile phone use while driving.

5.1.2. *Opinion about legislation*

A positive public opinion is significant for the success of certain legislation. Taking into account mobile phone ownership rates, this is obviously the case for mobile phone legislation.

In 1999, Gallup conducted a poll concerning opinions on mobile phone regulations in Finland (Lamble, Rajalin & Summala, 2002). Here are some of the results:
- 25.2% of respondents thought there should be no restrictions on phone use while driving.
- 48.3% of respondents thought that handheld phones should be banned while driving.
- 26.5% of respondents thought that all types of phones should be banned while driving.

Those who were 'pro' some kind of regulations were generally more likely to be female, older (+45), living in city areas and driving without owning or using a mobile phone in their car. Those who did not want restrictions on mobile phone use were more likely to be male, young (<24), living in rural areas and already using a mobile phone while driving (Lamble, Rajalin & Summala, 2002).

In July 2001, a US Gallup poll found that 70% of the public supported a ban on handheld phones use by drivers. The results of an ABC News national poll were almost identical (69%) (Gillespie & Kim, 2001). At the same time, 72% of the public believed that the use of hands-free phones should be legal.

In the Netherlands, in 2001, one year before the ban on handheld mobile phones was implemented, the inquiry conducted by the Dutch Ministry of Transport, Public Works and Water Management found that the vast majority of respondents considered the use of handheld phone while driving to be dangerous. The use of hands-free phones was felt to be far less dangerous, with almost 50% of respondents considering the use of a hands-free phone as not dangerous at all (Feenstra et al., 2002). The results of PROV 2003 - the first inquiry after the ban on handheld mobile phones - are almost the same: 95% of respondents considered handheld mobile phones to be dangerous, while only 56% of respondents considered hands-free mobile phones to be dangerous (Van der Houwen, Hazevoet & Hendriks, 2004).

5.1.3. *Summary and discussion*

Drivers do not seem to be entirely aware of the effects of mobile phone use on their driving performance. They feel that they can cope with its distracting potential. It is easier for them to notice drops in other drivers' performance. However, there is a general public 'feeling' regarding the dangers associated with mobile phone use while driving and the need for restricting their use. It seems that the public considers hands-free phones to be largely 'danger-free'. It is possible that this kind of opinion is the result of current mobile phone laws. By prohibiting the use of handheld phones while allowing the use of hands-free phones, legislators are sending the message to the public that, in contrast to the handheld phones, hands-free phones are not dangerous.

5.2. Effectiveness of mobile phone legislation and its enforcement

5.2.1. *Mobile phone legislation*

Although the real world data on the contribution/causation of mobile phone use to traffic crashes are far from extensive, existing data and calls of scientific authorities were enough for most of the countries to introduce some kind of legislation regarding mobile phone use while driving.

At this point in time, one of the most frequently accepted policies is the law that specially regulates the use of handheld mobile phones in cars. *Table 5.1* shows an overview of existing legislation in some of the countries.

Country	Handhelds banned	Notes
Australia	Yes	Banned in all states - fines vary though.
Austria	Yes	Fines vary - up to US$22 per incident
Belgium	Yes	Phones can be used without a hands-free unit when the car is stationary - but not while in traffic (such as at traffic lights)
Brazil	Yes	Ban imposed Jan. 2001
Botswana	Being debated	The attorney general is drafting the legislation
Bulgaria	Yes	Ban imposed May 2002 - fines of US$15 per infraction
Canada	Variable	Banned in Newfoundland (Dec2002) fines up to US$180
Chile	Yes	
Czech Republic	Yes	
Denmark	Yes	Ban imposed July 1998 - US$60 fine for infringements
Egypt	Yes	Fines of about US$100 per offence.
Finland	Yes	Ban imposed January 2003 - US$55 fine for infringements
France	Yes	Ban imposed June 2003 - US$42 fine per infraction
Germany	Yes	Ban imposed Feb. 2001 - usage allowed without a hands-free unit only when the engine is switched off.
Greece	Yes	
Hong Kong	Yes	
Hungary	Yes	Fines up to US$20 per infraction
India - New Delhi	Yes	Ban extended to all use of mobile phones when driving, including use with a hands-free unit - July 2001
Ireland	Yes	Banned, with a US$380 fine and/or up to 3 months imprisonment on a third offence. Hands-free kits allowed, although that is subject to review.
Isle of Man	Yes	Banned since July 2000
Israel	Yes	
Italy	Yes	Fines of up to US$124 per infraction
Japan	Yes	Ban imposed Nov. 1999
Jersey	Yes	Ban imposed Feb. 1998
Jordan	Yes	Ban imposed Oct. 2001

Country	Handhelds banned	Notes
Kenya	Yes	Ban imposed late 2001
Malaysia	Yes	
Netherlands	Yes	
New Zealand	Being debated	Under debate - consultation being sought from interested parties
Norway	Yes	Fines of over US$600 per infraction
Pakistan	Partial	Banned in Islamabad
Philippines	Yes	
Poland	Yes	Fines can be as high as US$1,000
Portugal	Yes	
Romania	Yes	
Russia	Yes	Ban imposed by Prime Minister - March 2001
Singapore	Yes	
Slovak Republic	Yes	
Slovenia	Yes	
South Africa	Yes	
South Korea	Yes	Ban imposed July 2001 - US$47 fine + 15 points on the license.
Spain	Yes	Ban imposed 2002 - only fully fitted car kits are permitted.
Sweden	No	
Switzerland	Yes	
Taiwan	Yes	If the driver has a reflective screen on the car, local privacy laws forbid stopping the car for violating the ban.
Thailand	Yes	Bill proposed in May 2000
Turkey	Yes	
Turkmenistan	Yes	Signed into law with effect from May 1st 2003, by President Saparmyrat Turkmenbasy
UK	Yes	Banned from December 2003
Zimbabwe	Yes	Ban imposed in Sept 2001, announced via official news agency only though, so not confirmed

Table 5.1. *Overview of existing mobile phone legislation in various countries (source: www.cellular-news.com/car_bans/; last update 04/10/2004).*

In the USA, there are several different types of laws and regulations that address the use of mobile phone while driving. Regulations range from bans (in New York), restricted use of head-sets, prohibiting school bus drivers from using phones while driving the school bus (Arizona, Arkansas, Illinois, Massachusetts, New Jersey, Rhode Island and Tennessee), forbidding drivers under age of 21 who only have a learner's permit from using any type of mobile phone while driving (Maine and New Jersey), to requirements for data collection. Data collection is the most common existing policy with at least 17 states now requiring law enforcement officers to collect information about mobile phone involvement in a crash. However, federal US government has not acted on the distracted driving issue.

Beside regulations specifically concerning the use of mobile phones while driving, most other countries have general regulations regarding careless or dangerous driving which can be applied in the case of mobile phone use (e.g. Multitasking statement, Highway code, etc.).

5.2.2. *Effectiveness of legislation and enforcement*

Although the ban on the use of handheld mobile phones while driving is the most frequent type of legislation together with the enforcement, there are still very few data on the effectiveness of these measures.

5.2.2.1. Japan

Regarding the effects of the mobile phone ban on crash involvement, at this moment only Japan has published an evaluation of the effect of its legislation on crashes involving drivers using mobile phones. Results from Japan show a substantial reduction in the number of crashes involving mobile phone use (-52%), in the number of people injured in such crashes (-53%) and in the number of people killed in mobile phone crashes (-20%) (RoSPA, 2002).

5.2.2.2. USA, short and long-term effects

The following two American studies (McCartt, Braver & Geary, 2003 and McCartt & Geary, 2004) are some of the rare attempts to investigate not only the immediate effects of the mobile phone ban, but also to investigate the long-term effectiveness of this type of legislation.
In November 2001, the state of New York was the first state in the US to ban handheld mobile phone use while driving (Mc Cartt, Braver & Geary, 2003) The law was accompanied by considerable publicity and it included a one-month warning phase and a three-month period in which fines could be waived if a driver could provide proof of purchase of a headset or speakerphone. The results of this study show that New York's ban had the intended result during the first months after it became effective. Observational data show that the percentage of drivers using handheld mobile phones declined significantly from 2.3% before the law to 1.1% after one month of the law being implemented. After four months, use was still at the same level of 1.1%. Overall reduction in mobile phone use in the period prior to the law to after the fine-without-waiver phase was 52%. The results of TRL surveys (TRL, 2004) showing a 40% decrease in the use of handheld phones four months after the ban became effective in the UK (December 2003) are in line with the results of McCartt, Braver & Geary, (2003). However, although the ban affected the use of handheld mobile phones, the effects of this ban on road crashes remained unknown.

The short-term effects of the New York law banning the use of handheld mobile phones while driving were substantial. To find out about the long-term effects of 'the cell phone law', McCartt & Geary (2004) observed drivers' handheld mobile phone use again in March 2003, one year after the law took full effect. The use of handheld mobile phones had risen to 2.1%. This level of use is significantly higher than the short-term compliance rate and does not differ significantly from the pre-law rate. Initial publicity about the law declined and there was no publicised targeted enforcement campaign that, according to McCartt & Geary, seems essential to achieve longer-term compliance with bans on mobile phone use by drivers. This study indicates that the long-term compliance with the ban on handheld mobile phone use will be a challenge for communities and states enacting such laws.

5.2.2.3. The Netherlands

Since 30 March 2002, Article 61a of RVV 1990 (the Dutch Highway Code), which regulates the use of mobile phones while driving in the Netherlands stipulates the following regulation: *"Het is degene die een motorvoertuig, bromfiets of gehandicaptenvoertuig bestuurt verboden tijdens het rijden een mobiele telefoon vast te houden."* Thus, the use of handheld mobile phones while driving is forbidden in the Netherlands. What are the effects of this ban? Do Dutch drivers comply with this law? One of the possible answers to this question can be found in the increased number of fines issued for the use of handheld phones while driving.

When considering the number of issued fines, it seems that the effectiveness of Dutch legislation follows an already recognised trend. Since the introduction of the ban on the use of handheld phones in the Netherlands in April 2002, the number of fines for using a handheld mobile phone while driving has risen significantly each year. However, without data on the intensity of enforcement, the question remains whether this increase is only due to increased mobile phone use or whether the intensity of enforcement in that period played a role too.

Period	Fines issued
April-December 2002	25,000
January-August 2003	55,000
January-December 2004	100,000

Table 5.2. *The number of fines issued in the Netherlands for using a handheld mobile phone while driving (source: BVOM, Bureau Traffic Enforcement of the Public Prosecution Service).*

5.2.2.4. Estimated number of traffic victims in the Netherlands resulting from mobile phone use while driving

In order to find out about the impact of using a mobile phone while driving in real life and what effective countermeasures could mean in terms of human lives, here is an estimate of the number of traffic victims who could have been saved in the Netherlands if mobile phones were not used in vehicles. This estimate is based on calculations by Oei (1998) and refers to 2004, this being the most recent year for which data were available at the time of this report.

Estimated use of mobile phones in vehicles in the Netherlands
As already discussed in the second chapter, there are still no data about the real use of mobile phones by drivers while driving in the Netherlands.

However, data about drivers' use of mobile phones from several surveys conducted in other European countries, as well in the US and Australia, are available.

The latest US results from 2004 show that at any given moment during a day, 8% of drivers are using some form of mobile phone in their vehicles (Glassbrenner, 2005). In the UK, in the last TRL survey from September 2004, it was found that 3.8% of drivers use mobile phones (handheld and hands-free phones taken together). With regard to Sweden, estimates by Thulin and Ljungblad from 2001 are that about 2% of total driving time in Sweden has been done while using a mobile phone (cited in Kircher et al., 2004).

Considering the fact that mobile phone use is generally higher in the US than in the Netherlands and taking into account the similarities between the Netherlands and European countries like the UK and Sweden, as well as the estimates made for Sweden four years ago, the percentage of total driving time in the Netherlands spent while using a mobile phone has been estimated at 3%. Assuming that time corresponds to distance, 3.2 billion kilometres in the Netherlands were covered by drivers using a mobile phone in 2004.

Estimated risk of using a mobile phone while driving
As discussed in the third chapter, the estimates of epidemiological studies aimed at determining the risk of mobile phone use while driving range from approximately 2 to 9. However, the most cited study of Redelmeier & Tibshirani (1997a) estimated the risk of collision when using a mobile phone to be four times higher than the risk when a mobile phone was not being used. The same factor 4 applies to the users of both hands-free and handheld phones. The latest epidemiological study performed in Australia (McEvoy et al. 2005), confirmed the Redelmeier and Tibshirani's estimates with the same finding that a person using a mobile phone when driving is four times more likely to have a crash that will result in hospitalisation. Based on these sound results, the value of the risk of using a mobile phone while driving has been taken as 4.

Total number of kilometres driven in the Netherlands in 2004
According to Statistics Netherlands (CBS), the total number of kilometres driven in the Netherlands in 2004 (by passenger, taxi and delivery vehicles) was 106.2 billion kilometres.

The number of traffic victims in the Netherlands in 2004
In 2004, the number of victims (dead and injured) from road crashes involving at least one car was 7,086. We can relate this number of victims to the number of kilometres driven *without* use of a mobile phone and the number of kilometres driven *with* a mobile phone according to the following formula (see Oei, 1998):

$$\frac{\textit{Number of victims}}{\textit{Kilometres driven without mobile phone + (kilometres driven with mobile phone x risk factor)}}$$

This rate expresses the number of victims per kilometre, driven without use of a mobile phone. For the Dutch situation in 2004, this rate corresponds to:

$$\frac{\textit{7,086 victims}}{\textit{(106.2 – 3.2) billion km + (3.2 billion km x 4)}} = \textit{61.2 victims per billion km}$$

That means that the risk for driving without using a phone is 61.2 victims per billion kilometres. Therefore, the number of victims in 2004 if no mobile phone were used would be 6500 (*61.2 x 106.2 billion km = 6500*). The difference between the real number of victims in 2004 (injured and dead taken together) and the number of victims if no mobile phone were used while driving is 585. That means that in 2004, if no mobile phones had been used in the Netherlands while driving, 585 people would have been saved from injury or death resulting from road crashes. This means that the use of mobile phone while driving was responsible for 8.3% of the total number of injured and dead traffic victims in the Netherlands in 2004.

Comparing this number of 585 for 2004 with the corresponding 127 for 1995 (see Oei, 1998), there is an increase of approximately 4.5 times in the number of potential victims.

5.2.3. *Summary and discussion*

In most countries, the ban on handheld phones while driving seems to be the most popular measure for regulating mobile phone use while driving. However the results of behavioural studies showing that there is no significant difference in the effects of handheld and hands-free phones do not seem to justify this form of legislation. The effectiveness of this and other types of mobile phone legislation on the level of use and even more on crash rates are still not very well known. Although some results show that the short-term effects of these laws on the level of use could be significant and led to approximately 50% reduction, the long-term effects seem to be far less positive: after one year the level of use could even return to the same level as before the law.

However, McCartt & Geary (2004) and Horberry et al. (2001) indicate that the effectiveness of legislation could be increased if supported by publicity campaigns.

6. Conclusions and recommendations

A mobile phone has become one of the most common devices present in vehicles today, with more than two thirds of drivers using a mobile phone at least sometimes while driving. Parallel with these increasing numbers and increased use of mobile phones in traffic, the concerns about their potential negative effects on traffic safety were also rising with the significant body of research focused on consequences of mobile phone use while driving.

In general, conclusions of behavioural studies are that the use of mobile phone negatively affects different aspects of a driver's performance. Reactions to traffic signals are slower, braking reactions are slower with shorter stopping distances, drivers miss more important traffic signals, they are inclined to riskier behaviour like accepting shorter gaps or making fewer speed adjustments or adjustments to dangerous road conditions.

These negative effects on driving performance are caused by physical, visual, auditory and cognitive distraction as a result of mobile phone use. Although the physical distraction could be reduced or even limited by various 'technical' aids like hands-free phones, speed dialling, voice activation, etc., the cognitive distraction remains the main problem involved in concurrent mobile phone use. This is why hands-free mobile phones do not have significant safety advantages over handheld mobile phones. The extent of the negative effects of mobile phone use while driving depends on the complexity of both mobile phone conversations and of the momentary driving situation. The more difficult and complex the conversation, the stronger its effects on driving performance. Similarly, phone use during undemanding driving periods might appear easy but with the increasing complexity and difficulty of the driving situation, the effects of mobile phone conversation become more pronounced.

In terms of crash risk, there is increasing agreement that drivers who use mobile phones in their vehicle have a four-times higher risk of having a road crash than drivers who do not.

Although current research only focuses on the influence of mobile phone conversations on the performance of car drivers, the question about mobile phone use in traffic by other road users like cyclists and pedestrians could be also raised. Although there has not yet been any research into the effect of mobile phone conversations on the behaviour of these categories of road users, and although the demands of their traffic tasks are far lower than those of drivers of motorised vehicles, everyday experience and the nature of interference caused by mobile phone conversations lead to the conclusion that mobile phone conversations could have a detrimental effect on the road behaviour of these road users too. Therefore, cautious use of mobile phones in traffic by these types of road users could be also recommended.

In order to better determine, control and diminish the effects of mobile phone use on road safety, several recommendations can be given:

- For better insight into the problem of mobile phone use while driving, it is necessary to establish the extent of drivers' use of mobile phone more precisely in order to generate more precise data regarding the exposure of drivers to the risk of mobile phone use.

- Mobile phone use should be recorded in accident reports in order to be able to really estimate the share of mobile phone crashes in the total number of crashes.

- Make drivers more aware of the dangers of mobile phone use and of other various distracting activities; drivers could be unaware of the decrements in their driving performance (Lesch & Hancock, 2003). Make this an official part of the driving curriculum. Drivers must be educated about the possible effects of distraction and their relative ability to compensate for it. Furthermore, give drivers practical recommendations on how to deal with mobile phones in their vehicle: never use a mobile phone in traffic but if you have to use it, stop the vehicle first.

- Design the Human-Machine Interface as ergonomically as possible so that if the mobile phone has to be used, it can be used as safely as possible.

- Develop precise criteria and methodologies for assessing the safety implications of in-vehicle information systems (IVIS), including mobile phones.

A number of standards and guidelines addressing the safety of telematics devices in general have already been published or are presently in development: ISO standards, Human Factor Process Standards, UK guidelines, European Statement of Principle on Human Machine Interface, Japan Automobile Manufacturers Association Guidelines and the Alliance of Automobile Manufacturers Statement of Principles, etc. Most of these guidelines are in the form of checklists that are under-specified, incomplete and do not enable quantification of safety problems. An additional problem is that compliance with these checklists is mainly voluntary.

The new initiative to help make valid, reliable and efficient tools that will help testing authorities in their safety evaluation of IVIS in general is the recently completed European project HASTE (Human machine interface And the Safety of Traffic in Europe) aimed to develop methodologies and guidelines for the assessment of in-vehicle information systems (IVIS). The HASTE project is especially significant as it attempts to differentiate between the effects of visual and cognitive distraction while attempting to carefully control the 'dose' of distraction inflicted at the time. However, one of the conclusions of the HASTE project is that it still remains extremely difficult, if not impossible, to translate the observed effects into some general safety criterion that can serve as benchmark for assessing the safety of an IVIS in actual use (e.g. mobile phone; Carsten & Brookhuis, 2005).

- Base legislation regarding mobile phone use on scientific evidence. If hands-free phones are not as safe as the ban of only handheld phones implies, draw attention to the dangers of using hands-free phones too. Pay additional attention to special categories of drivers like novice or bus drivers.

- Support company policies such as those imposing a complete ban on the use of mobile phones while driving (as is the case with some petrochemical companies in the Netherlands) and other kinds of policies contributing to the corporate safety culture.

- Use the ’technology against technology’ principle. With new technologies becoming available every day, it is not difficult to imagine that technology could also provide the answer to solving the problem of driver distraction (at least partly). Regarding the use of mobile phones, solutions can range from allowing drivers more time to answer incoming calls without being distracted by continuous ringing tones, designing complex human-machine interfaces that would regulate driver in-vehicle systems interaction based on, for example, the momentary level of driver workload and the momentary level of the driving task demands, automatically postponing the connection of incoming calls to a more appropriate moment, automatically enabling the use of mobile phone for some categories of drivers or especially dangerous segments of the road or other traffic or weather circumstances.

References

Braimaister, L.G. (2002). *Mobile computers in cars and possible road safety effects; An inventory*. R-2002-26. SWOV, Leidschendam.

Burns, P.C. et al. (2002). *How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol*. TRL 547. Transport Research Laboratory, Crowthorne.

Carsten, O. & Brookhuis, K. (eds.) (2005). *The relationship between distraction and driving performance; Towards a regime for in-vehicle information systems*. Special issue of Transportation Research Part F, vol. 7, no. 2, p. 75-196.

Consiglio, W. et al. (2003). *Effect of cellular telephone conversations and other potential interface on reaction time in a braking response*. In: Accident Analysis and Prevention, vol. 35, no. 4, p. 495-500.

Cooper, P.J. et al. (2003). *The impact of hands-free message reception/response on driving task performance*. In: Accident Analysis and Prevention, vol. 35, no. 1, p. 23-35.

Crundall, D. et al. (2005). *Regulating conversation during driving: a problem for mobile telephones?* In: Transportation Research Part F, vol. 8, no. 3, p. 197-211.

Eby, D.W. & Vivoda, J.M. (2003). *Driver hand-held mobile phone use and safety belt use*. In: Accident Analysis and Prevention, vol. 35, no. 6, p. 893-895.

Feenstra W. et al. (2002). *PROV 2001 - Periodiek Regionaal Onderzoek Verkeersveiligheid*. TT 02-052. Traffic Test, Veenendal.

Gillespie, W. & Kim, S-E. (2001). *Cellular phone use while driving; should it be banned or restricted in Georgia?* In: Public Policy Research Series, vol.2, no. 6, Carl Vinson Institute of Government, Athens, Georgia. (http://www.cviog.uga.edu/publications/pprs/84.pdf).

Glassbrenner, D. (2005). *Driver cell phone use in 2004 – overall results*. Research note DOT HS 809 847. Department of Transportation, National Highway Traffic Safety Administration NHTSA, Washington, D.C.

Green Flag (2000). *The Green Flag Report on Safe Driving*. Green Flag Motoring Assistance, London.

Hahn, R.W. & Tetlock, P.C. (1999). *The economics of regulating cellular phones in vehicles*. Working Paper 99-9. AEI-Brookings Joint Center for Regulatory Studies, Washington, D.C.

Haigney, D.E., Taylor, R.G. & Westerman, S.J. (2000). *Concurrent mobile (cellular) phone use and driving performance; Tasks demand characteristics* *and compensatory processes*. In: Transportation Research Part F, vol. 3, no. 2, p. 113-121.

Hancock, P.A., Lesch, M. & Simmons, L. (2003). *The distraction effects of phone use during a crucial driving maneuver*. In: Accident Analysis and Prevention, vol. 35, no. 4, p. 501-514.

Horberry, T. et al. (2001). *Drivers' use of hand-held mobile phones in Western Australia*. In: Transportation Research Part F, vol. 4, no. 3, p. 213-218.

Houwen, H.K. van der, Hazevoet, A.M. & Hendriks, V.M.W. (2004). *PROV 2003 - Periodiek Regionaal Onderzoek Verkeersveiligheid*. TT 04-028. Traffic Test, Veenendaal.

Kircher, A. et al. (2004). *Mobile telephone simulator study*. VTI meddelande 969A. Swedish National Road and Transport Research Institute. Linköping.

Laberge-Nadau, C. et al. (2003). *Wireless telephones and the risk of road crashes*. In: Accident Analysis and Prevention, vol. 35, no. 5, p. 649-660.

Lamble, D. et al. (1999). *Cognitive load and detection thresholds in car following situations; safety implications for using mobile (cellular) telephones while driving*. In: Accident Analysis and Prevention, vol. 31, no. 6, p. 617-623.

Lamble, D., Rajalin, S. & Summala, H. (2002). *Mobile phone use while driving: public opinions on restrictions*. In: Transportation, vol. 29, no. 3, p. 223-236.

Lesch, M.F. & Hancock, P.A. (2004). *Driving performance during concurrent cell-phone use; are drivers aware of their performance decrements?* In: Accident Analysis and Prevention, vol. 36, no. 3, p. 471-480

Lissy, K.S. et al. (2000). *Cellular Phone use While Driving: Risks and Benefits*. Harvard Centre for Risk Analysis, Harvard School of Public Health. Boston, MA.

Liu, B. & Lee Y. (2005). *Effects of car-phone use and aggressive disposition during critical driving maneuvers*. In: Transportation Research Part F, vol. 8, no. 4/5, p. 369-382.

Matthews, R., Legg, S. & Charlton, S. (2003). *The effects of cell phone type on drivers' subjective workload during concurrent driving and conversing*. In: Accident Analysis and Prevention, vol. 35, no. 4, p. 451-457.

McCartt, A.T. & Geary, L.L. (2004). *Long-term effects of New York State's law on drivers' handheld cell phone use*. In: Injury Prevention, vol. 10, no. 1, p. 11-15.

McCartt, A.T., Braver, E.R & Geary, L.L. (2003). *Drivers' use of handheld cell phones before and after New York State's cell phone law*. In: Preventive Medicine, vol.36, no. 5, p. 629-635.

McEvoy, S.P. et al. (2005). *Role of mobile phones in motor vehicle crashes resulting in hospital attendance; a case-crossover study*. In: British Medical Journal, July 12, 2005.

Oei, H. (1998). *Telefoneren in de auto en verkeersveiligheid*. R-98-41, SWOV. Leidschendam.

Parkes, A. & Hooijmeijer, V. (2000). *The influence of the use of mobile phones on driver situation awareness*. Available at http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/2.PDF

Patten, C.J.D. et al. (2004). *Using mobile telephones; cognitive workload and attention resource allocation*. In: Accident Analysis and Prevention, vol. 36, no. 3, p. 341-350.

Poysti, L., Rajalin, S. & Summala, H. (2005). *Factors influencing the use of cellular (mobile) phone during driving and hazards while using it*. In: Accident Analysis and Prevention, vol. 37, no. 1, p. 47-51.

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

Redelmeier D.A. & Tibshirani R.J. (1997a). *Association between cellular-telephone calls and motor vehicle crashes*. In: The New England Journal of Medicine, vol. 336, no. 7, p. 453-458.

Redelemeir, D.A. & Tibshirani, R.J. (1997b). *Is using a car phone like driving drunk?* In: Chance, vol. 10, no. 2, p. 5-9.

RoSPA (2002). *The risk of using a mobile phone while driving.* The Royal Society for the Prevention of Accidents RoSPA, Birmingham.

Strayer, D.L. & Johnston, W.A. (2001). *Driven to distraction; Dual-task studies of simulated driving and conversing on a cellular telephone*. In: Psychological Science, vol. 12, no. 6, p. 462-466.

Strayer, D.L., Drews, F.A. & Johnston, W.A. (2003). *Cell phone induced failures of visual attention during simulated driving*. In: Journal of Experimental Psychology: Applied, vol. 9, no. 1, p. 23-32.

Strayer, D.L., Drews, F.A. & Crouch, D.J. (2004). *A comparison of the cell phone driver and the drunk driver*. Working Paper 04-13, AEI-Brookings Joint Center for Regulatory Studies, Washington, D.C.

Sullman, M.J.M. & Baas, P.H. (2004). *Mobile phone use amongst New Zealand drivers*. In: Transportation Research Part F, vol. 7, no. 2, p. 95-105.

Sundeen, M. (2001). *Cell phones and highway safety: 2001 State legislature update*. In: National Conference of State Legislatures, August 2001, Washington, D.C.

Tornros, J. & Bolling, A. (2005). *Mobile phone use – Effects of handheld and hands-free phones on driving performance*. In: Accident Analysis and Prevention, vol. 37, no. 5, p. 902-909.

TRL (2002). *Mobile phone use by car drivers, 2000-2002*.TRL LF2088. Transport Research Laboratory, Crowthorne.

TRL (2004). *Mobile phone use by drivers, 2002-2004*. TRL LF2094. Transport Research Laboratory, Crowthorne.

Utter, D. (2001). *Passenger vehicle driver cell phone use; Results from the fall 2000 national occupant protection use survey*. DOT HS-809-293. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington.

Violanti, J.M. & Marshal, J.R. (1996). *Cellular phones and traffic accidents: An epidemiological approach*. In: Accident Analysis and Prevention, vol. 28, no. 2, p. 265-270.

Violanti, J.M. (1998). *Cellular phones and fatal traffic collisions*. In: Accident Analysis and Prevention, vol. 30, no. 4, p. 519-524.

Wang, J-S., Knipling R.R. & Goodman M.J (1996). *The role of driver inattention in crashes; new statistics from the 1995 Crashworthiness Data System*. In: 40th Annual Proceedings Association for the Advancement of Automotive Medicine AAAM, 7-9 October 1996, Vancouver, British Columbia, p. 377-392.

The list of consulted web-sites:

www.cellular-news.com
www.ctia.org
www.itfacts.biz
www.mobiletechnews.com
www.monet-info.nl