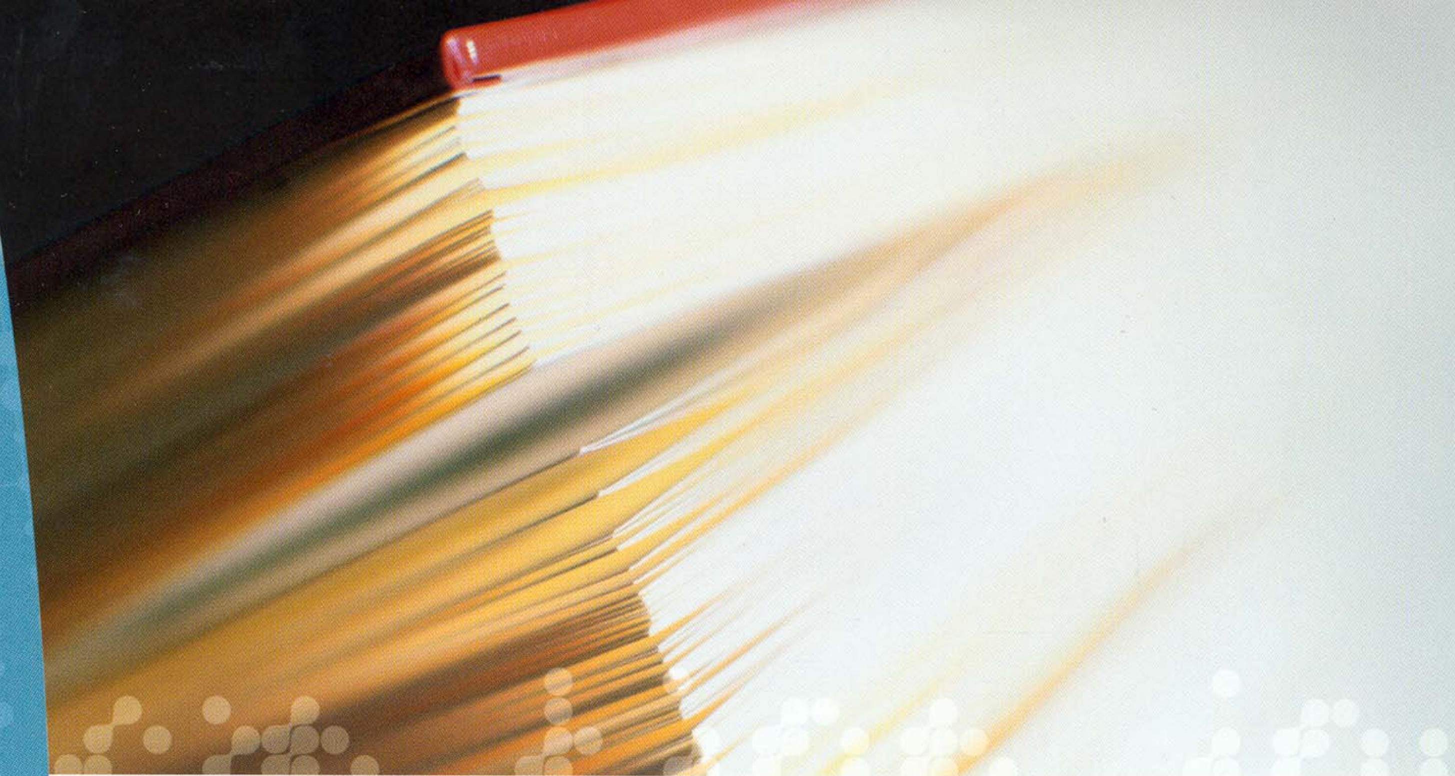

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PUBLIC HEALTH ADVISORY ON THE EFFECTS OF CELL PHONE USE WHILE DRIVING, WITH RECOMMENDATIONS

INSTITUT NATIONAL DE SANTÉ PUBLIQUE DU QUÉBEC

Québec

ADVISORY

PUBLIC HEALTH ADVISORY ON THE EFFECTS OF CELL PHONE USE WHILE DRIVING, WITH RECOMMENDATIONS

DIRECTION DÉVELOPPEMENT DES INDIVIDUS ET DES COMMUNAUTÉS

MARCH 2008

Institut national de santé publique Québec

AUTHORS

Étienne Blais
Unité sécurité et prévention des traumatismes
Direction développement des individus et des communautés
Institut national de santé publique du Québec

Assistant Professor
École de criminologie – Centre international de criminologie comparée
Université de Montréal

Diane Sergerie, Scientific Advisor
Unité Sécurité et prévention des traumatismes
Direction Développement des individus et des communautés
Institut national de santé publique du Québec

UNDER THE COORDINATION OF

Pierre Maurice, M.D., M.B.A., FRCP
Unité Sécurité et prévention des traumatismes
Direction Développement des individus et des communautés
Institut national de santé publique du Québec

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- François Bellavance – École des hautes études commerciales and the Centre for Research on Transportation
- Luc Lefebvre – ministère du Transport du Québec
- Léandre Bernier – ministère du Transport du Québec
- Lyne Vézina – Société de l'assurance automobile du Québec
- Claude Dussault – ministère de la Santé et des Services sociaux

We would like to offer our sincere thanks to the members of this committee for their generosity with their time and for the carefully formulated advice they provided throughout the preparation of this advisory.

SUMMARY

Still too many traffic victims!

From a public health perspective, there are still far too many road victims due to collisions that are mostly preventable: 704 deaths and 6,397 serious injuries, according to the SAAQ (2005). Their road safety statistics covering the five years from 2000 to 2005 show a general upward trend in Quebec. Indeed, the number of victims killed rose by more than 9% between 2004 and 2005, and serious injuries rose by 14.2%. In the hospital network, this represents an average of more than 4,000 hospitalizations per year (INSPQ, 2006).

The significant gains achieved over the last twenty years are mainly due to programs aimed at reducing the incidence of driving while impaired by alcohol (DWI), entrenching the use of seatbelts, and encouraging the construction of safer vehicles. However, several factors that have not been approached in the same way are currently reducing road safety in Quebec. Generalized disregard for the legal speed limit on the entire road network as well as driving while impaired by alcohol (DWI) can partly explain the stagnation, if not the worsening, of statistics. Included among these problems is the proliferation of in-vehicle sources of distraction; among these is the cell phone. Quebec has not escaped the global phenomenon of the cell phone craze. In Canada, the number of subscribers to wireless telecommunications services went from 6,000 to 17,000,000 between 1985 and 2005. Recent surveys report that more than 50% of Quebeckers who own a cell phone use it while driving, the equivalent of one driver in four. This advisory examines this behaviour and answers the following question: Does cell phone use while driving increase the risk of traffic collision and personal injury?

Other questions are also addressed:

1. Do “hand-held” and “hands-free” devices have the same effects on performance and collision risk?
2. Are the effects linked to cell phone use while driving similar to those linked to other sources of distraction (radio, conversation, other on-board devices and telematics)?
3. Does practice have an impact upon risk?
4. Should cell phone use while driving be banned and what effective measures can be taken to eliminate this risk?

To answer these questions, we systematically reviewed the scientific literature on the subject. Databases, web pages and road safety experts were consulted as part of our effort to locate and select studies and documents deemed relevant. Our overall conclusions are based on the application of strict review criteria to relatively homogenous populations of studies. The convergence of results from studies using a variety of methodologies and different data sources makes it possible to determine with increased validity the risk generated by this on-road behaviour (Simpson, 2005).

Analyses of the literature have made it possible to establish the impact of cell phones on driving performance, on-road behaviour and the risk of collision. The respective effects of hand-held and hands-free devices have also been established. And finally, the results of measures that have been taken to limit the risk associated with cell phone use while driving have been analyzed.

Cell phone use while driving deteriorates driving performance and increases collision risk

All of the studies reviewed pointed in the same direction: cell phone use while driving deteriorates driving performance and increases collision risk. Certain tasks, referred to as “primary” tasks, are essential to driving a motorized vehicle. Cell phone use constitutes a “secondary” task. And, according to the results of experimental studies that evaluate the effect of cell phone use on driving performance, it is harder for drivers to carry out the primary tasks essential to driving a vehicle when they are talking on a cell phone. This performance deterioration translates into slower braking reaction time, more difficulty in staying centered in a lane, a reduced field of vision, and reduced ability to avoid on-road obstacles, among other things. In short, cell phone use negatively affects cognitive, visual and biomechanical tasks. According to performance measurements, cell phone use has a greater effect on cognitive and visual tasks than on biomechanical ones.

This deterioration in performance results in an increased risk of collision. In fact, according to all of the epidemiological studies consulted, cell phone users have higher collision rates than non-cell phone users. These studies also show that risk increases with use. Frequent cell phone users run a higher risk of being involved in a collision than sporadic users. Other studies using various methodologies support these conclusions. Three studies have determined that people who use their cell phones while driving increase their risk of collision approximately fourfold. Moreover, it has been shown that this difference is not due to an increased propensity for risk-taking among these users. A Quebec study has demonstrated that before obtaining cell phones, current cell phone users had a collision rate comparable to that of non-cell phone users. Following their subsequent acquisition of cell phones, their collision rate rose. Not only does this same study show that cell phones increase the risk of collision, it also satisfies the criteria required for the assumption of causal inference between cell phone use while driving and collision risk.

Hand-held or hands-free devices: the risk of collision is the same

Both experimental and epidemiological studies demonstrate that hands-free devices affect driving as much as hand-held devices. Although performance deterioration affects all tasks, the distraction caused by cell phones is mainly cognitive. Thus, the distraction caused by cell phones cannot be eliminated by removing the manual tasks related to hand-held devices.

Even with practice, the risk endures

More in-depth analyses have shown that the element of distraction persists even when participants follow the same route several times during experiments. While participants sometimes improve from one session to the next, performance is always inferior when participants are using cell phones, compared to performance under the control condition of driving without distractions.

Other sources of distraction and the risk of collision: insufficient proof

While cell phones are not the only source of distraction while driving, the majority of studies focus on this device. Because of a scarcity of studies and the disparity of results, it is impossible to compare the effects of cell phones to that of other telematics or to make conclusive statements about the effects of other telematics and on-board devices on driving. We can, however, postulate that the use of any device that involves a secondary task and requires as much cognitive, visual or biomechanical attention as a cell phone would have similar effects on performance and the risk of collision. Thus, the use of speech-based e-mail systems would affect driving as much as cell phone use.

Finally, to trivialize the issue, people often compare cell phone use to listening to the radio or conversing with a passenger. However, the results of the studies reviewed lead to the conclusion that listening to the radio or conversing with a passenger is less detrimental than talking on a cell phone. Moreover, passengers can adapt their verbal output to the difficulty of the driving task, a phenomenon that does not occur during phone conversations. Passengers also have the advantage of being able to see the road, and will end a conversation if the driver’s task becomes more difficult.

In general, passive activities that do not require any reaction from drivers do not draw on cognitive resources and, therefore, allow drivers to focus all of their attention on driving. On the other hand, actions requiring responses that draw upon drivers’ cognitive resources risk compromising their safety.

Cell phone use while driving: a behaviour that should be banned

In order to regulate cell phone use while driving, numerous jurisdictions have enacted laws. Five studies have evaluated the effects of legislation, either on the rate of hand-held cell phone use or on collision rates. Some studies report a decrease in the rate of hand-held cell phone use following the introduction of a law and then a return to the initial rate that existed prior to the law’s enactment. However, these evaluations have many shortcomings. Analyses are often based on a simple before/after comparison and do not take into account other factors that may have influenced cell phone use or collision rates. For example, cell phone sales are on the rise. It is plausible that the laws do not reduce the rate of use, but stabilize it or slow its progression. However, this hypothesis is not considered in the studies. Moreover, these laws are often introduced without any supportive measures, thus limiting their potential effectiveness. The only study that has examined the effect of these laws on collision rates was carried out in Japan. According to this study, the number of collisions associated with cell phones fell by over 50% and fatal collisions went down by 20% following the enactment of a law banning the use of hand-held cell phones. However, in the absence of details making it possible to determine whether other measures introduced simultaneously had an impact on results, the same reservations apply to this study as to the others.

Even though many studies suggest that cell phone use while driving represents a risk factor, this behaviour is not yet regulated in Quebec. This subject has been much discussed in the media, with a series of “perspectives” conveying the idea that there is an absence of consensus about the risks associated with cell phone use while driving. However, a survey conducted in June 2006 indicates that 93% of Quebeckers think that cell phone use while driving should be banned, and more than half of these are in favour of a complete ban (INSPQ, 2006).

In light of the results of the empirical studies and the favourable climate of opinion, the Institut national de santé publique du Québec (INSPQ) maintains that cell phone use while driving represents a significant risk to road users and has formulated three recommendations.

Recommendation 1: A total ban on cell phone use while driving

In light of the main conclusions of this advisory, the INSPQ maintains that the task of driving is, by itself, sufficiently complex and that cell phone use while driving serves only to significantly increase the risk of collision, regardless of the type of device used. The scientific literature is unequivocal: using a hands-free device does not diminish the distraction associated with cell phones, because the distraction is mainly cognitive and visual in nature.

Given that cell phone use while driving:

- does not aid driving;
- adversely affects driving performance, particularly with respect to cognitive and visual tasks; and
- significantly increases the risk of road collision and personal injury,

the INSPQ recommends that cell phone use while driving should be completely banned.

Even though virtually all jurisdictional laws ban only hand-held devices, these laws are inconsistent with the scientific literature and may even have a detrimental effect. It is not the manipulation of the cell phone as such that distracts drivers. Rather, it is the act of conversing on the telephone. Laws that only ban hand-held devices convey the message that cell phone use is safe as long as the driver’s hands are free, which is false. Studies have shown not only that visual and cognitive distraction persists, but also that the poor quality of hands-free devices amplifies the distraction (Matthews *et al*., 2003). Our recommendation is also aligned with the opinion of Canadian and Quebec drivers, who, in a proportion of 2/3, see cell phone use while driving as a serious or extremely serious road safety problem (Beirness *et al*., 2002). Also, the 2006 INSPQ survey mentioned above reveals that 93% of Quebeckers are in favour of a law regulating cell phone use while driving. Finally, these recommendations in no way detract from the advantages of cell phones, including the ability to contact emergency services in case of collision or to report crimes to police. Drivers would simply have to pull over to the side of the road to make a call.

Recommendation 2: Regulate the installation of in-vehicle telematics

While cell phones are the most widespread and frequently-used telematics device, automobile manufacturers are increasingly equipping their vehicles with other basic telematics such as driving aid systems – which, in fact, contain several other telematics such as global positioning system (GPS) and e-mail systems – and DVD players/televisions. Some high-end vehicles are even equipped with portable computers that sit in the glove compartment.

Since the cell phone is the most popular of the devices mentioned, virtually all of the studies reviewed examine the effects of this device on performance and collision risk. However, devices such as cell phones, which draw on the cognitive and visual resources required to carry out primary tasks, are likely to distract drivers. This is the conclusion of Lee et al. (2001), who demonstrate that using speech-based e-mail system negatively affects driving performance. Again, the fact that such a device allows the driver to keep his or her hands on the wheel does not diminish the effect of distraction.

The INSPQ recommends that installation of in-vehicle telematics devices that do not assist with driving be prohibited unless they are proven not to be a source of distraction. In support of such a measure, Transport Canada should compel automobile manufacturers to perform certain tests to ensure that new telematics devices do not interfere with driving. The burden of proof would be on manufacturers, in accordance with the principle that applies to pharmaceutical companies that want to market a medication. The INSPQ also encourages researchers to focus more attention on the distraction caused by other in-vehicle telematics and devices.

Recommendation 3: Modify collision reports

Currently, accident reports contain no checkbox that would allow the presence of a cell phone to be systematically reported. Yet, there are standard areas on reports for marking whether someone was driving while impaired or speeding at the time of a collision. The INSPQ recommends that accident reports be modified to better measure the prevalence of accidents caused by cell phone use, and to allow for a better understanding of the circumstances surrounding collisions associated with cell phone use.

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LIST OF ACRONYMS AND ABBREVIATIONS

CWTA	Canadian Wireless Telecommunications Association
DWI	Driving while impaired by alcohol
FARS	Fatality Analysis Reporting System
INSPQ	*Institut national de santé publique de Québec*
NASS	National Automotive Sampling System
STEP	Selective Traffic Enforcement Program
RR	Relative risk
SAAQ	*Société de l'assurance automobile du Québec*

1 INTRODUCTION

In Quebec, traffic collisions are one of the main causes of accidental injury. Between 2000 and 2005, an increase in the number of road victims was recorded, with a total of 328,258 victims and an annual average of 54,710 injured (SAAQ, 2006). The SAAQ's most recent report indicates that between 2000 and 2005, an annual average of 675 deaths and 5,735 serious injuries requiring hospitalization occurred. The road toll has worsened in terms of both deaths and injuries. The number of deaths increased by 9.3% between 2004 and 2005, rising from 644 to 704; and serious injuries rose by 14.2% in 2005, compared to the period between 2000 and 2004.

In Quebec, driving while impaired (DWI) and speeding are the two main causes of collisions leading to personal injury. In fact, 27.4 of drivers killed and 13.3% of those seriously wounded in Quebec had a blood alcohol level of over 0.08mg/100ml (Traffic Injury Research Foundation of Canada, 2004). Police reports, for their part, indicate speeding as the main cause in 22% of deaths, 17% of serious injuries and 1% of minor injuries between 1999 and 2003; this adds up to 150 deaths, 900 serious injuries and 5,000 minor injuries on average per year (Brault, 2003).

In addition to DWI and speeding, distraction is identified as a significant risk factor in many research reports. It may be associated with more than 25% of collisions (Wang *et al.*, 1996; Ranney *et al.*, 2000; Stutts, 2005). Other studies report estimates varying between 35% and 50% when inattention is included (Sussman *et al.*, 1995; National Highway Traffic Safety Administration, 1997). Among the various sources of distraction, cell phone use while driving and in-vehicle telematics have received a lot of attention from the media and academics (Beirness *et al.*, 2002).[1] This concern is not surprising. For one thing, the wireless telecommunications market continues to register strong growth year after year. In addition, automobile manufacturers are offering more and more integrated in-vehicle telematics. In Canada, not only has the number of people who subscribe to a wireless telecommunications service risen exponentially during the past twenty years, going from 6,000 to 16,809,988 between 1985 and 2005 (Canadian Wireless Telecommunications Association), but people are also using their cell phones more and more while driving (Beirness, 2005).[2]

Although the use of cell phones and telematics represent secondary tasks that do not help with driving, and that enter into competition with the primary tasks involved in driving, few studies provide a thorough synthesis of the scope and nature of the associated public health risks.[3] This situation is all the more worrisome considering that the rate of cell phone use while driving is constantly rising and that telematics are becoming widespread. Moreover, cell phone use while driving appears to be a road safety issue of significant concern to Quebec and Canadian drivers (Beirness *et al.*, 2002; Beirness, 2005; SAAQ, 2004; INSPQ, 2006).

[1] "*In-Vehicle Telematics* refers to devices incorporating wireless communications technologies in order to provide information services, vehicle automation and other functions" (Transport Canada, 2003: 2).

[2] Cellular phones appeared on the Canadian market in 1985.

[3] This advisory is concerned with both cell phones and other telematics. However, the scientific literature rarely discusses the impact of other telematics on driving and collision risk. As a result, this text often refers solely to cell phones.

The absence of a synthesis that would support a clear assertion regarding the risk associated with the use of cell phones and telematics while driving is explained partly by the data sources typically used to document the issue and partly by the methods many researchers use to measure the relationship between cell phone use and the risk of collision. Advances in medicine and in the reconstruction of collision scenes now make it possible to determine if alcohol and speed were involved in a collision. However, only the questioning of drivers and witnesses makes it possible to determine whether a driver was using a cell phone at the time of a collision. Furthermore, accident reports generally contain no checkbox that would allow the presence or use of a cell phone to be systematically reported. In addition, only two meta-analyses have been performed and these refer to a limited number of experimental studies (see Horrey and Wickens (2004) and Caird *et al.* (2004)). Finally, there is no literature review or work of synthesis that qualifies as a systematic review of the literature.

Therefore, this public advisory has taken the form of a systematic review of the scientific literature aimed at documenting the risk related to cell phone use while driving. In compliance with its mission, the INSPQ has prepared this report to provide the Minister of Health and Social Services with information about the impact of public policies on population health. The report is intended to support the minister in his or her capacity as a government advisor whose role, as assigned by the Public Health Act, is to promote the adoption of healthy public policies.

More specifically, this advisory will answer the following questions:

1) Does cell phone use affect the performance of tasks that are essential to driving an automobile?
2) What risks does their use pose to the health and safety of road users?
3) Does the associated risk vary according to the type of device (hands-free versus hand-held)?
4) Is this risk significant enough to justify banning or limiting cell phone use, and what impact would this have on the number of collisions and injuries?
5) Is the risk associated with cell phones comparable to that generated by other telematics devices?
6) What effective measures can be taken to improve the situation?

This public health advisory is divided into six main sections (excluding the introduction and the background section).

Section 3 examines theoretical concepts that contribute to an understanding of the relationship between distraction and the risk of collision. This section introduces, among other things, the notions of primary and secondary tasks, and defines distraction.

Section 4 presents the trends in the number of subscribers to wireless communication services and the rate of cell phone use while driving. This section also describes public opinion regarding cell phone use while driving.

Section 5 describes the methodology. It presents the guiding principles behind the systematic review of the literature as well as the strategy used to locate studies, the inclusion criteria and the method of coding results.

Sections 6 and 7 present the results of the analyses. Section 6 focuses mainly on the effect of using cell phones and telematics on driving performance and the risk of collision, with reference to various data sources.

Section 7 presents the results of studies that examined ways of reducing the distraction caused by the use of cell phones and telematics while driving.

Finally, section 8 summarizes the key results and presents the INSPQ's recommendations.

2 BACKGROUND

Road collisions cost the lives of more than 1.26 million men, women and children around the world each year (World Health Organization, 2004). Between 20 and 50 million other people are injured or disabled as a result of road collisions. As stated earlier, 328,258 people were injured in collisions on Quebec's road network between 2000 and 2005, which represents an annual average of 54,710 injured (SAAQ, 2006). For the same period, the SAAQ reports an annual average of 675 deaths and 5,735 serious injuries requiring immediate hospitalization.

Despite the fact that much progress has been made over the years, as is clear when we consider that over 2,000 deaths were recorded in 1972 and 1973, it is still true that road collisions are one of the main causes of non-intentional injury in Quebec. While 90% of collisions are ascribed to human error (Evans, 2004), the manufacturing of safer vehicles, improvement of roads and law enforcement strategies have all contributed to improving Quebec's road toll. The introduction of selective traffic enforcement programs (STEPs) aimed at raising the rate of seatbelt use (Dussault, 1990) and at combating DWI (Mayhew et al., 1996) are two major achievements for Quebec. The results of meta-analyses and systematic reviews of the literature point in the same direction: STEPs and automated controls are effective in reducing road injuries both at targeted sites and in neighbouring zones (Blais and Dupont, 2005). In addition, Mountain et al. (2005) have demonstrated that vertical deflectors such as speed humps or cushions are effective in reducing collisions associated with speeding.

As the literature indicates, reduction in road injuries requires a multifaceted approach aimed at producing changes in behaviour, in the road environment, and in vehicles. The introduction of seatbelts and programs supporting the prevention of DWI and speeding are good examples. At present, numerous studies report that distraction while driving, caused mainly by the use of cell phones and telematics, represents a new problem in road safety (Beirness *et al.*, 2002). American studies even report that distraction could be associated with more than 25% of road collisions (Wang *et al.*, 1996; Ranney *et al.*, 2000; Stutts, 2005).

Thus, the elimination of sources of driver distraction would contribute, in part, to improving the road toll. Although many studies have been carried out, no systematic review, which adheres to the strictest scientific standards in interpreting the results of a population of studies, has yet been performed. A better understanding of the impact of cell phones and telematics on driving and collision risk, as well as a review of effective measures for controlling the use of these devices while driving, will be required before recommendations can be made. Such recommendations will help the government establish road safety priorities and support the introduction of legislation if necessary.

3 USE OF CELL PHONES AND TELEMATICS WHILE DRIVING

This section introduces the theoretical concepts central to understanding the issues relating to the use of cell phones and telematics while driving an automobile. The tasks essential to driving an automobile, the distinction between primary and secondary tasks, and the notions of inattention and distraction will be discussed.

3.1 TASKS ESSENTIAL TO DRIVING AN AUTOMOBILE

Driving an automobile involves the simultaneous performance of several tasks. Evans (1985 and 2004) defines driving an automobile as a "closed-loop compensatory feedback control process, meaning that the driver makes control input (to the steering wheel, brakes, and accelerator pedal), receives feedback by monitoring the consequences of the inputs, and in response to these consequences, makes additional inputs." (Evans, 2004: 174) Drivers must analyze their environments and control the lateral and longitudinal positions of their vehicles while consulting on-board instruments. Thus, driving also involves a cognitive process: drivers assess their present situations to estimate future manoeuvres.

Using a taxonomic approach, driving an automobile can be divided into four interdependent types of tasks: biomechanical, auditory, visual, and cognitive (Ranney et al., 2000; Evans, 2004). These tasks are not mutually exclusive because all information is processed cognitively. Visual, biomechanical and auditory stimuli are analyzed by drivers through the use of their cognitive faculties.

Biomechanical tasks involve the manipulation of on-board instruments, such as the steering wheel, the brake pedal and the accelerator, which are used to control the vehicle. The accomplishment of these tasks allows a driver to respect the speed limit, to stay centered in his or her lane, and to maintain a safe distance from other vehicles, for example.

Hearing and vision allow for the detection of various stimuli in the driving environment. The sound of an ambulance siren alerts drivers to change lanes to give way. Vision is used for consulting on-board instruments and tracking stimuli inside and outside the vehicle. For example, road signs allow drivers to take note of applicable speed limits or to prepare to negotiate a sharp curve (Charlton, 2004). Rockwell (1972) maintains that as much as 90% of the information processed while driving is visual. While visual acuity is a condition for obtaining a driver's licence, its relation to collision risk is not well-established. On the other hand, "changes in higher-level visual characteristics, in particular the useful field of view, the area from which useful visual information can be extracted in a single glance, has been shown to be related to crash involvement risk" (Evans, 2004: 175). In fact, Smiley (1999) has shown that drivers adjust their speeds mainly on the basis of information detected through peripheral vision. When peripheral vision is obscured, a driver relies solely on his or her central field of vision, and the assessment of his or her own speed is impaired. Requirements related to visual acuity and field of vision (central and peripheral) are, in fact, included in the medical and optical standards drivers must meet to drive a vehicle.

Finally, the cognitive resources allow drivers, firstly, to assess the situations in which they find themselves, and then to decide how to modify their driving. All along their route, drivers must select useful information from a driving environment rich in stimuli. Drivers analyze and react to information detected in their field of vision. Evans (2004) identifies two phases in the cognitive treatment of information. Firstly, a decision must be made, which involves the time it takes to react. Secondly, there is the response, which involves the time it takes to execute a manoeuvre. For example, there is a time lag between the moment drivers decide to brake and the moment they press the brake pedal.

3.2 PRIMARY AND SECONDARY TASKS

The tasks performed while driving a vehicle are generally characterized as primary or secondary. The tasks described above can be considered as primary, because they are essential to driving an automobile. In contrast, tasks that interfere with or do not help with driving are considered secondary. For example, dialling a phone number and holding the steering wheel are two biomechanical tasks, but the first is secondary because it is unrelated to driving a car. Such sources of distraction inside vehicles have increased at the same rate as technological innovation has advanced. At present, numerous telematics are offered as options or as basic equipment: satellite radio, pagers, personal wireless communications systems, on-board navigation systems and night vision systems (Beirness *et al.*, 2002). These telematics, like cell phones, are potential sources of distraction that can affect driving performance and jeopardize safety.

Secondary tasks are sources of distraction that draw attention away from the tasks essential to driving. Ranney *et al.* (2000) classify distractions into four categories that correspond to the types of tasks essential to driving an automobile: visual (taking one's eyes off the road), auditory (cell phone ring tones), biomechanical (dialling a number on a cell phone keypad) and cognitive (reflecting on a subject of conversation rather than analyzing road stimuli). The categories of Ranney *et al.* are consistent with the typology proposed by Goodman *et al.* (1999) to describe the tasks performed when cell phones are used while driving. This typology includes four categories linked to cell phone use: accessing the cell phone, dialling a number, talking, and performing related tasks (such as taking notes or consulting a booklet). All of these tasks are potential sources of cognitive, manual, auditory and visual distraction.

The notion of distraction is often used to explain the negative effect of cell phone use and other telematics on driving. Distracted driving is one dimension of the concept of driver inattention (Beirness *et al.*, 2002). Inattention applies to any condition, state or event (including being lost in thought) that causes a driver to pay less attention than required to driving a vehicle (Ranney *et al.*, 2000). Specifically, distracted driving occurs "when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person… compelled or tended to induce the driver's shifting attention away from the driving task" (Treat, 1980: 21;). In short, distraction is caused by a specific event, which causes the driver to be inattentive. Inattention can be present without necessarily having been triggered by an event.

In the relevant literature, the concept of divided attention often accompanies that of distraction. When drivers are distracted, their attention is divided between the accomplishment of primary and secondary tasks. During a cell phone conversation, for example, a driver's cognitive resources are being used to analyze both driving parameters and the statements being made by the other person talking on the phone.

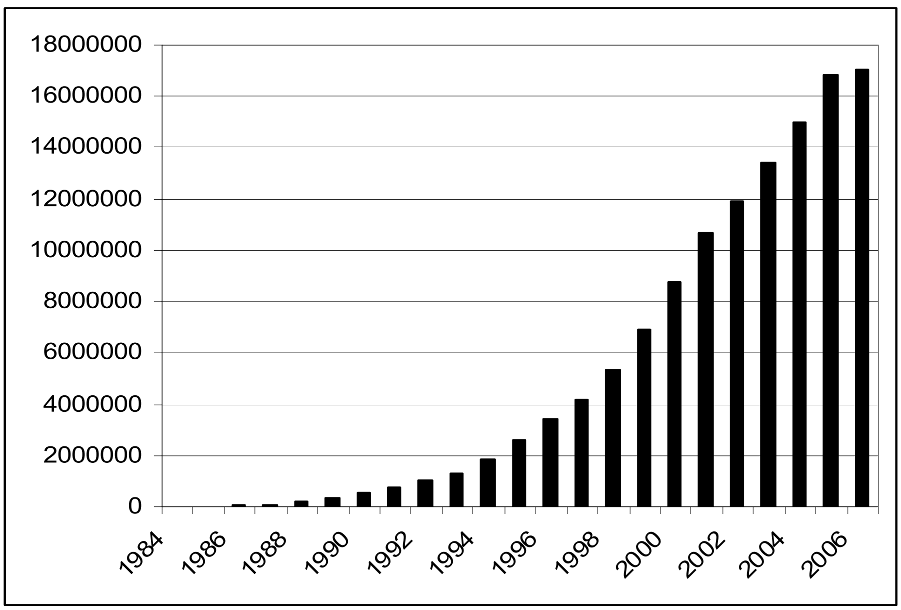
4 TRENDS IN THE RATE OF CELL PHONE USE AND PUBLIC OPINION

Section 4 presents the data on trends in the rates of cell phone possession and cell phone use while driving. Three data sources were used: field and telephone surveys, self-administered questionnaires and the Canadian Wireless Telecommunications Association (CWTA).

4.1 NUMBER OF CELL PHONE USERS

According to CWTA data, the number of cell phone users rose exponentially between 1985 and 2006.[4] Figure 1 indicates that there were approximately 6,000 subscribers to wireless telephone services in Canada in 1985 compared to 17,016,032 in 2006. In 2006, 64% of Canadian households subscribed to a wireless communication service. This situation varies only slightly in Quebec, where only 51% of households subscribed to a wireless communication service.

Figure 1 Trend in the number of subscribers to wireless telecommunications services (1984-2006)



Source: Canadian Wireless Telecommunications Association, retrieved May 21, 2006 from http://www.cwta.ca/CWTASite/english/industryfacts.html.
Note: The information for 2006 is incomplete and includes only the first three months of the year.

[4] The term cell phone "user" refers to someone who owns or uses a cell phone. A cell phone user does not necessarily use a cell phone while driving. The text specifies when this is the case.

4.2 TRENDS IN THE RATE OF USE WHILE DRIVING, ACCORDING TO VARIOUS SOURCES

4.2.1 Results of observational field surveys

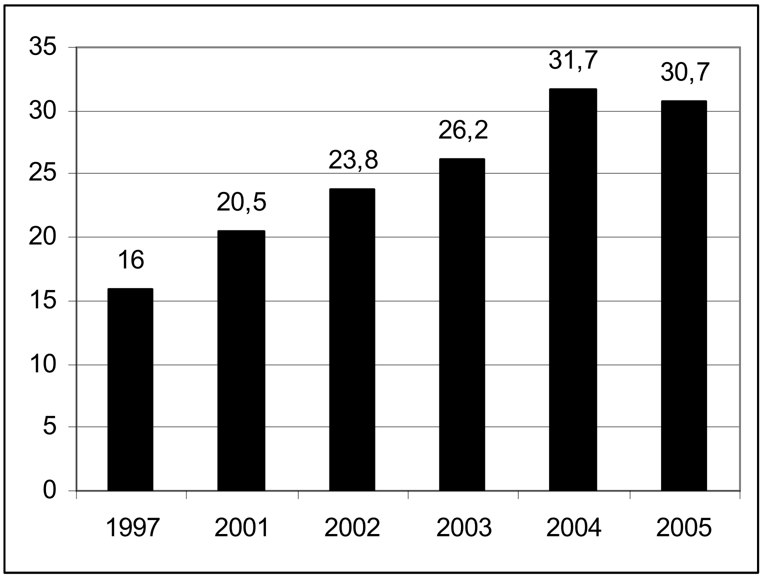
Field surveys allow the rate of hand-held cell phone use among drivers to be reliably estimated. These surveys are often carried out when conditions are clear and the rate of use is measured at several intersections to guarantee the reliability of results. The results of a national survey conducted in the United States indicate that 6% of drivers were driving with a cell phone in hand in 2005, which represents an increase over the 3% observed in 2000, 4% in 2002 and 5% in 2004 (Glassbrenner, 2004, 2005a, 2005b; Utter, 2001). Similar results were obtained through surveys conducted in different American states (Eby and Vivoda, 2003; Reinfurt *et al.*, 2001; Salzberg, 2002).

However, the rates reported by American surveys are generally higher than those of other countries. In Perth (Western Australia), the rate of use was reported to be 1.5% in 1998-99 and 2% in 2002-2004 (McEvoy *et al.*, 2005; Horberry *et al.*, 2001). The use of hand-held cell phones while driving has been illegal since 1988 in Melbourne, located in the Australian state of Victoria. Notwithstanding, Taylor *et al.* (2003) reported a 2% rate of use in 2002. In Finland, however, the rates of use observed in four large cities were 3% in the spring of 2003 and 6% in the spring of 2004 (Rajalin *et al.*, 2005), which approaches the American rates.

4.2.2 Results of telephone surveys and self-administered questionnaires

No field survey has been carried out in Quebec or Canada. However, many surveys have been conducted. The Traffic Injury Research Foundation conducts annual surveys focused on road safety issues. In 2002, Beirness *et al.* conducted a survey of 1,207 Canadians with a valid driver's licence. Among these, 23.8% admitted having used their cell phone while driving during the previous seven days. Figure 2 also shows that the rate of use almost doubled between 1997 and 2005, going from 16 to 30.7% (Beirness, 2005). The results of these surveys indicate that rates of use vary among provinces. In Quebec, 17.3% of drivers had used a cell phone while driving during the previous seven days in 2002 compared to 25.8% in the Prairie Provinces (Alberta, Manitoba, Saskatchewan).

Figure 2 Rate of cell phone use while driving between 1997 and 2005 in Canada



Source : Beirness, D. (2005). Distracted Driving. The Role of Survey Research. International Conference on Distracted Driving. Toronto (ON).

While cell phone use while driving is widespread in Canada, it would seem that frequent users are mainly male, single, urban dwellers, high earners, and those who spend more time on the road for work, have traffic violations on file, and are more likely to drive after drinking (Beirness, 2005).

In Quebec, the SAAQ published a survey in 2005 indicating that 49% of Quebec drivers (N=1150) used a cell phone (the survey took place between December 7 and 30, 2004). Among these, 58% used their cell phone while driving, which represents 28% of all drivers. The INSPQ conducted another telephone survey in June 2006. For comparison purposes, this survey contained questions identical to those asked by the Traffic Injury Research Foundation and the SAAQ. Of the 1,000 Quebec citizens surveyed, 85% held a valid driver's licence. Of this percentage, 47.2% were cell phone users (N=472). Among the drivers who used cell phones, 41% had used their cell phone while driving during the previous seven days. In comparing the percentages of users who admit to using their cell phone while driving as reported by the SAAQ (58%) and by the INSPQ (41%), it becomes clear that those who use cell phones while driving, do so regularly; that is, at least once a week. About 17% use their cell phone while driving less than once a week.

To complete their study, Laberge-Nadeau *et al.* (2001 and 2003) sent a questionnaire by mail to 175,000 drivers to ensure a representative sample of the Quebec population of licensed drivers. Among the 36,078 drivers in their sample, 35.2% owned a cell phone in 1999 (40.8% of men and 25.4% of women). The rate of ownership was 2.5% among this same sample in 1987 (Maag *et al.*, 2006). In their sample, 90% of drivers with cell phones used them while driving.

4.3 USE OF CELL PHONES WHILE DRIVING AND PUBLIC OPINION

Surveys conducted among Canadians concerning cell phone use while driving have led to two main observations. Firstly, the majority of Canadian and Quebec drivers consider cell phone use while driving to be a road safety problem. Secondly, the majority of Canadians and Quebeckers think that cell phone use while driving should be regulated.

The results of Beirness et al. (2002) indicate that 64% of Canadians consider cell phone use to be problematic and this tendency is more pronounced among women (69%) than among men (57%). According to data from Laberge-Nadeau et al. (2003), perceptions vary between cell phone users and non-users. Among non-users, 70.1% of men and 76.1% of women consider that cell phone use interferes considerably with driving; whereas for users the percentages were lower at 37.7 and 50.3% for men and women, respectively. Moreover, drivers consider cell phone use while driving to be potentially more dangerous than other forms of distraction. In fact, according to the Traffic Injury Research Foundation, two-thirds of Canadian drivers consider cell phone use while driving to be a serious or extremely serious road safety problem; whereas only two-fifths consider driver distraction to be a serious or a very serious problem (Beirness, 2005). Similar results have been produced in a study by Laberge-Nadeau *et al*. Listening to the radio and talking with a passenger are considered very detrimental to driving by less than 1% and approximately 2%, respectively, of drivers in their sample.

These concerns are also identified when Canadian drivers are surveyed about their acceptance of a law banning hand-held cell phone use. According to a survey conducted by Canadian Press (2001), 80.8% of Canadians are in favour of banning the use of hand-held cell phones while driving. In Quebec, this proportion rises to 85.7%. In December 2004, 53% of Quebeckers were of the opinion that cell phone use while driving should be permitted only for hands-free devices; whereas 38% thought their use should be completely banned (SAAQ, 2005). In June 2006, the situation had changed slightly: 49% of respondents thought cell phone use should be completely banned and 44% thought only hands-free devices should be permitted (INSPQ, 2006).

4.4 SUMMARY

Data from the CWTA reveal that the number of subscribers to wireless telecommunications services has increased exponentially over the course of the last twenty years. In fact, the number of subscribers went from 6,000 to 17,016,032 between 1985 and 2006. According to Statistics Canada, 64% of Canadian households subscribed to a wireless telecommunications service in 2006. Wireless telecommunications seems not only to have become an integral part of Canadian life, but, in addition, use of such services is becoming more widespread in various contexts, including while driving.

The latest surveys from the Traffic Injury Research Foundation indicate that the rate of cell phone use while driving is increasing. In 1997, 16% of drivers surveyed had used a cell phone while driving during the previous seven days; whereas in 2005, the rate had risen to 30.7% (Beirness *et al.*, 2002; Beirness, 2005). In 2004, in Quebec, 58% of drivers who used cell phones admitted to using their cell phone while driving (SAAQ, 2005). A recent survey by the INSPQ (2006) revealed that cell phone users had used their phones on a regular basis while driving. In fact, 41% of drivers who used cell phones had used a cell phone while driving during the previous seven days. Thus, it seems that the majority of users who use their cell phone while driving do so on a regular basis; that is, at least once a week.

This increase in the rate of use not only emphasizes the need to examine the issue of road safety related to cell phone use, but also the population’s concern over this behaviour. Among Canadians, 66% consider cell phone use while driving to be a serious or a very serious road safety problem. Finally, the most recent opinion survey reported that more than 93% of Quebeckers think cell phone use while driving should be regulated and 49% think their use should be completely banned (INSPQ, 2006).

5 METHODOLOGY

To establish the risk associated with the use of cell phones and other telematics while driving, it would have been preferable to use the results of meta-analyses, systematic reviews and data from accident reports. However, use of these data sources presents certain problems within the context of this advisory. Firstly, none of the reviews of the literature qualified as a systematic review, and this called into question the validity of their conclusions. Among other things, the researchers failed to document either their strategy for locating documents or their criteria for including and excluding studies.

Secondly, an analysis based solely on police reports would underestimate the risk of collision linked to cell phones. The information contained in accident reports does not allow for calculation of the percentage of cases involving cell phones and distraction.

Thirdly, only two meta-analyses have been published so far (Cain et al., 2004; Horrey and Wickens, 2004). These meta-analyses have two main limitations. Their strategy for locating studies is far from being optimal and well-documented and their results do not provide answers to all the questions raised in this advisory. Moreover, meta-analysis is probably not the best way to synthesize the effect of cell phone use while driving and collision risk. To calculate the overall effect of a given factor on a dependant variable, two parameters are required: an estimate of the factor's effect and an estimate of the associated error term (Lipsey and Wilson, 2000; Wolf, 1986). However, many studies failed to report these two parameters; thus, carrying out a meta-analysis of results would necessitate the rejection of numerous studies. Finally, the relative risk (RR) of collision is not always established using the same method from one study to another, which prevents calculation of an effect size.

Thus, this advisory is a systematic review of the literature on the effects of cell phone use while driving, on driving performance, and collision risk. A systematic review uses rigorous methods to locate, appraise and summarize the results of a group of empirical studies. According to Johnson *et al*. (2000, p. 35), systematic reviews "essentially take an epidemiological look at the methodology and results sections of a specific population of studies to reach a research-based consensus on a given study topic." This approach involves formulating clear objectives and criteria for inclusion and exclusion of studies, documenting the strategy used to locate documents throughout the world, and specifying the methods used to code and analyze the results of these studies (see Johnson *et al.*, 2000; Welsh and Farrington, 2001).

This systematic review, however, has one distinct characteristic: it is based on several populations of studies. While the percentage of collisions associated with DWI and speeding can be estimated by consulting reports, this is not so for cases involving cell phone use while driving. With few exceptions, jurisdictional police reports do not contain a checkbox for systematically reporting the presence of cell phone use (Stutts *et al.*, 2001 and 2002; Goodman *et al.*, 1997 and 1999). To compensate for this limitation, all studies that support documentation of the links between cell phone use, driving performance, traffic violations and the risk of collision have been considered. In this type of situation, the convergence of results from various groups of studies makes it possible to draw conclusions about the risk associated with cell phone use while driving (Simpson, 2005). Finally, this review has certain limitations. It involves a synthesis of studies published in English and in French. Also, it is understood that the proceedings of conferences and oral presentations are probably under-represented, given that they are not always indexed in databases. Finally, the results and characteristics of the studies reviewed have been coded by a single person.

5.1 SEARCH STRATEGY FOR IDENTIFICATION OF STUDIES: KEY WORDS, EXPRESSIONS AND DATA SOURCES

The following expressions were used to locate studies:

- Car phone
- Cell phone
- Wireless phone
- Wireless communication
- Car distraction
- Driver distraction
- Distract* device
- Cellular phone
- In-vehicle telematic
- In-car telematic

These expressions were used to search the following databases:

- TRIS / TRB Online (Transport Research Information Service - Transport Research Board)
- PUBMED
- Evidence Based Medicine Reviews (EBM):
    - MEDLINE
    - CAB abstracts
    - Cochrane Database of Systematic Reviews
    - Cochrane Central Register of Control Trials
    - DARE (Database of Abstracts of Reviews of Effects)
    - ACP Journal Club
- CINAHL (Cumulative Index to Nursing and Applied Health Literature)
- ERIC (Education Resources Information Center)
- HAPI (Health and Psychological Instruments)
- PsycInfo

The results of the search strategy are presented in Table 1. Database searches resulted in the identification of 2,105 documents. The title, key words and abstract of each document were then carefully read by a reviewer. Studies that did not examine the problem of cell phone use and the use of other telematics while driving were excluded. A total of 236 documents were retained for more in-depth analysis.

Table 1 Results of document search

Sources	Documents located through expressions	Documents considered for the study	Percentage of documents retained
TRB – TRIS (Transport Research Board)	973	132	13.6%
OVID: EBM reviews ACP journal Club Cochrane Controlled trials register Cochrane database of systematic reviews Database of abstracts of reviews of effects, ERIC Health and psychosocial instruments Medline Medline in-process and other non-indexed citations OldMedline PsycINFO	62	51	82.3%
Evidence Based Medicine Reviews (EBM): MEDLINE CAB abstracts Cochrane Database of Systematic Reviews Cochrane Central Register of Control Trials DARE (Database of Abstracts of Reviews of Effects) ACP Journal Club	85	4	4.7%
PUBMED	985	49	5.0%
Total[a]	2105	236	11.2%

a: duplications are not excluded from the total.

Finally, to ensure the studies included in the advisory were as representative as possible, three additional strategies were used. Firstly, the bibliographies of 236 studies were reviewed so that studies not found in the databases could be located. Secondly, an expert committee was put in place to help with the identification of studies and to identify the questions that should be addressed by the public health advisory. Finally, the following websites were consulted: the Traffic Injury Research Foundation (TIRF), Transport Canada, the French National Institute for Transport and Safety Research (INRETS), the AAA Foundation for Traffic Safety, the CAA Foundation for Traffic Safety, and the Transport Research Board.

5.2 INCLUSION CRITERIA FOR STUDIES AND CODING OF RESULTS AND CHARACTERISTICS

The search stage allowed four types of studies to be identified: experimental studies, epidemiological studies, studies evaluating the effect of control measures on the rate of cell phone use while driving and on road collisions, and various other documents such as reviews of the literature, various quantitative studies and papers. To be included in the systematic review, studies had to meet certain criteria. The review essentially encompasses experimental and epidemiological studies and evaluations of legislation.

5.2.1 Inclusion criteria for experimental studies and coding of information

5.2.1.1 Inclusion criteria

During the search stage, 122 references to experimental studies were located, including duplications. The experimental studies are mainly concerned with evaluating the effect of cell phone use while driving on the performance of participants with a valid driver's licence. In these studies, participants' driving performance is measured under two conditions: a control condition where participants simply drive and an experimental condition where participants perform a task using a cell phone or another telematics device. To ensure the validity of their results, experimental studies had to meet certain criteria be included in the review.

Firstly, the studies had to evaluate the effect of cell phone use on a driving performance indicator. This could be an indicator such as average speed, the vehicle's lateral position, braking reaction time or consultation of on-board instruments. Table 2 presents a detailed list of performance indicators.

Secondly, two research protocols were accepted. In the first, all participants were required to drive under control and experimental conditions. This allowed experimenters to measure the variation in performance between the two conditions. In the second protocol, all participants were randomly assigned into control and experimental groups. The two groups completed the same road trajectory with one difference: participants in the experimental group used a cell phone or another telematics device at the same time. In both protocols, the control condition involved simply driving. There are, however, other studies that have measured variations in performance under different experimental conditions. This was the case in Ludice et al. (2005) who compared the effects of cell phone use, driving while under the influence, and fatigue on driving performance. These studies do not determine whether cell phone use results in poorer driving performance than undistracted driving. Rather, they indicate whether cell phone use has a more adverse effect on driving than other risky driving behaviour (see also Wolffsohn et al., 1998; Mazzae et al., 2004; Salvucci, 2001). The results of these studies cannot be consolidated with those of the others, and will be analyzed and catalogued separately, as needed.

Thirdly, the studies had to use inferential statistic tests. All experimental studies use analysis of variance (ANOVA). This method makes it possible to determine whether the averages of two or more groups are similar. For example, the performance of participants during experimental and control conditions can be compared. An F statistic with a significance level lower than 0.05 indicates that the two averages vary significantly from a statistical standpoint. However, many studies measure driver performance at several points or under varying conditions. Thus, the researchers must perform repeated measures ANOVA to ensure the validity of results.[5] Studies that did not include such an analytic strategy when necessary were not considered for the review (see Crawford et al. (2001) for an example). Finally, the order of treatments had to be counterbalanced. This strategy helps "avoiding confounding treatment effects with fatigue effects, practice effects, carryover effects, and order effects" (Shadish et al., 2002).

Of 122 references, 53 were retained, after exclusion of numerous duplications and studies that did not meet the inclusion criteria. This systematic review includes more than twice as many studies as the meta-analyses of Caird *et al.* (2004) (n=22) and Horrey and Wickens (2004) (n=16).

5.2.1.2 Coding of results and characteristics of experimental studies

In this advisory, the vote-count method is used to objectively measure the effect of cell phone use on driving performance (Cook *et al.*, 1992). This method consists of counting "how many results are statistically significant in one direction, how many are neutral (i.e., "no effect"), and how many are statistically significant in the other direction" (Cook *et al.*, 1992: p. 4). In this advisory, reference is made to positive, neutral and negative effects associated with cell phone use while driving. For example, if the experimental group performs significantly less well than the control group, resulting in a "weaker" average for an indicator (for example, a greater braking reaction time), this counts as a negative effect. If there is no statistically significant difference between two averages, the effect is neutral. Once all the effects have been counted, the category (negative, neutral or positive) observed most frequently determines the modal or most typical result. In this way, a conclusion can be reached regarding the overall effect of cell phone use on driving.

An ordinal scale with three modes was created to tabulate the results.[6] Each main effect (each F or t test) for which it was possible to compare the performance indicator averages under experimental and control conditions was assigned one of the following values:

- 1 if cell phone use significantly diminished performance;
- 0 if there was no significant difference between the performances of control and experimental groups;
- -1 if cell phone use improved driving performance.

A significance level of 0.05 was used to classify these results. This means that for an effect to be classified under "diminished performance" or "improved performance," the t or F test values had to reach the significance level of 0.05, failing which the effect was classified as neutral. While 335 effects were catalogued, this nevertheless represents a conservative number. Many studies compared the control condition to two experimental conditions; in

[5] ANOVA for repeated measures allows for verification of the sphericity assumption and calculation of the variance attributable to blocks. An ANOVA that does not take into account time of measurement risks overestimating the variance explained by the variables (Vickers, 2003).

[6] As stated earlier, we did not perform a meta-analysis of the results, because many of the required parameters, including estimates of the effect and of the error term, were not always given. Our strategy is aimed at producing a synthesis that is representative of the literature. It may be that certain studies do not systematically report the prediction error, but are nevertheless rigorous. Our approach has been used by others as well, including Weisburd *et al.* (2001), who used this approach to code the results of crime and justice studies.

particular, one condition requiring use of a hand-held cell phone and the other requiring use of a hands-free device. However, a simple statistical *F* test does not indicate if the three means are statistically different. Post hoc tests (Tukey or Scheffe, for example) must be performed afterwards to determine which means are statistically different. These tests were not included in all the studies, which influenced our decision to consider a single effect.

Each effect was classified according to the typology proposed by Ranney *et al.* (2000) because of the wide variety of performance indicators. As Table 2 illustrates, a distinction was made between cognitive, visual and biomechanical indicators. In addition, indicators related to perceived difficulty of the task were included (for example, the NASA-TLX results).

Table 2 Performance indicator categories

Biomechanical performance indicators ✓ Average speed and variation in average speed; ✓ Speed violation; ✓ Lateral position of vehicle and variation in lateral position of vehicle (remaining centred in a lane); ✓ Intervehicular distance and variation in intervehicular distance (maintaining distance requested by experimenter); ✓ Steering angle (measures adjustments made while driving: the greater the variation, the more adjustments made by the driver); ✓ Time to complete the course.
Visual performance indicators ✓ Detection of stimuli in driving environment – image recognition; ✓ Eye movements – periods of fixation; ✓ Amplitude of visual field; ✓ Glances away from the road; ✓ Pupil dilation; ✓ Consultation of on-board instruments.
Cognitive performance indicators ✓ Braking reaction time; ✓ Road hazard reaction time; ✓ Poor decisions in a potentially dangerous situation; ✓ Interpretation of driving situations; ✓ Memorization of driving environment.
Indicators of perceived difficulty of task ✓ NASA-TLX; ✓ Heart rate; ✓ Other instruments that measure the subjective difficulty of the task.

The following characteristics were recorded for all the studies: year of publication, type of publication, type of cellular device (hands-free or hand-held), experimental context, average age of participants, number of participants, number of men and women, type of transmission, participants' years of driving experience and the proportion of cell phone users in the study. In addition, the tasks performed during the experimental condition were described in detail.

5.2.1.3 Analysis of results of experimental studies

Two strategies were used to analyze the results. Firstly, the positive, neutral and negative effects were counted. According to the vote-count method, the category observed most often is used to establish the effect of cell phones on driving performance. However, the effects are not necessarily independent of each other. It is likely that a participant who performs poorly with respect to visual performance indicators will also have a weaker score for cognitive indicators. In addition, it is often the case that many indicators are used to measure one dimension of driving. To measure visual performance, for example, the number of saccadic eye movements, time spent looking at instrument and mirrors and the length of periods of fixation are often used in the same study. Consequently, the results (effects) of each study were aggregated into one average, which represents the direction of the effect. Thus, the closer the average is to 1, the more negative the cell phone's effect on driving. On the other hand, a score approaching -1 indicates that the cell phone improved performance. (An average close to 0 indicates that the cell phone had no significant effect on performance.)

The calculation of this average is part of the second analysis strategy. Testing the averages makes it possible to determine if the average effect varies from the central point of our ordinal scale ($p \leq 0.05$) and to compare the effect of cell phone use under different driving conditions. For example, it becomes possible to compare the averages of effects based on the type of cellular device used and to answer the following question: do hands-free devices distract drivers more than hand-held ones? Weisburd *et al.* (2001) used such a method to ascertain whether crime prevention programs lead to a significant reduction in criminality. In addition to demonstrating that such programs are effective at combating criminality their approach had two important implications. Firstly, this approach made it possible to compare results on the basis of study characteristics (for example, on the basis of evaluation protocol), and secondly, their conclusions were in keeping with those obtained by meta-analyses. Their conclusions remain valid, even though they are not based on standardized effect sizes.

5.2.2 Inclusion criteria for epidemiological studies and coding of information

5.2.2.1 Inclusion criteria

Eighteen epidemiological studies were retained after an initial sorting of the references. The epidemiological studies had to meet one main criterion: they had to examine the link between cell phone use and road injuries. The epidemiological studies selected can be divided into two categories.

In the first category are studies that use information from collision reports to establish the proportion of collisions associated with various distractions, including cell phones and in-vehicle telematics. Ten documents focus on the prevalence of cell phone use during collisions. In the second category are 11 studies that calculate the RR of collision associated with cell phone use while driving or compare the collision rates of cell phone users and non-users. In some cases, the independent variable is the fact of being a cell phone user (not necessarily while driving), while in other cases, the focus is on cell phone use while driving. Some studies fall into both categories because they examine both the prevalence of cell phone use during collisions and the collision risk associated with its use (Violanti, 1997 and 1998; Lam, 2002).

5.2.2.2 Coding of results and characteristics of epidemiological studies

Due to the variety of methods used to calculate the RR of collision associated with cell phone use, the results of the 18 studies are analyzed descriptively. Information is still provided about the about the type of study, the sample, the dependent variable, the results and the comparison with other risk factors. Once again, the vote-count method is used to determine the effect of cell phone use on collision risk.

5.2.3 Evaluation studies of laws and other measures that regulate cell phone use while driving

Studies evaluating the effect of laws had to meet two criteria. Firstly, they had to evaluate the impact of laws on collision rates or on the rate of cell phone use while driving. Thus, several studies examining the cost of implementation or efficiency were rejected. Secondly, the studies had to at least perform a before/after comparison to determine if the status of the dependent variable changed after the law was introduced. For these studies, a descriptive approach was again used. Only one study evaluates the effect of a law banning the use of hand-held devices on road collisions (Royal Society for the Prevention of Accidents, 2002) and four studies compare the rate of hand-held cell phone use while driving before and after the introduction of a law banning the use of hand-held devices (McCartt and Geary, 2002; McCartt *et al.*, 2004; Johal *et al.*, 2005; Rajalin *et al.*, 2005).

5.2.4 Other documents consulted

Many literature reviews, papers, articles and surveys were consulted so that road safety issues linked to the use of cell phones and other telematics while driving could be better pinpointed and understood. Among these, two studies made it possible to document the link between distraction and collision risk in real driving situations. In the first, Neale *et al.* (2002) followed 100 instrumented vehicles for a one-year period to document the relationship between driving behaviour, collisions and risky situations. The vehicles were equipped with computers and video cameras so that information could be filmed and recorded. In the second study, Strayer (2005) observed 1,748 drivers crossing an intersection. Strayer collected two pieces of information: was the driver using a cell phone and did the driver stop at the stop line. Finally, other documents also examine control measures intended to reduce distraction caused by cell phone use. However, we found no evaluations of these measures.

6 RESULTS

In order to document the problems related to the use of cell phones and other telematics while driving a car, three sets of results are presented. These sets of results follow a logical sequence which establishes links between: 1) the use of such devices and driving performance, 2) the use of these devices and risk of collision, 3) the use of cell phones and other telematics and risky behaviours. Control measures are discussed in a separate section (see section 7).

The first section deals with the influence of cell phones and other telematics on driving performance as measured by biomechanical, visual, cognitive and perceived difficulty indicators. The experimental studies' findings are analyzed in order to document this relationship. The second section presents the results of the epidemiological studies which focus on the collision risk associated with the use of cell phones and other telematics devices. The third section presents the results of studies that are deemed to be pertinent, but are unique in nature. Primarily, these studies document the driving infractions committed and the risky behaviours engaged in by drivers during a phone conversation.

6.1 RESULTS OF EXPERIMENTAL STUDIES

The results of the experimental studies are discussed from two perspectives. First, the effect of cell phone use while driving on general performance and on biomechanical, cognitive, visual and perceived task difficulty performance indicators is considered.

Three questions are then addressed in turn:

1. Do hand-held and hands-free devices produce the same effects on performance?
2. Does cell phone use produce the same effect on performance as other on-board instruments and telematics?
3. Does the distraction caused by cell phone use diminish with practice? Can a learning effect be observed?

6.1.1 General effect of cell phone use on driving

The main results and characteristics of the experiments are presented in Table 3. The search process identified 53 documents that satisfy the inclusion criteria and contain a total of 64 experiments. The analyses are based on the results of these 64 experiments, since the latter are independent of each other. The 64 experiments contain 335 comparisons between the control and experimental conditions. In this section, our analyses are thus based on 335 effects.

The studies retained were published between 1969 and 2005 (with 75.1% published after the year 2000).[7] Scientific articles (publications in peer-reviewed journals account for 78.1% of the documents found while research reports and conference proceedings represent 15.6 and 6.3% of the documents, respectively.

[7] Studies and experiments are used interchangeably throughout the document.

Of the 64 experiments, 59.4% evaluate only the effect of hands-free cell phones on driving performance. Of the studies, 12.5% evaluate only the effect of hand-held cell phones on performance, while 28.1% of the studies consider the two types of devices. Thus, more than 87% evaluate the effect of hands-free devices. As for context, 12.5% of the studies were carried out under laboratory conditions,[8] 56.3% in a driving simulator, 9.4% on a closed circuit and 21.9% on open road.

Three participant characteristics are reported in the majority of the studies: sex (n=58), age (n=52) and number of participants (n=64). On average, participants are 31.6 years old (standard deviation = 9.1). The studies include on average 33.8 participants (standard deviation = 45.6). The median of 24 is most representative as a measure of central tendency because the average is affected by the value of one study which includes 350 participants. Finally, 58 studies specify the number of men and women. The percentage of men varied between 30 and 100% (average=58.1; standard deviation=16.4).

To analyze the relationship between cell phone use while driving and driving performance, this study examines 335 main effects. On average, the experiments evaluate the effect of cell phone use while driving on slightly more than five performance indicators. Certain studies have relied on only one indicator. (Consiglio et al., 2003; Cooper and Zheng, 2002; Golden et al., 2003) and others use up to 16 or 18 indicators (Ranney et al., 2004; Burns et al., 2002).

With the exception of experiments by Spence and Reed (2003) and Nunes and Recarte (2002-2), all the studies report diminished performance while using cell phones with respect to at least one performance indicator. The fact that the above two experiments did not observe a statistically significant difference between control and experimental conditions, is probably due to their small sample size. The Spence and Reed (2003) study had eight participants and the Nunes and Recarte (2002-2) study had six.

In most cases, cell phone use while driving resulted in a decrease in participants' performance in comparison to the performance registered in the comparison group or the control condition. In fact, 66.3% (n=222) of the 335 effects coded show a statistically significant deterioration in performance. On the other hand, 32.2% (n=108) of the effects are neutral and 1.5% are positive.[9] Using the vote-count method to tally the direction of effects (positive, neutral and negative), it appears that cell phone use while driving leads to a significant decline in participants' performance in the majority of cases. This conclusion is all the more plausible since most of the studies are statistically weak due to their small sample size. Although the studies do not compute statistical power, the latter must be at least above 0.50 and ideally in the neighbourhood of 0.80 (Cohen, 1988; Gelber and Zelen, 1985). Experiments obtaining such coefficients maximize their chance of detecting statistically significant differences between the results of two groups if the stimulus produces an effect on the dependent variable.

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8 Laboratory studies are also know as simulators which reproduce driving conditions with a minimum of verisimilitude (low fidelity simulator).

9 These results include indicators for perceived task difficulty. In removing these indicators, the analyses are based on 314 effects and the results remain the same: 65.3% of the effects are negative, 33.1% are neutral and 1.6% are positive.

Table 3 Summary of experimental studies

Authors/year of publication	Type of device / context	Participants' characteristics	Tasks carried out with cell phones	Performance indicators	Effects (positive, neutral, negative)
Alm and Nilsson(1994)	Hands-free / simulator	X age = 32.40 years. N = 40 (20 women, 20 men). Minimum 5 years of driving experience	Conversation: "Baddeley Test." Tell if a sentence makes sense (yes or no).	10 biomechanical indicators, 2 cognitive and 1 perceived difficulty of the task.	7 neutral effects and 6 negative effects on performance.
Alm and Nilsson (1995)	Hands-free / simulator	X age = 48.45 years. N = 40 (10 women, 30 men).	Conversation: (*Working Memory Span Test*).	7 biomechanical indicators, 1 cognitive and 1 perceived difficulty of the task.	6 neutral effects and 3 negative effects on performance.
Atchley and Dressel (2004)	Hands-free / laboratory	X age = 23.20 years. N = 30 (21 women, 9 men). 100% cell phone users.	Conversation: give a word which starts with the last letter of the word read by the experimenter.	2 cognitive indicators.	2 negative effects on performance.
Barkana *et al.* (2004)	Hands-free / laboratory	X age = 32.20 years. N = 41 (21 women, 20 men).	Conversation: questionnaire to simulate everyday conversation.	12 visual indicators.	12 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Briem and Hedman (1995)	Hands-free / laboratory	X age = 34 years. N = 20 (10 women, 10 men). 40% cell phone users.	Conversation: (*Working Memory Span test*)	8 biomechanical indicators and 1 collision.	3 negative effects and 5 neutral on performance.
Brookhuis *et al.* (1991)	Hands-free and hand-held / open road	X age = 44.00 years. N = 12 (2 women, 10 men).	Conversation: perform addition (PASAT test).	3 biomechanical indicators, 1 visual, 1 cognitive and 1 perceived difficulty of the task.	4 negative effects, 1 positive and 1 neutral on performance.
Brown *et al.* (1969).	Hands-free / closed track	X age = 39 years. N = 24 men. 20 years of driving experience on average. 1 participant had previously used a CB radio.	Conversation: “Baddeley Test.” Tell if a sentence makes sense (yes or no).	2 biomechanical indicators, 5 visual and 2 cognitive.	4 negative effects and 5 neutral on performance.
Burns *et al.* (2002)	Hands-free and hand-held / simulator	X age = 32 years. N = 20 (10 women, 10 men). 100% cell phone users.	“Rosenbaum Verbal Cognitive Test Battery” (resolve problems and remember sentences one has heard).	11 biomechanical indicators, 6 cognitive, 1 perceived difficulty of the task.	12 negative effects and 6 neutral on performance.
Charlton (2004)	Hands-free / simulator	X age = 28.43 years. N = 30 (17 women, 13 men).	Conversation: repeat words and find rhymes	4 visual indicators, 1 cognitive and 1 perceived difficulty of the task.	6 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Consiglio *et al.* (2003)	Hands-free and hand-held / simulator	X age = 21 years. N = 22 (11 women, 11 men). 77.30% cell phone users.	Everyday topics of conversation using a questionnaire.	1 cognitive indicator.	1 negative effect on performance.
Cooper and Zheng (2002)	Hands-free / closed track	X age = 39.50 years. N = 39 (11 women, 28 men).	Conversation: word association exercise.	1 potential collision indicator.	1 negative effect on performance.
De Ward and Brookhuis (2001)	Hand-held / simulator	X age = 35 years. N = 20 14 years of driving experience on average.	Find and dial a telephone number using a programmed list.	4 biomechanical and 1 perceived difficulty of the task indicators.	5 negative effects on performance.
Fuse and Matsunaga (2001a)	Hand-held / simulator	N = 8 men. No cell phone users.	Pick up a ringing phone from the passenger seat and talk.	1 cognitive indicator.	1 negative effect on performance.
Fuse and Matsunaga (2001b)	Hand-held / simulator	N = 8 men. No cell phone users.	Pick up a ringing phone from the passenger seat and talk.	1 cognitive indicator.	1 neutral effect on performance.
Fuse and Matsunaga (2001c)	Hand-held / simulator	N = 8 men. No cell phone users.	Pick up a ringing phone from the passenger seat and talk.	1 cognitive indicator.	1 negative effect on performance.
Golden *et al.* (2003)	Hands-free and hand-held / laboratory	X age = 30.10 years. N= 45 (24 women, 21 men).	Everyday topics of conversation.	1 visual indicator.	1 negative effect on performance.

Table 3 Summary of experimental studies (continued)

Graham *et al.* (2001)	Hands-free and hand-held / simulators	X age = 35.20 years. N = 48 (21 women, 27 men).	Dial a phone number using different devices.	2 biomechanical indicators and 1 perceived difficulty of the task.	2 negative effects and 1 neutral on performance.
Green *et al.* (1993)	Hands-free and hand-held / open road	X age = 42 years. N = 8 (4 women, 4 men). No cell phone users.	1) Make a call, 2) listen and make a decision 3) describe something and 4) make a list (fruits or cities)	8 biomechanical indicators.	4 negative effects, 1 positive and 3 neutral on performance.
Gugerty *et al.* (2004a)	Hands-free / simulator	X age = 19.5 years. N = 29. At least 1 year of driving experience.	Conversation: provide a word starting with the same letter as the preceding word.	5 cognitive indicators and 1 collision.	3 negative effects and 3 neutral on performance.
Gugerty *et al.* (2004b)	Hands-free / simulator	X age = 21.3 years. N = 39 At least 1 year of driving experience.	Conversation: provide a word starting with the same letter as the preceding word (faster pace than for "a").	5 cognitive indicators and 1 collision.	5 negative effects and 1 neutral on performance.
Haigney *et al.* (2000)	Hands-free and hand-held / simulator	X age = 26.93 years.N = 30 (17 women, 13 men).4.37 years of driving experience on average 63 % cell phone users.	Conversation: "Baddeley Test." Tell if a sentence makes sense (yes or no).	6 biomechanical indicators and 1 perceived difficulty of the task.	2 negative effects and 5 neutral on performance.

Table 3 Summary of experimental studies (continued)

Hancock *et al.* (1999)	Hands-free / closed track	X age = 36 years. N = 10 (5 women, 5 men).	Answer the telephone while pressing on a key and recognize an initially memorized number.	1 biomechanical indicator and 2 cognitive.	3 negative effects on performance.
Hancock *et al.* (2003)	Hands-free / closed track	X age = 44.43 years. N = 36 (17 women, 19 men). 25.75 years of driving experience on average.	Answer the telephone while pressing on a key and recognize an initially memorized number.	3 biomechanical indicators and 2 cognitive.	5 negative effects on performance.
Harbluk *et al.* (2002)	Hands-free / open road	N = 21 (9 women, 12 men). 9.70 years of driving experience on average.	Memorization and identification of memorized telephone numbers.	2 cognitive indicators and 3 of the perceived difficulty of the task.	5 negative effects on performance.
Horrey and Wickens (2004)	Hands-free / simulator	X age = 22 years. N = 22 (8 women, 14 men).	Dial a number with 4, 7 or 10 digits.	3 biomechanical indicators and 1 visual.	2 negative effects and 2 neutral on performance.
ICBC (2001) and Cooper *et al.* (2003)	Hands-free / closed track	X age = 37.33 years. N = 41 (11 women, 30 men).	Conversation: “Baddeley Test.” Tell if a sentence makes sense (yes or no).	6 biomechanical indicators and 8 cognitive.	14 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Irwin *et al.* (2000)	Hands-free / laboratory	X age = 31.50 years. N = 16 (8 women, 8 men).	Conversation: answer a variety of questions.	5 biomechanical indicators.	2 negative effects and 3 neutral on performance.
Ishida and Matsuura (2001)	Hands-free and hand-held / closed track	N = 50 (1 woman, 49 men). 4.32 years of driving experience on average. 42% cell phone users.	Conversation: solve mathematical equations.	5 biomechanical indicators, 5 visual and 2 cognitive.	7 negative effects and 5 neutral on performance.
Jenness *et al.* (2002)	Hands-free and hand-held /simulator	X age = 28.50 years. N = 24 (14 women, 10 men). 11.94 years of driving experience. 91.6% cell phone users.	Dial a telephone number.	1 biomechanical indicator and 2 visual.	3 negative effects on performance.
Kubose *et al.* (2004a)	Hands-free / simulator	X age = 21.73 years. N = 48 (21 women, 27 men). 5.13 years of driving experience.	Conversation: give directions and identify the names of buildings based on information received.	2 biomechanical indicators.	2 negative effects on performance.
Kubose *et al.* (2004b)	Hands-free / simulator	X age = 20.20 years. N = 48 (28 women, 20 men). 3.96 years of driving experience.	Conversation: give directions and identify the names of buildings based on information received.	2 biomechanical indicators.	2 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Lamble *et al.* (1999)	Hands-free and hand-held / open road	X age = 22.70 years. N = 19 (9 women, 10 men). 2.38 years of driving experience.	Dial a number and add the last figures mentioned on the telephone.	1 biomechanical indicator, 1 visual and 2 cognitive.	2 negative effects and 2 neutral on performance.
Laramée *et al.* (2002)	Hands-free / laboratory	X age = 55.50 years. N = 38 (23 women, 15 men).	Conversation: answer a questionnaire.	2 visual indicators.	2 negative effects on performance.
Liu and Lee (2005)	Hands-free / open road	X age = 35.20 years. N = 12 (6 women, 6 men. 4.20 years of driving experience. 100% cell phone users.	Conversation: 24 additions of two digits.	3 biomechanical indicators and 1 perceived difficulty of the task.	4 negative effects on performance.
Matthews *et al.* (2003)	Hands-free and hand-held / open road	X age = 36.60 years. N = 13 (4 women, 9 men). Minimum 5 years of driving experience. 100% cell phone users.	Conversation: find rhymes with words read (*Modified Rhyme Test*).	1 indicator of perceived difficulty of the task.	1 negative effect on performance.
Mazzae *et al.* (2000)	Hands-free and hand-held / simulator	N = 54 (27 women, 27 men). Minimum 6 years of driving experience. 100% cell phone users.	Dial a telephone number using three devices.	1 indicator of perceived difficulty of the task.	1 negative effect on performance.

Table 3 Summary of experimental studies (continued)

McKnight and McKnight (1991 and 1993)	Hands-free / simulator	X age = 39 years. N = 151. 33% cell phone users.	Dial a number, solve easy and difficult equations.	2 cognitive indicators.	2 negative effects on performance.
McPhee and Scialfa (2004)	Hands-free / laboratory	X age = 43.41 years. N = 32 (12 women, 20 men). 24.36 years of driving experience	15 yes / no questions. (*Logical memory test of the second and third editions of the Wechsler Memory Scale*).	2 visual indicators and 3 cognitive.	4 negative effects and 1 neutral on performance.
Nunes and Recarte (2002a)	Hands-free / open road	N = 6 (3 women, 3 men).	1) interview on driving habits and 2) make a call to ask for weather conditions (pre-programmed number).	1 indicator of perceived difficulty of the task.	1 neutral effect on performance.
Nunes and Recarte (2002b)	Hands-free / open road	N = 6 (3 women, 3 men).	1) interview on driving habits and 2) make a call to ask for weather conditions (pre-programmed number).	1 visual indicator and 2 cognitive.	3 neutral effects on performance.
Nunes and Recarte (2002c)	Hands-free / open road	N = 12 (6 women, 6 men).	1) convert dollars to euros and 2) remember where they were at 3 p.m. 3 days ago.	9 visual indicators and 1 perceived difficulty of the task.	9 negative effects and 1 neutral on performance.

Table 3 Summary of experimental studies (continued)

Nunes and Recarte (2002d)	Hands-free / open road	N = 12 (6 women, 6 men).	1) convert dollars to euros and 2) remember where they were at 3 p.m. 3 days ago.	9 visual indicators and 1 perceived difficulty of the task.	9 negative effects and 1 neutral on performance.
Parkes and Hooijmeijer (2000)	Hands-free and hand-held / simulator	X age = 24 years. N = 15. Minimum of 3 years of driving experience.	Conversation: memorize figures and letters and solutions to mathematical and logic problems.	5 biomechanical indicators and 9 cognitive.	8 negative effects and 6 neutral on performance.
Patten *et al.* (2004)	Hands-free and hand-held / open road	X age = 39.60 years. N = 40 (8 women, 32 men).	Answer the telephone and conversation: adding and repeating numbers.	1 cognitive indicator.	1 negative effect on performance.
Radebord *et al.* (1999)	Hands-free / simulator	X age = 33.60 years. N = 20 (10 women, 10 men). 13.50 years of driving experience on average.	Conversation: “Baddeley Test.” Tell if a sentence makes sense (yes or no).	2 cognitive indicators.	2 negative effects on performance.
Rakauskas *et al.* (2004)	Hands-free / simulator	X age = 20.40 years. N = 24 (12 women, 12 men). 4.70 years of driving experience.	Conversations with two levels of difficulty (1 = easy questions – short answers and, 2 = hard questions – development questions - thinking).	4 biomechanical indicators, 2 cognitive and 1 perceived difficulty of the task.	4 negative effects and 3 neutral on performance.

Table 3 Summary of experimental studies (continued)

Ranney *et al.* (2004)	Hands-free and hand-held / simulator	X age = 38.00 years. N = 12 (6 women, 6 men). 100% cell phone users.	“Baddeley Test.” Tell if a sentence makes sense (yes or no).	12 biomechanical indicators and 4 cognitive.	4 negative effects, 2 positive and 10 neutral on performance.
Recarte and Nunes (2003)	Hands-free / open road	X age = 23.40 years. N = 12 (6 women, 6 men). 4.80 years of driving experience.	Conversation: listen to two messages to summarize and give directions.	6 visual indicators and 1 cognitive.	2 negative effects and 5 neutral on performance.
Reed and Green (1999a)	Hand-held / open road	X age = 42 years. N = 12 (6 women, 6 men).	Dial an 11-digit telephone number.	3 biomechanical indicators.	3 negative effects on performance.
Reed and Green (1999b)	Hand-held / simulator	X age = 42 years (6 women, 5 men).	Dial an 11-digit telephone number.	3 biomechanical indicators.	3 negative effects on performance.
Salvuci (2001)	Hands-free and hand-held / simulator	X age = 25 years. N = 11 (5 women, 6 men). 2 years minimum of driving experience. 63.60% cell phone users.	Dial a telephone number and confirm that the right person answered.	2 biomechanical indicators.	2 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Shinar and Tractinsky (2004)	Hands-free / simulator	X age = 38.67 ans. N = 30 (9 women, 21 men). 15.67 years of driving experience 100% cell phone users.	2 types of conversations: 1) mathematical problems and 2) emotional topics.	5 biomechanical indicators and 1 cognitive.	2 negative effects, 1 positive and 3 neutral on performance.
Slick *et al.* (2004)	Hand-held / simulator	X age = 17 years. N = 62 (31 women, 31 men.	Answer a call and prepare food (take the lid off a beverage or open a bag of chips).	2 biomechanical indicators and 1 perceived difficulty of the task.	2 neutral effects and 1 negative on performance.
Spence and Read (2003)	Hands-free / simulator	X age = 31 years. N = 8 (4 women, 4 men).	Repeat a series of words.	7 biomechanical indicators and 2 cognitive.	9 neutral effects on performance.
Strayer *et al.* (2004-1)	Hands-free / simulator	N = 64.	Conversation about a predetermined topic using a questionnaire.	4 biomechanical indicators and 1 perceived difficulty of the task.	2 negative effects and 3 neutral on performance.
Strayer *et al.* (2004-2)	Hands-free and hand-held / simulator	X age = 26 years. N = 41 (15 women, 26 men).	Conversation about a predetermined topic using a questionnaire.	1 biomechanical indicator, 2 cognitive and 1 collision.	4 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Strayer *et al.* (2003a)	Hands-free / simulator	X age = 23.0 years. N = 40 (22 women, 18 men). 57.50% cell phone users.	Conversation about a predetermined topic using a questionnaire.	1 biomechanical indicator and 3 cognitive.	4 negative effects on performance.
Strayer *et al.* (2003b)	Hands-free / simulator	X age = 20.10 years. N = 20 (9 women, 11 men). 57.50% cell phone users.	Conversation about a predetermined topic using a questionnaire.	1 visual indicator.	1 negative effect on performance.
Strayer *et al.* (2003c)	Hands-free / simulator	X age = 20.60 years. N = 20 (5 women, 15 men). 75% cell phone users.	Conversation about a predetermined topic using a questionnaire.	3 visual indicators.	1 negative effect and 2 neutral on performance.
Strayer *et al.* (2003d)	Hands-free / simulator	X age = 19.60 years. N = 30 (13 women, 17 men).	Conversation about a predetermined topic using a questionnaire.	1 visual indicator.	1 negative effect on performance.
Strayer and Drews (2004)	Hands-free / simulator	X age = 45 years. N = 40 (20 women, 20 men).	Conversation about a predetermined topic using a questionnaire.	2 biomechanical indicators and 2 cognitive.	4 negative effects on performance.
Strayer and Johnson (2001)	Hands-free and hand-held / laboratory	X age = 21.30 years. N = 48 (24 women, 24 men).	Questions about allegations brought against Bill Clinton or about the Olympic Games in Salt Lake City.	1 visual indicator and 1 cognitive.	2 negative effects on performance.

Table 3 Summary of experimental studies (continued)

Tirbovich and Harbluk (2003)	Hands-free / open road	N = 20.	Easy and hard mathematical equations.	3 visual indicators.	2 negative effects and 1 neutral on performance.
Woo and Lin (2001)	Hand-held / simulator	X age = 32.93 years. N = 350 (120 women, 230 men).	Dial a telephone number.	5 cognitive indicators.	5 negative effects on performance.

Note: Letters (a, b, c, d) indicate experiments included in the same document.
Numbers (for example, 2002-1 and 2002-2) indicate that an author published more than one study in the same year.

6.1.1.1 Cell phone use and cognitive task performance

Thirty five of the 64 experiments in this review analyzed the effect of cell phone use on cognitive performance indicators. Of the 335 effects, 28.1% (n=94) refer to a primary cognitive task. The vote-count method demonstrates that cell phone use while driving significantly diminishes performance of cognitive tasks related to operating a motor vehicle: 81.9% (N=77) of 94 effects are negative, 17 are neutral and none are positive.

Table 4 shows the effect of cell phone use while driving when the average is used. According to these results, cell phone use while driving results in significant deterioration of cognitive task performance, as indicated by the average of 0.82, which varies significantly from 0 ($t\ [df = 34] = 14.19$; $p < 0.01$).

Two types of cognitive tasks were also distinguished in coding the results: reaction time and accuracy. Participants take longer to react to a situation ($t\ [df = 29] = 10.88$; $p<0.01$) (e.g. to brake or make a decision during a risky situation) and have more trouble making a correct decision based on the situation ($t\ [df = 15] = 27.21$; $p<0.01$) (e.g. to swerve left when cars are approaching from the opposite direction or to apply the brakes when a pedestrian crosses the road) as indicated by the respective averages of 0.78 and 0.95.

Table 4 Effect of cell phone use on cognitive tasks related to driving a car

	Average effect on cognitive tasks	Average effect on reaction time	Average effect on accuracy
Number of studies including this type of indicator	35	30	16
Arithmetic mean	0.82	0.78	0.95
Median	1.00	1.00	1.00

6.1.1.2 Cell phone use and biomechanical task performance

Half (n=32) of the 64 experiments evaluate the effect of cell phone use on the performance of biomechanical tasks while driving, for a total of 137 effects. Of this number, 66 (48.2%) have a negative effect on performance, 66 (48.2%) are neutral and 5 (3.6%) are positive. In approximately one out of two cases, cell phone use while driving results in diminished performance of biomechanical tasks.

The results in Table V also show that cell phone use leads to a substantially diminished performance of various biomechanical tasks. The average effect of 0.56 demonstrates that cell phone use while driving leads to a significantly diminished performance of biomechanical tasks in more than 50% of cases ($t\ [df = 31] = 7.63$; $p<0.01$). More precisely, cell phone use has a greater effect on the ability of participants to maintain the necessary requested speed (average effect = 0.62) ($t\ [df = 21] = 6.17$; $p<0.01$) than on their ability to control the vehicle (average effect = 0.53) ($t\ [df = 29] = 6.20$; $p<0.01$).

Table 5 Effect of cell phone use on biomechanical tasks related to driving a car

	Average effect on biomechanical tasks	Effect on capacity to maintain necessary speed	Average effect on control of vehicle position
Number of studies including this type of indicator	32	22	30
Arithmetic mean	0.56	0.62	0.53
Median	0.48	1.00	0.50

6.1.1.3 Cell phone use while driving and visual task performance

Twenty of the 64 experiments study the relation between cell phone use while driving and performance of primary visual tasks. In general, the effects show that cell phone use negatively affects the participants' performance of primary visual tasks. Three quarters of the effects (58/77) are negative while 19 are neutral and none are positive. The overall averages calculated from the average scores of each study are reported in Table 6. The average of 0.80 shows that cell phone use while driving leads to a significant deterioration in the performance of visual tasks (t [df = 19] = 12.03; p<0.01).

Table 6 Effect of cell phone use on visual tasks related to driving a car

	Average effect on visual tasks	Average effect on detection of stimuli/objects	Average effect on using on-board instruments	Average effect on range of visual field
Number of studies including this type of indicator	20	7	8	13
Arithmetic mean	0.80	0.62	0.81	0.59
Median	1.00	0.50	1.00	0.67

This result also applies when visual tasks are divided into three distinct categories, detection of stimuli, use of on-board instruments, and range of visual field. The average of 0.81 shows that participants consult on-board instruments less during cell phone use (t [df = 7] = 6.18; p<0.01). Although the average effects are a little weaker, cell phone use while driving negatively influences participants' capacity to detect stimuli (t [df = 6] = 4.16; p<0.01) and significantly reduces their field of vision (t [df = 12] = 4.79; p<0.01), as demonstrated by the respective averages of 0.62 and 0.59.

6.1.1.4 Cell phone use and perceived difficulty of driving task

The perceived difficulty of a task is a central concept of risk theories. According to the theory of risk homeostasis, an increase in the perceived difficulty of a situation would lead a driver to adjust his or her behaviour to maintain the same level of risk (see Wilde, 1988 and 1994).

Therefore, there should not be a difference in driving performance between experimental and control conditions, yet this is contradicted by the results presented previously. However, according to this theory, performance should be better in the studies where participants are aware that cell phone use increases task difficulty. In other words, diminished performance should be less notable in studies where participants find the experimental task more difficult.

Average effects on indicators of perceived task difficulty

Nineteen studies evaluated perceived task difficulty using questionnaires filled out by participants after the experiments. These studies cover a total of 21 effects and show that participants generally consider that cell phone use increases the difficulty of the task of driving: 81.0% of effects are negative (N=17) and four effects are neutral (19.0%). The four neutral effects are found in two documents which comprise four experiments (Nunes and Recarte, 2002; Strayer *et al.*, 2004a). The average of the effects is 0.79. Participants in the experiments generally consider that cell phone use significantly increases the difficulty of the task of driving (t [17] = 7.71; $p< 0.01$].

Relation between perceived task difficulty and performance

In order to better understand the link between perceived task difficulty and performance, the studies were classified into two groups: those which show a significant increase in perceived difficulty and those which do not. The average performance of the two groups was then compared. Although average performance is not as high in the studies with less perceived difficulty (respectively 0.55 and 0.71), this difference is not statistically significant (*t* [df = 16] = 0.92; $p=0.37$).

This result does not support the risk homeostasis theory, according to which drivers seek to maintain a constant risk level by adapting their behaviour to the perceived task difficulty. Although participants are aware that performing a secondary task is more difficult, they do not adjust their behaviour (Lesch and Hancock, 2004). However, only 19 of the 64 studies examined the link between perceived difficulty and performance, which raises the issue of statistical power. Nevertheless, these 19 studies are similar to the other 45, which indicates that the *t* test result is not attributable to the studies' characteristics. These 19 experiments are identical to the others with respect to the averaging of effects, the average age of participants in the sample, the percentage of men in the sample, the number of performance indicators, the type of publication, the type of cellular device used during the experiment and the context.

6.1.1.5 Cell phone use and collision risk in the experiments

The primary goal of these experimental studies is to evaluate the effect of cell phone use on performance. Nevertheless, six experiments included collision indicators (Briem and Hedman, 1995; Cooper and Zheng, 2002; Gugerty *et al.*, 2004; Shinar and Tractinsky, 2004; Strayer *et al.*, 2004a). These indicators vary from one study to another. They may simply refer to the number of collisions, the ability to avoid collisions, or the number of collisions where the participant's vehicle hits another vehicle from behind (*rear-end collisions*).

All these studies were done in a driving simulator or laboratory with the exception of the study carried out by Cooper and Zheng (2002), who performed their experiment on a closed track. In this latter study, the act of going over a stop line constituted a collision with a stationary vehicle. These studies contain six collision indicators. Four experiments report a higher average number of collisions in the experimental situation than under the control condition ($p < 0.05$), while two others show no difference between the two conditions. While the number of experiments was limited, cell phone use while driving significantly increased the probability of having a collision.

6.1.2 Specific questions about cell phone use during experiments

So far, our analyses show that cell phone use while driving significantly diminishes driving performance. However, several questions need to be addressed. For example, some postulate that the use of a hands-free device is safe, while others stress that the effect of cell phone use would vary depending on the secondary tasks performed (Wickens, 1984; Horrey and Wickens, 2004). For example, if conversation requires only cognitive resources, there should be no impact on primary biomechanical tasks which consist of handling instruments used to control the vehicle. These questions are addressed in turn using the results of the experimental studies.

6.1.2.1 Respective effects of hand-held and hands-free devices on performance

Analysis of the respective effects of hands-free and hand-held devices is of crucial importance in relation to legislation. Many jurisdictions have banned the use of hand-held devices but allow hands-free devices. In fact, the effectiveness of laws allowing the use of hands-free cell phones relies on the premise that cell phone use is, above all, a source of biomechanical distraction. Others consider cell phone use while driving to be first and foremost a source of cognitive distraction (Briem and Hedman, 1995; Strayer et al., 2004a). According to this view, the effect of handling cell phones on driving is minimal. Conversation is the main source of distraction.

This section deals with two questions: 1) Do the two types of devices affect automobile driving in the same way? 2) Is there a relationship between performance of primary driving tasks and the nature of the task carried out while using a cell phone?

As for the first question, Table 7 demonstrates that the two types of devices produce primarily negative effects on performance. Nineteen of the 22 (86.3%) effects collected by the studies which evaluate only hand-held devices are negative and three are neutral. In the studies examining only hands-free devices, 67.9% (n=142) of the effects are negative, 31.6% (n=66) are neutral and only one effect is positive. Finally, the 18 studies that examine the effects of the two devices establish that 58.7% are negative (n=61), 37.5% (n=39) are neutral and 3.8% (n=4) are positive.

Table 7 Number of negative, neutral and positive effects according to cellular device

	Negative effects	Neutral effects	Positive effects	Total number of effects (number of studies)
Hand-held	19 (86.4%)	3 (13.6%)	0 (0.0%)	22 (8)
Hands-free	142 (67.9%)	66 (31.6%)	1 (0.5)	209 (38)
Both	61 (58.7%)	39 (37.5%)	4 (3.8%)	104 (18)

The results of Table 8 also support the assertion that the two types of devices diminish driving performance in a similar manner. The Kruskal-Wallis test shows that the average effects of the two devices are similar (chi-square = 0.87 [2]; p = 0.65).[10] The average effects for hand-held and hands-free devices are 0.79 and 0.72, respectively.

Table 8 Average effects according to cellular device

	N	Average effect	Median
Hand-held	8	0.79	1.00
Hands-free	38	0.72	0.90
Both	18	0.74	0.83

Despite the accumulation of evidence showing that the two devices produce identical negative effects on automobile driving, some might stipulate that the effect of cell phone use on driving depends on the nature of the primary and secondary tasks. Specifically, the primary and secondary tasks must necessarily draw on the same resources (for example, biomechanical resources) for a performance deterioration to occur (Wickens, 1984; Horrey and Wickens, 2004).

The results in Table 9, however, do not support this hypothesis. In fact, none of the differences is statistically significant, as the values obtained through chi-square tests indicate. Average effects do not seem to vary according to the type of cellular device. Rather, the results show that, independent of device, cell phone use while driving negatively affects all tasks required for driving a car. The extra biomechanical task involved in handling a hand-held device does not seem to unduly affect performance. These results suggest, moreover, that cell phone use primarily causes cognitive distraction, which affects overall performance due to the interdependence of tasks required for driving (Evans, 2004; Briem and Hedman, 1995; Strayer *et al.*, 2004-2).

[10] The Kruskal-Wallis test is based on the average rank instead of the arithmetic mean. This test is used when the analysis of variance assumptions are not respected. The critical threshold is determined using a chi-square distribution.

Table 9 Average effects according to device and nature of the primary task

	Device	N	Average of effects	Median
Effect on biomechanical tasks	Hand-held	4	0.75	1.00
	Hands-free	16	0.64	0.88
	Both	12	0.42	0.39
	Chi-square = 2.23 (df = 2); p = 0.33			
Effect on visual tasks	Hand-held[a]	0	---	---
	Hands-free	14	0.81	1.00
	Both	6	0.77	1.00
	Chi-square = 0.04 (df = 1); p = 0.85			
Effect on cognitive tasks	Hand-held	4	0.75	1.00
	Hands-free	21	0.79	1.00
	Both	10	0.91	1.00
	Chi-square = 0.79 (df = 2); p = 0.68			

a: this category is not included in the calculation.

6.1.2.2 Effects of cell phone use compared to other sources of distraction: telematics and on-board instruments

So far, the results demonstrate that cell phone use while driving leads to deterioration in the performance of all primary tasks, independent of cellular device. However, cell phone use is probably not the only source of distraction. For one thing, passengers and the radio form other auditory and cognitive sources of distraction. In addition, car manufacturers are integrating more and more equipment and telematics into their vehicles that are likely to distract drivers (Beirness *et al.*, 2002).

This section addresses two questions. Firstly, does any type of auditory stimulus, whether it is conversation with a passenger or cell phone use or listening to the radio, produce the same effects on driving? Secondly, do cell phones and other on-board telematics devices produce the same effects on driving performance? Our systematic review of the literature has led to the identification of eight studies which deal with the effects of other telematics devices and sources of cognitive distraction. These eight studies tally very few performance indicators. Consequently, the results of the studies are analyzed descriptively.

Comparison of the effects produced by cell phone use and listening to the radio

The results of the five studies that compared the effects of the radio and cell phones suggest that cell phone use affects driving more than listening to the radio.

Ishida and Matsuura (2001) carried out an experiment on a closed track. The 50 participants drove under four conditions: 1) driving alone, 2) driving while listening to the news on the radio, 3) driving while using a hand-held cell phone and 4) driving while using a hands-free cell phone. The participants solved mathematical problems during telephone conversations. In general, their results show that cell phone use produces more distraction than listening to the radio and, in the majority of cases, listening to the radio does not affect performance. During telephone conversation, participants had more trouble maintaining speed as well as the required distance between vehicles, they limited their field of vision and deviated more from the center of the road. These results were not observed under the "radio" condition.

The results of Fuse *et al*. (2001) also show that listening to the radio does not affect driving performance. They compared the braking reaction time of 8 participants under three conditions: 1) control, 2) listening to the radio and 3) listening to the radio and repeating its content. The participants' braking reaction time was significantly higher only under the third condition, compared to the other two. In fact, the participants took an average of 1086 milliseconds (1.08 seconds) to activate the brake pedal, compared to the averages of 790 and 716 respectively for the control and listening to the radio conditions. The Fuse *et al*. (2001) study has an important characteristic. It makes a distinction between passive listening and active listening, during which the passenger interacts with the radio. It is probable that simply listening to the radio does not distract the driver because the latter is not required to respond. The driver's cognitive resources are dedicated to driving and nothing else. Consiglio *et al.* (2003) obtained results which point in the same direction: braking reaction times are similar under the control condition and when listening to the radio.

The results of Liu's study (2003), however, cast doubt on the passive listening hypothesis. This study compared the effects produced by three experimental conditions: 1) simple conversation with a hands-free device, 2) demanding conversation with a hands-free device and 3) listening to the radio – on the ability of 24 participants to keep their vehicle centered on the road.[11] Liu does not report a difference between the two types of conversation. On the other hand, the participants had more difficulty staying centered on the road while listening to music than while answering easy questions.

McKnight and McKnight (1991 and 1993) are the only ones to have evaluated the effect of tuning into a radio station on performance. They carried out an experiment in a driving simulator where the participants had to react to stimuli that varied from one scenario to the next. Among other things, participants had to brake when a pedestrian crossed the road or slow down when the car ahead of them did the same. McKnight and McKnight compared the participants' reactions under five conditions: 1) dialling a telephone number using a keyboard placed on the dashboard, 2) simple conversation about various subjects with a hands-free device, 3) intense conversation requiring problem solution with a hands-free device, 4) tuning a radio and 5) simply driving (control condition). While the participants' performance was diminished under all four experimental conditions, compared to the control condition, the intense conversation produced the most notable negative effect. During this situation, 44.2% of the participants' responses were not adjusted in response to circumstances. Furthermore, 44.0% of their reactions were inappropriate while tuning the radio. According to these results, adjusting the radio results in a greater deterioration of performance than holding a simple conversation (41.1%) or dialling a number (41.1%).

[11] The first condition involves a "simple" conversation with personal questions and small talk. The second condition involves a "demanding" conversation centered on calculations, and space-time and language questions. The third consists of listening to the radio.

In general, the results indicate that listening to the news (Ishida and Matsuura, 2001) and listening to music on the radio (Fuse *et al.*, 2001; Consiglio *et al.*, 2003) do not affect performance. Everything points to the conclusion that drivers must interact with the content of the message for their performance to be adversely affected (Fuse *et al.*, 2001). However, these conclusions are not shared by Liu (2003) who reports worse control of the vehicle while participants listened to music. For their part, McKnight and McKnight (1991) are the only ones to report that changing radio stations affects driving. In light of the small number of studies and the divergence of their results, it would be prudent to carry out other studies before reaching a clear verdict about the radio's effect on driving performance.

Comparison of effects produced by cell phone use and conversation with a passenger

The majority of studies are concerned with telephone conversation. However, some researchers have posed the following question: does conversation with a passenger have the same impact as a conversation on a cell phone. Three experimental studies addressed this question.

In their study, Gugerty *et al.* (2004) put forward the hypothesis that passengers would slow down their speech flow when driving became more difficult and that this effect would be absent during cell phone conversation because the speaker can not see the road. To test this hypothesis, they recruited 58 participants between 18 and 22 years old and carried out an experiment in a driving simulator. Twenty-nine driver/passenger pairs were formed. The participants completed the same course twice. During the first test, performance under the control condition was compared to performance under the experimental condition that involved the driver talking with the passenger. During the second test, the performance recorded under the control condition was compared to performance under the experimental condition that involved a conversation on a hands-free cell phone. Each course consisted of 35 scenarios lasting 18 to 35 seconds. Sometimes the participants had to assess potentially dangerous situations (n=10 scenarios), manoeuvre to avoid objects (n=15 scenarios) or perform both actions (n=10 scenarios). The results indicate that participants adapted their speech flow to that of their partner. On the other hand, participants talked at the same rate independent of the type of conversation (on a cell phone or with a passenger). Furthermore, the two types of conversation had the same impact on driving performance. The participants had more trouble remembering other cars in the driving environment, were worse at interpreting scenarios and detected fewer road dangers during conversation. The study does not demonstrate a difference between the two types of conversation, either on the level of speech flow or on the level of performance, which invalidates their hypothesis.

For their part, Consiglio *et al.* (2003) measured the braking reaction time of 22 participants under five laboratory conditions: 1) control, 2) listening to music on the radio, 3) talking with a passenger, 4) talking on a hand-held cell phone and 5) talking on a hands-free cell phone. They had to step on the brake pedal as fast as possible when a red light appeared representing the rear of a vehicle. The participants took on average 392 and 408 milliseconds respectively before hitting the brake pedal under the control condition and when listening to the radio, which is significantly lower than the times observed under the three other conditions. The braking reaction times are comparable under the three other conditions, which demonstrates, on one hand, that conversation with a passenger

(453 milliseconds) is as disruptive as hands-free cell phone use (465 milliseconds) and hand-held cell phone use (464 milliseconds) and, on the other hand, that the two cellular devices affect driving equally.

Finally, Crundall *et al.* (2005) carried out an experiment on public roads which addressed the same question. Contrary to the two studies presented previously, their findings support the suppression hypothesis, according to which passengers reduce their speech flow or put an end to conversation when driving becomes more demanding. Twenty participants, 18 men and 2 women aged on average 25.7 years, traveled a distance of 20 miles in four driving environments (on highways, on rural routes, in the city and in the suburbs). Conversation took place under three conditions: 1) with a passenger in the vehicle, 2) with a passenger in the vehicle wearing a blindfold, 3) with a hands-free cell phone. The authors wished to verify whether the passenger would stop talking during demanding situations. The results indicate the presence of an interaction effect between conversation and road conditions. During conversation with a passenger, there is a reduction in the number and length of sentences used on city roads as compared to highways. This reduction is absent during cell phone conversation. These results support the hypothesis that “conversation is suppressed in difficult situations.” The different roads generated varying levels of conversation; speech flow lessened on city roads during conversation with a passenger. However, the speaker on the cell phone maintained the same level of conversation, even increasing the ratio of questions to responses to stimulate conversation.

The three studies that compared the effect of cell phone use to that of conversation with a passenger obtained divergent results, which prevents us from responding to the question posed at the start. The studies of Consiglio *et al.* (2003) and of Gugerty *et al.* (2004) show that conversation with a passenger produces similar effects to telephone conversation. However, Crundall *et al.* (2005) obtained results that support the hypothesis of “conversation suppression.” They report a slowing down of speech flow when the driving environment requires more attention or becomes more difficult. On the other hand, their study does not involve the use of performance indicators. As stated by McCartt *et al.* (2005), additional studies are required so that this question can be better documented.

Comparison of effects produced by other telematics

A single study examines the effect of other telematics on driving performance. Lee *et al*. (2001) suggest that any device whose operation draws on cognitive, biomechanical or visual resources required to perform primary tasks will negatively affect driving performance. In brief, the effect will be similar to that of using a cell phone while driving.

To verify their assertion, Lee *et al.* (2001) studied the relation between performance and use of a speech-based e-mail system. These allow users to activate menus with different options that send and receive e-mails. The 24 participants drove during 5 different driving scenarios which lasted between 5 and 7 minutes while maintaining a speed of 40 mph. During these scenarios, the participants sent e-mails using various devices while covering routes of varying difficulty.[12] Regardless of the type of road or the type of device, the braking reaction time was higher when participants sent e-mail than under the control condition.

6.1.2.3 Distraction and learning effects

Shinar and Tractinsky (2004) define cell phone use and automobile driving as two tasks in which the pace is dictated by the driver. Drivers can adjust their speed to make it easier to process information about road conditions and stop conversation temporarily when a task becomes more demanding. Moreover, "as in other tasks in life, performance improves with practice and feedback, so that the more practiced a task is, the more it (or parts of it) can be automated; consequently, more attentional capacity is left for other tasks" (Shinar and Tractinsky, 2004: 3).

The question of improving with practice is approached in two ways in the experimental studies. Firstly, some studies verify whether performance improves as soon as participants carry out the same series of tasks. Due to a scarcity of studies that address this issue, their findings are presented descriptively. Secondly, the coded effects are used to verify whether participants who are cell phone users perform better than non-users. If there is no learning effect, there should be no relation between the proportion of users in an experiment and the average effect of a cell phone on performance. In short, the average effect should be stable, independent of the proportion of users in the study sample.

Performance and cell phone use: is there a learning effect?

In the Brookhuis *et al.* (1991) study, 12 participants carried out different tasks on a daily basis over a period of three weeks. Each day, the participants answered easy (simple addition) and difficult questions (memorization and complex addition) asked via a hand-held or hands-free cell phone. This process allowed the researchers to study the day to day variations in participants' performances. On the other hand, Brookhuis *et al,* (1991) analyze the learning effects only with respect to the perceived difficulty of the task and the answers to the questions. Their findings indicate that the participants' heart rate decreased and the participants answered questions more accurately from one week to the next. In short, the participants perceive the secondary task as less difficult, but nothing indicates that their performances will improve.

For their part, Rakauska *et al.* (2004) compared participants' performances on three occasions (participants followed the same course three times), using six performance indicators and one indicator of perceived task difficulty. They noticed an improvement in performance only in reaction time to road hazards. On the other hand, improvement occurs independently of condition. In other words, the participants perform better on the third trial than on the first, but performance always remains lower under experimental conditions.

[12] The two devices that allow e-mail to be sent are actually computers that recognize voice. The two devices vary in complexity. The simple device has three menu levels, each with two options. The complex device also has three menus, but they have 4 to 7 options. The difficulty of a driving environment is defined by the number of objects encountered per minute in the driving environment. In the simple environment, the participants come across 0.5 objects per minute, while the number jumps to 20 in the difficult environment.

Shinar *et al.* (2002) and Shinar and Tractinsky (2004) are the only ones to state clearly that one of the main objectives of their research is to study the learning effect from one session to another. Shinar and his colleagues (2002, cited in Shinar and Tractinsky, 2004) carried out a first experiment in a driving simulator in which the participants completed the same course five times over a period of two weeks. On the course, the participants were subjected to different experimental conditions which required the use of a cell phone while driving. The results indicate that the secondary task led to a decline in performance for certain indicators, but no learning effect was observed. Shinar *et al.* assert that the tasks were too simple and that the participants reached their full potential in the first session. There was no room for improvement thereafter.

To work around this limit, Shinar and Tractinsky (2004) undertook another study, taking care to incorporate three driving scenarios – moving at 50 mph, moving at 65 mph and following a vehicle – and to create three age groups –18-22 years old, 30-33 years old and 60-71 years old. The 30 participants were placed in the three driving scenarios under three different conditions: 1) driving, 2) driving while having an emotional conversation on a hands-free cell phone and 3) driving while solving mathematical calculations on a hands-free cell phone. So that the learning effects could be measured, the participants repeated the procedure five times over a period of 14 days. According to the authors, improvement should occur mainly in difficult situations; i.e. when the participants are solving mathematical equations and driving at 65 mph (117km/h). Shinar and Tractinsky (2004) use six performance indicators, five of which are biomechanical and one, cognitive.

Firstly, their findings show interaction effects among the four independent variables (the participants' age, the scenario, the session and the experimental condition) with respect to the "average speed" and "variation in average speed" performance indicators. The authors interpret the results as an improvement in performance that occurs when the participants are driving at 65 mph and answering mathematical questions. Furthermore, this effect is observed only in drivers from 60-71 years old. However, this interpretation is more or less adequate, since the progression is far from being linear, logarithmic or even exponential. Although the lowest average speed is recorded during the fifth session, average speed and variation in average speed was up and down. From this trend, there is evidence to suggest that future performance could just as easily be better or worse. Moreover, even if there is a learning effect, average speed and variation in average speed remain highest under the most demanding experimental condition.

Secondly, Shinar and Tractinsky (2004) evaluated the effect of learning on lateral position of the vehicle and variation in lateral position. Their results show a learning effect for the lateral position, but only for the "65 mph" and "following a vehicle" scenarios while participants were performing mathematical calculations. However, the authors cannot explain why the variation is at its lowest in the most demanding conditions and sometimes deteriorates over subsequent days under the control condition. For example, during emotional conversations at 65 mph, variation in the lateral position of the vehicle increases from one session to the next.

Thirdly, they observed an interactive effect between age, scenario, session and condition for the "variation in steering" indicator. This time, there was a learning effect for all participants while driving at 65 mph and answering mathematical problems. However, the opposite effect was observed during conversation.

The results obtained by Shinar and Tractinsky (2004) are not easily interpreted even though the authors claim to have evidence that supports the learning effect hypothesis. Certain clarifications must be provided. Firstly, speed remains higher under the most demanding conditions. While the participants improve their driving, performance is always inferior to that observed under the control condition. Secondly, the authors often interpret the relation between session and performance as a learning effect while the trend displays a saw tooth relationship. Thirdly, participants aged 60-71 are often those who improve the most, which does not allow the results to be generalized to the whole sample. Fourthly, the results show that the participants manage the mathematical tests better as the trials go by. There is reason to wonder whether emotional conversations, which do not involve answers that can be memorized, represent the most difficult situation. In other words, it is likely that the participants would be more distracted if the mathematical equations changed from session to session. The learning effect is perhaps attributable to the memorization of answers to mathematical tests, rendering this experimental condition uninformative. Finally, it is impossible to draw any conclusion about the effect of learning on visual and cognitive tasks.

Performance of users vs. non-users

The second way to approach the learning effect hypothesis is to study the relationship between the average effect of the studies and the proportion of cell phone users in their sample. When that information was available, the proportion of cell phone users was calculated for each study. Thereafter, a correlation coefficient was calculated for the proportion of cell phone users and the average effect of each study. Only 23 studies report the proportion of users, which limits the analyses to one dependent variable; namely, the average effect on performance. According to our findings, there was no statistically significant relationship between the proportion of users in a study and performance results (Spearman's rho = 0.22; p = 0.44).[13] The decline in performance proves to be independent of the number of users in the experiment. This observation also arises from studies that distinguish users from non-users in their analyses (Jenness *et al.*, 2002; Radebord *et al.*, 1999; Lee *et al.*, 2001). Users do not perform better than non-users under the experimental condition.

6.1.3 Summary

The results of the experimental studies are clear: cell phone use while driving results in a significant reduction in participants' performance. This reduction in performance is observed in each type of primary task: biomechanical, cognitive and visual. However, the effect is more pronounced in the visual and cognitive tasks. Our results concur with those reported in the

[13] These 23 studies were compared to 41 others on the basis of their characteristics. The average effect, the proportion of men, and the average age of participants are identical in the two groups of studies. The contexts in which the studies were carried out and the type of publication are also similar. It is not very probable, therefore, that the correlation coefficient is influenced by the properties of these 23 studies.

meta-analyses of Caird *et al.* (2004) and of Horrey and Wickens (2004) and establish that cell phone use primarily causes cognitive and visual distraction. Due to the interdependence of the tasks, a reduction in cognitive resources used for primary tasks would affect all the other tasks necessary for driving (Evans, 2004).

The cognitive distraction argument is reinforced by the fact that the two types of devices, hands-free and hand-held, produce the same negative effects on driving performance. The inherent biomechanical dimension of a hand-held device does not increase the effect on performance. This result also calls Wickens' (1984) model into question. Regardless of the task carried out with a cell phone, the distraction remains. It is sufficient to say that a telephone conversation, which requires cognitive resources, will affect primary biomechanical, visual and cognitive tasks. Moreover, the hands-free device may produce more distraction than the hand-held cell phone in some cases. Sometimes, a speaker placed in the vehicle's ceiling light combined with poor quality sound may demand more attention than the hand-held device (Matthews *et al.*, 2003).

Cognitive distraction is therefore primarily caused by conversation, which implies that conversation with a passenger might produce a similar distraction. That being said, the results of the experimental studies are insufficient to present a firm conclusion regarding this hypothesis. However, many arguments suggest that conversation with someone on a cell phone is more demanding than a conversation with a passenger. Crundall *et al.* (2004) have shown that passengers reduce or slow down their flow of speech as the difficulty of primary task increases; this effect was absent during telephone conversation. Passengers can assess the road environment and adjust their conversation according to the complexity of driving conditions.

Finally, our results establish that cell phone use while driving produces the same negative effects on performance independent of age, sex and the context in which the experiment takes place (Reed and Green, 1999). Furthermore, the current level of knowledge does not support the learning effect hypothesis. The studies that carried out comparisons between user and non-user performance under the same conditions reported no difference: the two groups are equally affected by cell phone use (Jenness *et al.*, 2002; Radebord *et al.*, 1999; Lee *et al.*, 2001). Shinar and Tractinsky (2004) are the only ones to report improvement in performance with practice, but interpretation of their results is debatable and there is no doubt that performance always remains lower under the experimental condition.

6.2 CELL PHONE USE AND COLLISION RISK: RESULTS OF EPIDEMIOLOGICAL STUDIES

The results of experimental studies show that cell phone use leads to a decline in driving performance. But does this deterioration of performance necessarily translate into an increased risk of collision? This section attempts to answer this question using the results of epidemiological studies. We reviewed 18 studies that allow, to varying degrees, the relationship between cell phone use and collision risk to be documented.

These 18 studies do not all establish this effect in the same way. Firstly, ten studies examine the factors associated with collisions using the information contained in reports. Secondly, 10 studies calculate, using various methods, the RR of collision associated with being a cell phone user or using a cell phone while driving, or collision rates for users and non-users, for comparative purposes.[14]

6.2.1 Collisions associated with cell phone use based on police reports

Collision reports are a source of information that make it possible to determine the prevalence of cell phone use while driving as a factor associated with collision. However, the information contained in these reports no doubt underestimates the scope of the phenomenon. In fact, with the exception of three US states, police reports generally do not provide a checkbox for indicating the presence of cell phones. In Oklahoma, police must specify in their reports if a cell phone was installed or used. Also, in Minnesota, reports have checkboxes for recording the presence/use of a cell phone or CB radio. Finally, researchers at the *Highway Safety Research Center* in North Carolina requested that police officers temporarily add sections to their collision reports to measure the extent of the problem of cell phone use during collisions.

Even so, it is hard to incriminate the cell phone as a factor contributing to collisions. Only the information collected from drivers, passengers and witnesses allows us to determine whether cell phone use was present. Contrary to DWI, no test detects cell phone use, which complicates the job of accident scene analysts. Moreover, Stutts *et al.* (2001) demonstrate that people are not inclined to admit that they were talking on a cell phone at the time of a crash for fear of insurance coverage problems and concern over social desirability.

American studies

Four studies carried out in the United States used or set up databases using collision reports in order to document the prevalence of cell phone use during collisions. Goodman *et al.* (1997) consulted four different databases. Firstly, they analyzed narrative information of fatal crashes in the *Fatality Analysis Reporting System* (FARS). For 1994 and 1995, respectively, 36 and 40 fatal crashes were associated with cell phone use. Secondly, they consulted data from the *National Automotive Sampling System* (NASS). This database complements the *FARS*. Five thousand collision reports were selected randomly and analyzed in detail. Of five thousand collision reports, 8 were tied to cell phone use, which, extrapolating to all collisions, yields 3,857 collisions of varying severity associated with cell phone use for the entire United States. Thirdly, Goodman *et al.* studied 28 collisions related to cell phone use, of which 11 were filed in FARS and NASS (17 were tracked using other sources). In these 28 cases, the driver was at fault. Drivers had veered out of the lane in 15 cases, run into a stationary vehicle on the road in 8 cases and not stopped at a red light in 5 cases. Fourthly, Goodman *et al.* (1997) also analyzed narratives from 900,000 North Carolina police reports for the years 1989, 1992 to 1994 and the first six months of 1995. Reinfurt *et al.* (2001) completed the picture by including the years 1995 to 2000. The data in Table 10 show that the number of collisions associated with cell phone use has been rising since 1989. Furthermore, 45.8% of the collisions occur during conversation, reinforcing the position that cell phone use while

[14] The term cell phone user refers to motorists who are cell phone owners. In the same way, non-user refers to a motorist who does not possess a cell phone. In each case, the term does not refer to someone who uses his or her cell phone while driving. When a cell phone user uses his or her cell phone while driving, this is specified in the text.

driving constitutes, above all, a source of cognitive distraction. Finally, Goodman *et al.* (1997) carried out a regression analysis that shows there is a statistically significant relationship between the number of collisions linked to cell phones and the number of wireless service subscribers. Result: the more subscribers there are, the more that collisions linked to cell phones will increase.

For their part, Stutts *et al.* (2001) analyzed 32,303 collision reports, occurring between 1995 and 1999, from *FARS* and *NASS* to assess the importance of distraction during collisions. Out of all the collisions, the driver was distracted in 7.4% of cases (2,380 collisions during the five years). Cell phones were the cause in 1.5% of collisions involving distraction. The authors, however, emphasize that distraction is difficult to identify when analyzing collision scenes. It was impossible to draw a conclusion about whether distraction was a factor in 41.5% of cases.

Table 10 Collisions associated with cell phones according to verbatim reports in North Carolina by year and driver action

Driver action		Goodman *et al.* (1997)					Reinfurt *et al.* (2001)					Total	
		1989	1992	1993	1994	1995	1996	1997	1998	1999	2000*	N	%
Dial a number		1	0	3	3	0	4	5	4	13	11	44	8.2
Answer the cell phone		2	3	3	1	1	3	6	11	18	31	79	14.7
Talk on the cell phone		6	7	5	12	7	12	15	19	44	120	247	45.8
Hang up		2	1	3	0	1	0	4	3	3	9	23	4.8
Reach for the cell phone		1	2	4	0	4	1	1	8	12	20	53	9.8
Drop the cell phone		0	0	0	0	0	1	0	1	2	0	4	0.7
Pick up the cell phone		0	1	2	3	4	1	1	2	5	15	34	6.3
Look for the cell phone		0	0	2	0	1	0	2	4	11	19	39	7.2
Disturbed by ringing		0	0	0	0	0	0	0	1	3	4	8	1.5
Pull over to use the cell phone		0	0	0	1	1	0	1	0	0	2	5	0.9
Total	N	12	14	22	20	19	22	35	53	111	231	539	100
	%	2.2	2.6	4.1	3.7	3.5	4.1	6.5	9.8	20.6	42.9	100	

* January to August. The years 1990 and 1991 are not included because the verbatim accounts in the collision reports were not computerized due to a staff shortage (Reinfurt *et al.*, 2001).

In 2002, Stutts *et al.* published a report that focused more closely on collisions due to cell phones. The narrative sections from 425 reports were analyzed in order to identify the characteristics of collisions involving cell phone use. Among the 425 collisions, 2 involved fatal injuries, 2.1% involved serious injuries, 6.4% led to minor injuries, 36.2% involved possible injuries and 54.8% involved property damage only. The collisions involving cell phone use occurred primarily on local roads and between 10 a.m. and 6 p.m. Finally, 92.5% of the collisions associated with cell phones involve Highway Code infractions such as failure to slow down, failure to observe road signs, and failure to stop.

Violanti (1998) examined reports filed by Oklahoma State Police between 1992 and 1995. Of 1,548 fatal collisions, the reports indicate the presence of cell phones in the vehicle in 65 cases and their use in 7. In a prior study by Violanti (1997), 2.6% (5,292) of drivers had a cell phone in their vehicle and 0.24% (492) were using it, out of a total of 206,639 collision reports filed by Oklahoma police.

The studies carried out using American data show that cell phones are the cause of some collisions, but certainly underestimate the scope. On one hand, the most recent data date from 2000, a period for which the number of subscribers to a wireless telecommunication service is lower than in 2007 (see Figure 1, p. 11). On the other hand, the police experience problems determining if a driver was talking on a cell phone or not at the time of a crash. In spite of these limitations, the American studies show that collisions associated with cell phone use tend to increase at the same rate as sales of cell phones and their use while driving (Goodman *et al.*, 1997; Stutts *et al.*, 2001 and 2002; Reinfurt *et al.*, 2001).

Studies carried out in other countries

Stevens and Minton (2001) looked at 5,740 reports of fatal collisions filed between 1985 and 1995 in England. According to the authors, the United Kingdom reports are more detailed than those of other countries and allow for a more precise count of the proportion of collisions related to distraction. According to their results, 2% (N=101) of 5,740 fatal collisions were related to distraction. Moreover, cell phone use was the cause in 3 cases.

For his part, Lam (2002) studied 414,136 collisions reported by the New South Wales (Australia) police between 1996 and 2000. Of this number, 63,779 involved serious or fatal injuries of which 3.8% (N=2,400) were attributable to distraction. Cell phone use was responsible for 120 collisions, of which 30 produced serious or fatal injuries.

Finally, Woo and Lin (2001) requested that police in three cities in Taiwan add two indicators to their collision reports for a period of four months in order to report the presence or use of a cell phone at the time of a collision. This allowed them to analyze information from 3,075 reports. Cell phone presence was reported in 22% (n=676) of collisions, with the driver using a cell phone at the time of the crash in about 20% of the cases (133/676). In other words, cell phones were involved in 4.3% (133/3,075) of the collisions, which is greater than the rate reported by Violanti (1997 and 1998).

Quebec

In Quebec, only the report of coroner Claude Paquin deals with the prevalence of cell phones during collisions. Between 1998 and 2004, coroner Paquin counted ten road deaths associated with cell phone use. In some cases, it could be established that cell phone use was the direct cause of the fatal collision, while in other cases this link could not be established, but cell phone use was a contributing factor (SAAQ, 2006).

6.2.2 Cell phone use and collision risk

Collisions with property damage

Three epidemiological studies that address the relationship between cell phone use and collisions with property damage report an overall increase in collision risk for cell phone users or for users who make use of them while driving.[15] The results of the epidemiological studies appear in Table 11.

Redelmeier and Tibshirani (1997) carried out the most frequently cited study using Toronto data. They used the case-crossover method to evaluate the RR of collisions associated with cell phone use. They conducted their study among drivers who were cell phone users and who reported collisions with property damage at the North York Collision Reporting Center between July 1, 1994 and August 31, 1995. The drivers who participated in the study filled out a brief questionnaire and authorized access to their cell phone records. In a sample of 699 driver-cell phone users who had a collision with property damage, 157 were talking on the phone during the "hazard" period, between T_{-10} minutes and T_{-1} minute before the crash, but were not talking on the cell phone during the same "hazard" period the day before. On the other hand, 24 drivers did not use a cell phone during the hazard period, but had used it during the hazard period the day before.

The RR is estimated by dividing 157 by 24. Cell phone use increases the risk of collisions with property damage 6.54 times (95% IC: 9.99; 4.50). However this report probably overestimates the RR since some drivers probably did not drive the day before the collision. Redelmeier and Tibshirani (1997) accordingly adjusted their estimate based on the results of a survey of about 100 drivers, 65% of whom admitted to having driven during the hazard period the day before the collision. Consequently, the RR equals 4.3; that is, 0.65 multiplied by 6.54. Finally, Redelmeier and Tibshirani (1997) establish that risk is present no matter what the device. Using the same method, the authors calculate a risk of 3.9 for hand-held devices and 5.9 for hands-free devices.

[15] The Laberge-Nadeau *et al.* (2001 and 2003) study takes into account collisions with property damage and personal injury. However, it is impossible to distinguish between the two types of collision. This study is addressed in the section on "personal injury", below. The same applies to the Violanti and Marshall (1996) study. Finally, the results presented in the section "property damage" could be applied to collisions with more severe consequences. However, the authors do not always classify risk according to severity of the collision. Although risk of collision is presented according to the seriousness of the injuries, the categories of seriousness are not always exclusive.

Despite the many advantages of the case-crossover method compared to other epidemiological studies, it is probable that collision time is not precise in the collision reports and as a result, it is not possible to establish with certainty that drivers were speaking on a cell phone at the time of the collision even if it is known they were using it 10 minutes before the reported collision time. Thus, these rates can vary according to the time interval selected (Bellavance, 2005).

For their part, Wilson *et al.* (2002 and 2003) put together a sample of 3,869 drivers in the greater Vancouver area using field observations. Observers were posted at 42 intersections. When a driver used his or her cell phone while going through an intersection, the observers noted various characteristics and the driver was incorporated into the sample. The researchers did the same for the non-user driver that followed. This approach produced a sample composed of an equal number of users and non-users. A follow-up review of the drivers' records established that 452 of the 3,869 drivers had been involved in 513 collisions reported to police between 1997 and 2000. Wilson *et al.* (2002 and 2003) established that the cell phone users were 13% (RR=1.13) more likely to be involved in an "at-fault" collision than non-users.

Finally, Violanti (1997) examined the types of collisions in which cell phone users are involved. His sample is made up of 206,639 collision reports completed between 1992 and 1995 by Oklahoma State Police (United States). The police reports indicate that a cell phone was present in the vehicle in 2.6% of the cases (n=5,292) and the driver was using a cell phone at the time of the collision in 492 cases. Compared to non-users, users and cell phone users while driving had double the risk of getting into a collision with a stationary object and were five times more likely to roll over during a collision. According to Violanti, this "result suggests that drivers with a phone in the vehicle had accidents in a significantly greater rate during 1992-1995 than those who did not have a phone, despite the concurrent increase in all traffic accidents" (Violanti, 1997: 425).

Table 11 Summary of epidemiological studies

Type of study	Sample	Dependent variable	Results	Comparison with other risk factors
Laberge-Nadeau *et al.* 2001 and 2003 Retrospective epidemiological study (case-control) and case-crossover method	36,750 Quebec (Canada) motorists who answered a questionnaire and gave access to their driving and cell phone records With the case-crossover method: 407 collisions occurring between 1998 and 2000 in a sample of 36,750 Quebec motorists	Collision with property damage or personal injury (time frame January 1, 1996 to August 31, 2000).	Users' RR of having a collision is 1.38 times higher. Risk increases with usage (dose-response relationship). In men, the RR goes from 1.97 to 2.73 for those who make between 14-26 and 259-384 calls per month, respectively. Results with the case-crossover method: The driver-users who use their cell phones while driving have an RR of 5.13 compared to users who do not use them while driving.	Risk of collision is higher for those who work on the road, travel more kilometres than average, drive after 8 p.m. and rarely or never have passengers.
Violanti and Marshall, 1996 Epidemiological study, case-control method	200 New York (United States) motorists. Group 1: 100 motorists who had a collision with property damage of $1,000 and up or with personal injury. Group 2: 100 motorists who had not had a collision in the past 10 years.	Collision with property damage or personal injury (time frame: 1992-1993 for Group 1).	Users who talk between 51-180 minutes per month have an RR of collision 5.59 times higher than those who talk less than 50 minutes.	Number of kilometres travelled annually (RR = 6.75) and manual activities performed (RR = 1.66) such as drinking and adjusting controls increase risk of collision.

Table 11 Summary of epidemiological studies (continued)

Redelmeier and Tibshirani, 1997 Case-crossover method	649 motorists who are cell phone users who reported a collision with property damage, North York Collision Reporting Center (Toronto – Canada)	Collision with property damage occurring between July 1, 1994 and August 31, 1995 between 10 a.m. and 6 p.m.	Those who use their cell phones while driving have an RR of 4.3 compared to those who do not use them. The RR is 3.9 for hand-held devices and 5.9 for hands-free devices. The RR does not decrease with experience related to cell phone use.	No other risk factor included.
Lam, 2002 Epidemiological study, case-control method	63,779 fatal collisions or personal injuries reported to the New South Wales (Australia) police between 1996 and 2000, of which 2,400 involved some type of distraction.	Fatal collision or personal injury	RR for 16-19 year olds = 1.13 RR for 20-24 year olds = 0.50 RR for 25-29 year olds = 2.37 RR for 30-39 year olds = 1.67 RR for 40-49 year olds = 1.69 RR for 50-69 year olds = --- RR for 70 year olds + = 0.46 RR for hand-held cell phone	Distraction inside the vehicle RR for 16-19 year olds = 1.56 RR for 20-24 year olds = 1.38 RR for 25-29 year olds = 1.45 RR for 30-39 year olds = 1.56 RR for 40-49 year olds = 1.08 RR for 50-69 year olds = 1.55 RR for 70 year olds + = 1.82 Distraction outside the vehicle does not increase collision risk
Violanti, 1998 Epidemiological study, case-control method	223,137 accident reports from the Oklahoma State Department of Public Safety between 1992 and 1995 with 1,548 fatal collisions	Fatal collision	Having a cell phone in the vehicle increases the RR by 2.11. Using a cell phone while driving increases the RR to 9.29. Cell phone effect increases when a driver exceeds the speed limit, drives under the influence of alcohol or veers out of his or her lane.	With an RR of 9.29, the cell phone represents a risk two times greater than that of speeding (RR = 4.90), six times greater than inattention (RR = 1.36) and three times greater than DWI (RR = 2.83).

Table 11 Summary of epidemiological studies (continued)

Wilson *et al.*, 2003 Epidemiological study based on field observations and drivers' records (case-control)	3,869 motorists who went through one of 42 intersections between August 18 and November 2, 1999 between 7 a.m. and 6p.m. (Vancouver).	At-fault collision (time frame:1997 to 2000)	Using a cell phone while driving increases RR by 1.16.	Having had a ticket for dangerous driving (RR = 1.84), having been stopped for DWI (RR = 1.66) and having more than one at-fault collision (RR = 2.03) increases the risk of at-fault collision.
Violanti, 1997 Epidemiological study with cross-sectional data (case-control)	206,639 accident reports from the Oklahoma State Department of Public Safety between 1992 and 1995 with 5,292 indicating that the driver had a cell phone and 492 indicating the cell phone was being used at the time of collision.	Specific types of collisions	**Cause of collision when cell phone was being used** RR = 1.93 - excessive speed RR = 1.19 - distraction RR = 1.52 - wrong side of the road **Type of collision** RR = 2.29 - hit stationary object RR = 4.78 - rolled over **Driver action** RR = 1.35 swerved RR = 1.17 veered into other lane RR = 2.96 went off the road **Place** RR = 2.31 city Fatal collisions: RR of 10.9 for cell phone use while driving and RR of 2.50 for owners.	No other risk factor
McEvoy *et al.*, 2005 Case-crossover method	456 driver-cell phone users aged 17 years and over and who were admitted between April 2002 and July 2004 to emergency at one of three main hospitals in Perth (Western Australia). Fatal collisions are excluded.	Collision with personal injury occurring between April 2002 and July 2004.	Driver-users using their cell phones while driving have an RR of 4.1 compared to those who do not use them. RR = 4.9 for hand-held cell phone RR = 3.8 for hands-free cell phone	No other risk factor

Collisions with injuries

The five studies that focus on collision risk causing personal injury come to the same conclusion as the studies evaluating collision risk with property damage. Using a cell phone while driving, and being a cell phone user, increase the risk of collisions with injuries. However, some studies combined collisions with injuries and material collisions together as their dependent variable. Therefore, it is not always possible to distinguish the risk for each of the two collision categories.

One of the two most important studies undertaken in the world was conducted in Quebec. Laberge -Nadeau *et al.* (2001 and 2003) sent out 175,000 questionnaires to Quebec driver's licence holders in order to get a representative sample.[16] Of this number, 36,078 questionnaires were returned along with a consent form allowing the researchers to examine the participants' driving records and cell phone records. Their analyses are a mine of results and allow a better understanding of the relationship between use and possession of a cell phone and the risk of collision with property damage or personal injury. Firstly, their analyses show that the RR of collisions is 38% (RR=1.38) higher for cell phone users than for non-users. Secondly, their findings establish the existence of a "dose-response" relationship between the frequency of cell phone use and collision risk. The RR is 2.78, 3.55 and 3.33 for those logging a monthly call total of between 193-258, 259-384, and 385 and above, respectively. Thirdly, the data were re-analyzed using the case-crossover method. The hazard period is identical to that of Redelmeier and Tibshirani (1997); i.e. between T_{-10} minutes and T_{-1} minute before collision. Altogether, 407 collisions were reported to the police: 292 with property damage and 115 with personal injury. Cell phone use is associated with an RR of collisions of 5.13 (Laberge-Nadeau *et al.*, 2001 and 2003; Bellavance, 2005).

Not only did Laberge-Nadeau *et al.* (2001 and 2003) obtain their results using a sample of Quebec motorists, they also complied with certain criteria which make it possible to suggest a causal relationship between cell phone use and collision risk. Firstly, an association was detected using three types of analyses: 1) users have 1.38 times more risk of being involved in a collision than non-users, 2) risk of collision increases with frequency of use and 3) risk of collision increases 5 times for users when they use their cell phone while driving. Secondly, risk of collision increases with use (dose-response relationship). Thirdly, the authors made sure the motorists had obtained their driver's licences before their mobile phones (X comes before Y). Fourthly, the results are the same for drivers with different characteristics. Fifthly, the results corroborate those of other experimental and epidemiological studies. Sixthly, statistical models make it possible to control the effects of other factors such as exposure to risk, driving habits, age and sex. Finally, their sample was formed from the entire population of Quebec motorists.

[16] Their data were collected in 1999, a period during which there were not as many cell phone users as in 2006. In order to recruit a sufficient number of users, they had to oversample certain layers of the population; namely, people living in urban areas and having high incomes.

Maag *et al.* (2006) re-analyzed the data from Laberge-Nadeau *et al.* (2001 and 2003). Their approach aimed at answering two questions. Firstly, the epidemiological studies show that cell phone users are more at risk of collision than non-users. Maag *et al.* (2006) asked if people using mobile phones were a priori more or less at risk of collision than those who do not use them. Secondly, they attempted to verify a widespread belief among users that cell phones do not constitute a road safety problem since the rate of use is increasing and the road toll is improving. To answer these two questions, Maag *et al.* (2006) used those participants who had a driver's licence in 1987, which included 18,707 respondents out of a total of 36,078. They then compared the variations in collision rates between 1987 and 1999 in the cohorts of users and non-users.

Two important results surfaced from their analyses. Firstly, users had significantly more collisions in 1999 than non-users with an odds ratio of 1.55. This difference is not significant for women (OR = 1.27), but it points in the same direction. Secondly, Table 12 shows that:

> (…) the group of people who acquired a mobile phone after 1987 is not significantly more at risk of collision at the start, but after the acquisition, this group is more at risk than the group that remained non-users. Men who own a cell phone have a 55% greater chance of having at least one collision per year than men who do not use them. (Maag *et al.*, 2006: 455) *[Translation]*

These findings show conclusively that the declines in the collision rates of the two cohorts differ. The rate of collision for non-users decreased more than that for users and the difference is yet more pronounced for the 35-54 age group. The authors therefore conclude that.

Unless driving style and exposure to collision risk changed in very different ways for the two groups during the 1987-1999 period, the argument made by mobile phone supporters who say there is no problem because the collisions rates are going down even though the number of users is growing steadily is not valid. (Maag *et al.*, 2006: 455) *[Translation]*

Table 12 Drop in number of drivers with at least one collision recorded in a police report; comparison of percentage decrease on use or non-use of a mobile phone for men and women and according to age

Number of people with at least one collision	Men				Women			
	Users		Non-users		Users		Non-users	
Age in 1987	16-34	35-54	16-34	35-54	16-34	35-54	16-34	35-54
1987	156	138	155	243	32	25	69	101
1999	77	82	64	95	14	15	28	47
Drop	79	56	91	148	18	10	41	54
%	50.6	40.6	58.7	60.9	56.2	40.0	59.4	53.5

Source: Maag, U., Laberge-Nadeau, C., Augers, J-F., Bellavance, F., Poirier, L-F., Desjardins, D. and Messier, S. (2006). Les collisions entre 1987 et 1999 : comparaisons entre les personnes utilisatrices du téléphone cellulaire en 1999 et les toujours non-utilisatrices. *Assurance et gestion des risques*, 73: 443-456.

Finally, the collision rates presented by Maag *et al.* (2006) make it possible to estimate the number of collisions associated with cell phone use. Extrapolating the results of Maag *et al.* (2006) to the entire Quebec motorist population, as Goodman *et al.* (1997) did with the American data, it is possible to get an approximate estimate of collisions linked to cell phones for Quebec in 1999. To produce this estimate, only male licence holders are used, because the odds ratio between users and non-users is not significant for women. In 1999, there were 2,386,680 male driver's licence holders in Quebec. According to the data in Maag *et al.*, 39.6% of licence holders in their sample are cell phone users. Extrapolating this percentage to all male permit holders, about 945,125 holders were users in 1999. Considering that 3.1% of the driver-users had one collision in 1999, this makes a total of 29,298. If they had not been cell phone users, they would have had 18,902 collisions, which corresponds to 2.0% of non-users having collisions. This is a difference of 10,396 collisions with property damage and injury for 1999 alone, which accounts for more than 7% of all collisions.

The estimate obtained using the data from Maag *et al.* (2006) is, however, conservative because of certain limitations. Firstly, in constructing the sample, Laberge-Nadeau *et al.*, (2003) oversampled certain strata of the population; namely, motorists residing in an urban area, men, and the more affluent, in order to recruit a sufficient number of users for their sample. Secondly, 36,078 motorists returned their questionnaire out of 175,000 that were sent out. One of the ways respondents differed from non-respondents was that their collision rate per 1,000 drivers was lower, especially among men.

Although their sample is more limited than that of Laberge -Nadeau *et al.* (2001 and 2003), McEvoy *et al.* (2005) also used the case-crossover method and obtained similar results, but only for risk of collision with injuries. McEvoy *et al.* contacted 1,625 drivers admitted to a hospital in Western Australia between April 2002 and July 2004. Of this number, 941 were interviewed and phone records for 744 drivers were obtained. Their analyses show that cell phone use increases the risk of collision with personal injury requiring hospitalization by 4.1 times (fatal collisions excluded). Finally, the McEvoy *et al.* study calculate the RR for each type of cell phone. The relative risks are 4.9 and 3.8 respectively for hand-held and hands-free devices.

Lam (2002) used traffic incidents reported by New South Wales Police (Australia). His study focuses not only on the relationship between cell phones and collision risk, but also integrates other sources of distractions. Although distraction is under-reported in collision reports as a "cause" of collision, cell phones increase the risk of fatal or personal injury collisions for all age groups. However, the effect is more pronounced in the 25-29 (RR=2.37), 40-49 (RR=1.69) and 30-39 (RR=1.67) age groups. Lam establishes that distractions inside the vehicle increase the RR of collisions. The risk varies between 1.08 and 1.82 depending on the age of the drivers. However, this variable includes many internal sources of distraction which are not specified by the author. Therefore, it is difficult to identify the sources of distraction that actually increase risk.

Finally, Violanti and Marshall (1996) used the case-control method to determine the collision risk associated with cell phone use. They randomly set up two cohorts of 100 New York drivers. In the first cohort, the drivers reported at least one collision between 1992 and 1993. In the second, the drivers had not had a collision for the past ten years. Taking into account 18 other sources of distractions and the participants' characteristics in their analyses, Violanti and Marshall (1996) show that users who talk between 51-180 minutes per month (not necessarily while driving) have 5.59 times more chance of being involved in a collision with property damage than those with more limited use. According to their findings, "[a]pparently, cellular phone use as a single behavior may affect accident risk to a greater degree than many other in-car activities" (Violanti and Marshall, 1996: 269). However, their sample includes only 14 users and their analyses do not take into account exposure to risk.

Fatal collisions

Two studies addressed the issue of cell phone use while driving and the risk of fatal collisions. Violanti (1998) used collision reports to measure the RR of being involved in a fatal collision, making a distinction between cell phone owners and those who use them while driving. This study used 223,137 collision reports from the Oklahoma police. Of this total, 1,548 reports involved fatal injuries. A cell phone was present in 65 cases and the police were sure that the driver was using a cell phone in five cases. Using logistic regression analyses, Violanti establishes that the presence of a cell phone in the vehicle at the time of collision increases the risk of dying by 2 and cell phone use while driving increases the risk of fatal collisions by 9. The risk associated with cell phones is even greater than when the driver exceeds the speed limit, drives while impaired (DWI) or drives left of center. In fact, the risk of fatal collisions linked to cell phone use is 9, which is double the RR associated with speed (RR=4.90). The RR linked to cell phones is also greater than that of other "causes" such as general inattention (RR=1.36) and DWI by alcohol or another drug (RR=2.83). However, this study has certain limitations, particularly with regards to its assessment of the collision risk linked to cell phones. The estimate of this risk is imprecise, as indicated by a 95% confidence interval, which varies between 3.7 and 23.1 for the RR.

At the outset, Dreyer *et al.* (1999) wanted to verify whether hand-held cell phone users had a higher death rate from cancer of the brain than hands-free users. They hypothesized that hand-held cell phone users should have a higher mortality rate linked to brain cancer than hands-free users. The reason: cell phone waves reach the brain with a hand-held device, which is not the case with a hands-free telephone. Moreover, the risk of brain cancer should increase with frequency of use. Their analyses show that:

> The only category of cause of death for which there was an indication of increasing risk with increasing minutes of use was motor vehicle collisions, for which the handheld vs nonhandheld distinction does not apply since either type of telephone may interfere with driving. (Dreyer *et al.,*1999: 1815)

Effects of other sources of distraction on collision risk

Some epidemiological studies are not concerned solely with the effect of cell phones on driving. In order to achieve credible results, they include other factors and sources of distraction that likely influence collision risk in their prediction model (Violanti and Marshall, 1996; Laberge-Nadeau *et al.*, 2003). The results of these two studies suggest that cell phones increase the risk of collision more than other potential sources of distraction.

In addition to evaluating the effect of cell phones on collision risk, Violanti and Marshall (1996) took into account secondary cognitive and biomechanical activities. They created two dichotomous variables (yes or no), being 1) cognitive activities (e.g. thinking about problems, looking at the countryside or talking with passengers) and 2) biomechanical activities (e.g. drinking, adjusting the radio or lighting a cigarette). Their results show that biomechanical activities increase the risk of collision with property damage or personal injury by 66% (RR=1.66), but that cognitive activities have no impact. The risk associated with biomechanical activities is still less than that of talking for 51-180 minutes per month on a cell phone (RR=5.59).

In their analyses, Laberge-Nadeau et *al.* (2003) took into account many factors such as carrying passengers, listening to the radio and handling/changing CDs or cassettes. Their results show that listening to the radio and handling CDs/cassettes did not influence risk of collision with property damage or personal injury. On the other hand, motorists who never or rarely carry passengers increase their collision risk in comparison to those who carry them often. The RR is 1.14 for women and 1.18 for men. According to these results, having passengers acts as a safety factor.

6.2.3 Summary

All the epidemiological studies arrive at the same conclusion: cell phone use while driving increases the risk of collision. This assertion prevails independently of the seriousness of the collision and the methods used to estimate the risk. The most rigorous studies, those that use the case-crossover method, show that cell phone use while driving significantly increases the risk of collisions with property damage and personal injury. However, the RR of collision, which varies between four and five, is probably overestimated because of the hazard period. The risk diminishes if the period is greater than ten minutes (Bellavance, 2005), but still remains significant.

The epidemiological studies make it possible not only to assess the RR of collision, but also to verify if the risk is constant with respect to certain conditions or driver characteristics. Firstly, the RR of collisions is a function of the intensity of cell phone use: the more users use their cell phones, the more collision risk increases (Laberge-Nadeau *et al.*, 2003; Violanti and Marshall, 1996). Secondly, collision risk is the same for hands-free and hand-held devices (Redelmeier and Tibshirani, 1997; McEvoy *et al.*, 2005; Dreyer *et al.*, 1999). These observations corroborate the findings of the experimental studies showing that cell phone use is principally a source of cognitive, rather than biomechanical distraction. Finally, cell phone use is the source of distraction that most increases collision risk. The risk of collision is higher for motorists who rarely or never carry passengers (Laberge-Nadeau *et al.*, 2003). Drinking and eating increase the risk of collision with property damage or personal injury by 66% (Violanti and Marshall, 1996), which is less than the risk of 400 to 500% associated with cell phone use.

Although all the empirical studies link cell phone use to increased collision risk, some might ask if the risks are the same in Quebec. In fact, the summary presented in this report encompasses the world literature. However, the Laberge-Nadeau *et al.* (2003) study was carried out using a sample drawn from the Quebec motorist population. According to their results, cell phone users show an RR of collisions with property damage or personal injury 38% greater than that of non-users, and cell phone use while driving increases the RR of collision to 5.13 (Laberge-Nadeau *et al.*, 2003). Finally, Maag *et al.* (2006) show that even though the road toll has improved over the years, the rate of collision remains higher for users than for non-users. The empirical results demonstrate that the number of collisions would be lower if cell phones were not used while driving.

6.3 OBSERVATION STUDIES OF REAL SITUATIONS: CELL PHONE EFFECT ON USER BEHAVIOUR

Two other studies which used different methodologies also studied the relationship between cell phone use, collision risk and drivers' behaviours. In the first study, Strayer (2005) verified whether there was a relationship between cell phone use and the ability to stop at a stop line (stop sign). To do this, data were collected at four intersections between 5 and 6 p.m. on Mondays, Wednesdays and Fridays during good weather conditions. The observers determined whether the driver stopped at the line and was using a cell phone. Out of a total of 1,748 observations, 110 drivers were using a cell phone. The results show that drivers using cell phones were ten times more likely not to stop at the stop line than non-user drivers (RR=2.93 vs. 0.27). Three quarters of users did not stop at the stop line compared to 19.2% of non-users (chi-square [1] = 129.8; p <0.01).

The National Highway Traffic Safety Administration (NHTSA) funded a study (the 100-car naturalistic study) aimed at examining the factors associated with collisions in real driving situations. One hundred drivers were recruited in the metropolitan area of Northern Virginia and Washington (DC) using leaflets left on vehicles and announcements in newspapers.[17] Participants' vehicles were equipped with computers and video cameras to collect data. The participants were to drive their vehicles as usual. Over a period of 12 to 13 months, the researchers were able to collect information on 2,000,000 miles travelled and 43,000 hours of video recording for 241 drivers (sometimes the car was used by more than one driver). Then an epidemiological database was used to process three types of events: collisions, quasi-collisions and other road incidents.[18]

Of all the drivers, only 7.5% were not involved in some incident. In addition, 7.4% of the drivers were involved in several incidents, resulting in up to three or four collisions. Altogether, 69 collisions, 761 quasi-collisions and 8,295 incidents were recorded. Distraction

[17] As emphasized by Neale *et al.* (2005), the sample is not representative of the American driving population. The researchers also excluded very careless and overly cautious drivers using questionnaires. Finally, the volume of traffic varies from moderate to high in this region and the participants were to drive one of six vehicle models (Toyota Camry, Toyota Corolla, Chevrolet Cavalier, Chevrolet Malibu, Ford Taurus or Ford Explorer) because of compatibility with the equipment required for the experiment.

[18] A collision is defined as any contact between a participant's vehicle and another vehicle, a stationary object, a pedestrian or even an animal. Quasi-collisions are defined as a problem situation which requires a rapid response in order to avoid a collision. Finally, incidents represent a problematic situation requiring a rapid manoeuvre but of lesser scope than a quasi-collision.

linked to secondary tasks is the main cause in the three categories of events. Use of a wireless communications device is the principal source of distraction associated with problem situations. Dialling a number on the telephone and conversation were the two main tasks associated with incidents and quasi-collisions, while all collisions happened during conversation.

7 RESULTS: MEASURES FOR CONTROLLING CELL PHONE USE WHILE DRIVING

For many jurisdictions, the risk associated with cell phone use while driving is unacceptable. They have, therefore, enacted laws and taken measures to limit such use. Four types of measure have been identified. Firstly, many jurisdictions have enacted laws to limit or ban cell phone use. According to the documents consulted, over 50 countries have enacted laws regulating cell phone use while driving (McCartt *et al.*, 2005). The majority of jurisdictions ban the use of hand-held cell phones while driving. Secondly, in some cases, design guidelines have been imposed on automobile manufacturers. For example, the Japan Automobile Manufacturers Association (JAMA) has established strict safety guidelines to ensure that manufacturers design telematics devices whose tasks can be performed in less than one second. However, these guidelines have not yet been evaluated. Thirdly, some government agencies and associations have launched media campaigns to raise drivers' awareness of the risks associated with using a cell phone while driving a motorized vehicle (SAAQ, 2006; CWTA, 2006). Although these educational campaigns have not been evaluated, they generally have little effect when used alone (Delhomme *et al.*, 2000; Elliott, 1993). Finally, some companies oblige their employees to use hands-free devices or turn off their cell phones while driving (Royal Society for the Prevention of Accidents, 2002). Apart from legislation, other initiatives have not been evaluated to determine their effectiveness.

7.1 EFFECTS OF LEGISLATION ON COLLISION RATES AND HAND-HELD CELL PHONE USE

According to the documents consulted, two countries have completely banned cell phone use while driving. In Portugal and India (New Delhi only) drivers are prohibited from using cell phones while driving, irrespective of the type of device. Despite the numerous laws that have been enacted in many countries, evaluations are rare (Vanlaar, 2005). Database searches for various works of synthesis resulted in five studies that have evaluated the effects of laws banning hand-held cell phone use.

On June 26, 2001, New York became the first American state to ban the use of hand-held cell phones in a moving vehicle. Drivers caught contravening the ban received a $100 fine unless they were making an urgent call. The law came into effect on November 1, 2001 and, during the first month, police gave out warnings to drivers caught contravening the law. The authorities introduced a period of grace between December 1 and February 28, 2002, cancelling the infractions of all drivers who presented proof in court that they had purchased a hands-free device. The period of grace ended on March 1, 2002 and drivers stopped after this were required to pay their fines. McCartt *et al.* (2003) evaluated the impact of the law on the rate of cell phone use among drivers. Based on data collected from four major cities in New York and two cities in Connecticut, for comparison purposes, the authors reported a 1.2% reduction in the rate of hand-held cell phone use. The rate went from 2.3% in September/October 2001 to 1.1% in March 2002 (the rate of use was the same for the two experimental periods; that is, during the period of grace and the period during which drivers were obliged to pay the fine).

McCartt *et al.* (2004) reevaluated the impact of the law, including the data from the month of March, 2003. Their analyses show that the rate of use went back up to 2.1%, which is comparable to the rate observed before the law took effect. Nevertheless, the increase observed in New York is still 21% lower than that observed in the state of Connecticut (see Table 13).

Table 13 Rate of hand-held cell phone use among drivers in the states of New York and Connecticut

	Rate of hand-held cell phone use		
State	Observations before the law (September/October 2001)	Observations after the law: March 2002	Observations after the law: March 2003
New York	2.3%	1.1%	2.1%
Connecticut	2.9%	2.9%	3.3%

Source: McCartt, A.T. and Geary, L.L. (2004). Longer term effects of New York State's law on driver's handheld cell phone use. *Injury Prevention*, 10: 11-15.

In the United Kingdom, a law banning the use of hand-held cell phones was introduced in December, 2003. Johal *et al.* (2005) observed a rate of use of 1.9% during the months of September and October, 2003 (comparison period) and of 1.0% in February and March, 2004 (experimental period) in the city of Birmingham, England. For their part, Rajalin *et al.* (2005) noted an increase from 3.1 to 5.8% in the rate of hand-held cell phone use among Finnish drivers, an increase that coincides with the enactment of their hands-free law in 2003. This result does not necessarily indicate that the law had an aberrant effect, because the evaluation does not take into account the fact that rates of use are rising in Western countries.

The only evaluation of the effect of a law banning hand-held cell phone use on collision rates was carried out in Japan. Since November 1, 1999, it has been illegal for drivers to use a hand-held cell phone while their vehicle is moving. Only emergency calls are permitted. Drivers who use hand-held cell phones while driving are subject to a fine that can go as high as 50,000 yen (approximately 500 Canadian dollars) or a maximum prison sentence of three months. A before/after comparison demonstrated that collisions linked to cell phone use while driving decreased by 52.3% (Japanese Directorate General for Policy Planning and Co-ordination, cited in the Royal Society for the Prevention of Accidents, 2002). Table 14 shows that decreases of 53.3 and 20.0% respectively were reported in the number of persons injured and killed in collisions caused by cell phone use.

Table 14 Comparison of the number of collisions during periods before and after the introduction of a law banning hand-held cell phone use in Japan

	12 months before introduction (November 1998 to October 1999	12 months after introduction (November 1999 to October 2000)	Variation expressed as a percentage
Number of collisions during which a driver was using a cell phone	2,830	1,351	- 52.3%
Number of persons injured in collisions linked to cell phone use by a driver	4,118	1,925	- 53.3%
Number of traffic deaths linked to cell phone use by a driver	25	20	- 20.0%

Source: Japanese Directorate General for Policy Planning and Co-ordination, cited in the Royal Society for the Prevention of Accidents (2002). The risk of using a mobile phone while driving. ROSPA: Birmingham (UK).

7.2 SAFETY GUIDELINES FOR AUTOMOBILE MANUFACTURERS

In some countries, manufacturers must respect certain guidelines aimed at ensuring that telematics devices do not distract drivers. The Japan Automobile Manufacturers Association (JAMA) has published version 2.1 of the *Guideline for In-vehicle Display Systems*. The Japanese government has approved the document, thus obliging manufacturers to comply with guidelines. “The fundamental approach of the Guideline is that telematics devices are to be used by the driver when the demands of driving are low and that in-vehicle display systems must not act as a distraction” (Transport Canada, 2003: 25). For example, when the vehicle is moving the dialling of a ten-key number on a cellular telephone is forbidden and televised pictures and video images are forbidden (see the Royal Society for the Prevention of Accidents (2002) for a complete list of the restrictions on in-vehicle telematics imposed on manufacturers).

The guidelines in effect in Japan demonstrate that it is possible to limit the distraction caused by in-vehicle telematics devices. Technology makes it possible to disable some telematics devices such as televisions and on-board navigators. These “standards” seem promising, considering that telematics devices are increasingly being installed in vehicles as basic equipment (Transport Canada, 2003). Also, the technology in question is passive and requires no action on the part of the driver.

7.3 SUMMARY

According to the authors of evaluative studies, results suggest that the laws banning the use of hand-held cell phones while driving lead to a short-term reduction in the rate of use (McCartt *et al.*, 2003 and 2004). However, these evaluations have some shortcomings which make it impossible at this time to draw definite conclusions about the overall effect of laws that partially ban cell phone use while driving.

The authors' interpretation of the evaluation results leads to the formulation of hypotheses that might explain the relatively high rate of use following the introduction of laws. Firstly, no study took into consideration the trend in cell phone sales. Given that cell phone sales are on the rise, it is likely that laws would not decrease the rate of use, but rather would slow its progression. At least this is suggested by the results of McCartt *et al.* (2004), which indicate that the increase in the rate of use is greater in Connecticut than in the state of New York. Secondly, the enactment of a law is no guarantee that users of the road network will obey it. Similar observations were produced by evaluations of laws focused on DWI and wearing seat belts. In fact, the reduction in the incidence of driving while impaired by alcohol and the associated reduction in collisions (Blais and Dupont, 2005) and the significant increase in the rate of seatbelt wearing (Dussault, 1990; SAAQ, 2001) are closely linked to the perceived risk of being stopped and, therefore, to the implementation of intensive enforcement programs. In the case of laws banning the use of hand-held cell phones while driving, no program of this type was implemented or enforcement activities were not documented (McCartt *et al.*, 2003 and 2004; Rajalin *et al.*, 2005).

A single study evaluated the effect of laws on the collision rate. According to data provided by the Japanese Directorate General for Policy Planning and Co-ordination, the law banning cell phone use while driving resulted in a considerable reduction in the number of collisions associated with cell phones. However, this evaluation has several limitations. Among other things, the results are based on a simple before/after comparison. It is likely that the decrease in collisions was partly due to a general downward trend in collisions and not only to the enactment of the law. The analyses do not take into account other factors likely to have had an impact on collision statistics. More sophisticated time series analyses would overcome this difficulty (see Shadish *et al*., 2002).

Finally, the potential of "hands-free" laws (i.e. where hands-free cell phone use is permitted, and hand-held cell phone use is not) seems limited. For one thing, experimental and epidemiological studies demonstrate that cell phone use while driving is, above all, a source of cognitive and visual distraction. Yet, the laws only prohibit drivers from using hand-held devices, which is inconsistent with the scientific literature. Furthermore, hands-free laws may even have an aberrant effect on road safety statistics. They send a false message to motorists; namely, that the use of hands-free cell phones is safe. Not only could this message encourage users to make more calls, it could also lead non-users to obtain hands-free cell phones. Beyond legislation, there is current technology that allows the use of cell phones and other telematics to be disabled or restricted while vehicles are moving. These technological measures have the advantage of being passive.

8 CONCLUSIONS AND RECOMMENDATIONS

The aim of this public health advisory has been to document the effects of cell phone use while driving on road safety. To this end many document sources were consulted. It is difficult to affirm that cell phones are a causal factor in collisions by analyzing collision scenes. Moreover, collision reports generally do not systematically report the presence of cell phones, and without their inclusion in collision reports, it is difficult to arrive at a reliable estimate of the prevalence of cell phones during collisions. To compensate for these limitations, this advisory relied on the results of several populations of studies (Simpson, 2005). By studying the meaning of various results and their convergence, we have arrived at our conclusions and recommendations. The results of our study leave no room for doubt and are consistent with the observations of other reviews of the literature: cell phone use while driving constitutes a risk factor for users of the road network. Not only does cell phone use while driving adversely affect driving performance, it also significantly increases the risk of road collision (McCartt *et al.*, 2005; Goodman *et al.*, 1997; Horrey and Wickens, 2004; Caird *et al.*, 2004).

8.1 MAIN CONCLUSIONS

Integration of the results of empirical literature confirms that the use of a cell phone while driving, whether it is a hands-free or hand-held device, diminishes driving performance and increases the risk of collision. In this section, the main results of our analyses are given and the questions posed at the beginning of this text are answered (see sections 1 and 6).

Cell phone use while driving diminishes driving performance

Our search strategy led to the identification of 53 documents containing a total of 64 experiments. The latter examine the effect of cell phones on performance and generally demonstrate that their use adversely affects driving performance. Of the 335 effects inventoried, 66.3% (n=222) are negative, providing evidence of a statistically significant deterioration in performance under experimental conditions ($p<0.05$). All the studies, except those of Spencer and Reed (2003), and Nunes and Recarte (2002b) report a drop in performance during cell phone use for at least one indicator. However, these studies included 8 and 6 participants, respectively, which considerably reduced the statistical power of their analyses. In general, the evidence indicates that more negative effects would have been identified if the studies had been based on larger samples.

The results of experiments demonstrate not only that cell phone use negatively affects performance, but also that this deterioration in performance affects all of the primary tasks necessary for driving. In other words, cell phone use while driving adversely affects biomechanical, visual and cognitive tasks. However, it is the primary cognitive and visual tasks that are most adversely affected by cell phone use while driving. These results corroborate the conclusions of Caird *et al.* (2004) and of Horrey and Wickens (2004) who affirm that cell phones are mainly a source of cognitive and visual distraction. Due to the interdependence of primary tasks (Evans, 1985 and 2004), cognitive distraction has an impact on all aspects of performance.

Cell phones increase the risk of collision

Integration of the results of experimental and epidemiological studies leads to the conclusion that the performance deterioration caused by cell phone use while driving results in an increase in collision risk. All of the epidemiological studies show that cell phones users have higher collision rates than non-cell phone users. Moreover, users who use their cell phones while driving increase their risk of collision. This conclusion carries all the more weight given that different study designs and analytical strategies produced the same results.

In addition, collision risk increases with use, which signifies that frequent users are more at risk than occasional users (Laberge-Nadeau *et al.*, 2003; Violanti and Marshall, 1996). Also, these results can not be attributed to cell phone users being prone to riskier road behaviour to begin with. The results of studies using the case-crossover method indicate that users who use their cell phones while driving multiply by about four their risk of collision with property damage (Redelmeier and Tibshirani, 1997) and injuries (McEvoy *et al.*, 2005). Maag *et al.* (2006) have shown that cell phone users, before obtaining cell phones, had collision rates similar to those of non-users (reference year=1987), but after obtaining phones, their collision rates worsened (reference year=1999). This result has two major implications. Firstly, Maag *et al.* demonstrate that the acquisition of a cell phone, and more likely its use while driving, was responsible for an increase in the collision risk of users in 1999. Secondly, these results disprove the popular belief that cell phones do not constitute a road safety problem because sales have been rising, while the road toll has been improving. In fact, traffic collision statistics have worsened during the last five years (SAAQ, 2006) and the statistics would probably be better if motorists did not use cell phones while driving.

The results of epidemiological studies are consistent from one study to the next and, moreover, these results are partly based on Quebec data (Laberge-Nadeau *et al.* 2001 and 2003; Maag *et al.*, 2006; Bellavance, 2005). For example, the results of the Laberge-Nadeau team demonstrate that the risk of collision with property damage or with injuries is 38% higher among cell phone users than among non-users in a sample of 36,750 Quebec motorists. Based on data from the same sample, Laberge-Nadeau *et al.* calculated the risk for users, using the case-crossover method. They demonstrated that the collision risk is five times higher among users who use their cell phones while driving.

Hands-free or hand-held devices: the risk is the same

Many laws allow cell phone use as long as drivers use a hands-free device (McCartt *et al.*, 2005). In short, some believe that hands-free devices are safer than hand-held ones. However, the results of experimental and epidemiological studies prove the contrary. The results of experimental studies show that cell phone use, regardless of the type of device, adversely affects participants' performance. This deterioration of performance affects all of the primary biomechanical, visual and cognitive tasks. Even when using a hands-free device, which eliminates the secondary biomechanical task (of handling the cell phone) participants had as much difficulty, among other things, maintaining a constant speed, maintaining a safe following distance, detecting stimuli in the driving environment and making appropriate decisions in situations that required a rapid response.

Distraction decreases with practice: the debunking of a myth

Two series of results disprove the belief that distraction decreases with usage. Firstly, we would have expected the results of experimental studies to vary according to the proportion of users in a sample; that is, users would be more used to handling such devices and their performance would be less affected. However, the studies do not support this hypothesis. Secondly, the two studies that examined the notion of learning effects do not support this hypothesis. This was the case for Rakauska *et al.* (2004) who observed a learning effect across road trials, but for all conditions. In fact, participants equally improved under the experimental condition and the control condition, which meant their performance during cell phone use was consistently inferior. Similarly, Shinar *et al.* (2002) did not observe any learning effect, but they attribute this result to the nature of the tasks participants were required to perform. These secondary tasks were thought to have been so simple that no room was left for improvement. Therefore, Shinar and Tractinsky (2004) conducted a second experiment involving more difficult secondary tasks. Although the authors report a learning effect, their interpretation is debatable. An examination of the results indicates the presence of a saw tooth relationship between trials and performance.

Effects of other sources of distraction: insufficient evidence

Several organizations claim that cell phones are one source of distraction among many and that their use is no more problematic than listening to a radio, conversing with a passenger or using a driving aid system (CAA, 2006; Canadian Wireless Telecommunications Association, 2006). However, it is impossible to back up this claim with the results of empirical studies. Very few studies have evaluated the performance of drivers while they are handling on-board instruments or using telematics. At this point, it is too early to make conclusive statements about the effects of other on-board instruments and telematics. We can at best identify certain trends or draw parallels with the effects of cell phones, depending on the nature of the secondary tasks involved. In addition to the effects of cell phones, some studies have analyzed the effects of radios, passengers and automated e-mail systems on performance. Among the epidemiological studies, the Laberge-Nadeau (2003) study examined the effect of passengers in their analysis, whereas Violanti and Marshall (1996) integrated other activities requiring motor skills, such as handling controls, eating and drinking.

The results of the experiments suggest that listening to the radio does not affect driving performance (Ishida and Matsuura, 2001; Fuse *et al.*, 2000; Consiglio *et al.*, 2003). However, McKnight and McKnight (1991) showed that participants had more trouble performing an appropriate manoeuvre during a potentially dangerous situation when they had to tune into a radio station.

The results of experimental studies of the effect of conversation with a passenger are mixed. Consiglio *et al.* (2003) and Gugerty *et al.* (2004) assert that conversation with a passenger affects performance as much as telephone conversation. However, Crundall *et al.* (2005) obtained results that suggest conversation with a passenger does not interfere with driving as much as cell phone conversation. Their analyses indicate that passengers adapt their verbal flow to the difficulty of primary tasks. Thus, passengers speak more slowly or simply end a conversation when the road demands more of the driver’s attention. This effect is absent during cell phone conversations. This result supports the suppression hypothesis, according to which passengers adapt their verbal flow and the complexity of their conversation to the difficulty of the driving environment. Laberge-Nadeau *et al.* (2001 and 2003) demonstrated that motorists who frequently carry passengers reduce their risk of all collisions or collisions with injuries. However, nothing indicates whether the passengers converse with the drivers. It is possible that drivers drive more carefully so as not to endanger the safety of passengers. Laberge-Nadeau *et al*. (2001 and 2003) also established that listening to the radio and handling CDs/cassettes did not have an impact on collision risk. Violanti and Marshall (1996) report that performing biomechanical tasks (drinking, eating, or changing a CD) while driving increases collision risk, but this increase is minimal compared to that caused by cell phone use.

Finally, Lee *et al.* (2001) carried out the only study of the effect of a speech-based e-mail system. Their results show that using an e-mail system adversely affected participants' performance, resulting in increased braking reaction times. This effect was always present, regardless of the difficulty of the driving environment and the complexity of the device. These results imply that any device that draws on cognitive and visual resources would constitute a source of distraction and would affect driving an automobile. Moreover, cognitive and visual distractions could potentially affect all primary tasks.

Laws and measures for restricting cell phone use while driving

Although many measures exist to restrict the use of cell phones and telematics while driving, evaluation of these measures are scarce and the evaluation protocols they use are not always very rigorous. For example, the CWTA initiated two programs to raise awareness entitled "Distracted Driving" and "Focus on Driving" (CWTA, 2006: 4), but these have not been evaluated. No evaluation has examined the impact of design guidelines imposed on manufacturers. Five evaluations among all the documents were located. These evaluations estimate the effect of legislation banning hand-held cell phones on rates of use or on collision rates.

According to the results of four studies, there is sometimes a decrease in the rate of use in the months following the introduction of a law, after which the rate increases (McCartt *et al.*, 2003 and 2004; Johal *et al.*, 2005; Rajalin *et al.*, 2005). However, these evaluations have certain shortcomings that undermine the validity of their results. Analyses are often based on a simple before/after comparison and do not take into account other factors that may have influenced cell phone use or collision rates. For example, cell phone sales are on the rise and it is possible that while laws are not reducing the rate of use, they have stabilized it or slowed its progression. Moreover, these laws are often introduced without any enforcement or supportive measures, thus limiting their potential effectiveness. Other studies based on more rigorous research designs are needed to identify promising methods of reducing the use of cell phones and all other telematics while driving. Japanese legislation introduced on December 1, 1999 is reported to have reduced collisions associated with cell phone use by 50%, which accounts for a 20% reduction in collisions. However, this evaluation, like those examining the rates of hand-held cell phone use, has certain limitations.

8.2 RECOMMENDATIONS

Recommendation 1: A total ban on cell phone use while driving

In light of the main conclusions of this advisory, the INSPQ maintains that the task of driving is, by itself, sufficiently complex and that cell phone use while driving serves only to significantly increase collision risk, regardless of the type of device used. The scientific literature is unequivocal: using a hands-free device does not diminish the distraction associated with cell phones, because the distraction is mainly cognitive and visual in nature.

Given that cell phone use while driving:

- does not aid driving;
- adversely affects driver performance, particularly with respect to cognitive and visual tasks; and
- significantly increases the risk of road collision and personal injury,

the INSPQ recommends that cell phone use while driving be completely banned.

Although virtually all jurisdictional laws ban only hand-held devices, these laws are inconsistent with the scientific literature and may even have an aberrant effect. It is not the manipulation of the cell phone as such that distracts drivers. Rather, it is the act of conversing on the telephone. Laws that ban only hand-held devices convey the message that cell phone use is safe as long as the driver's hands are free, which is false. Studies have shown not only that visual and cognitive distraction persists, but also that the poor quality of hands-free devices amplifies the distraction (Matthews *et al*., 2003). Our recommendation is also aligned with the opinion of Canadian and Quebec drivers, who, in a proportion of 2/3, see cell phone use while driving as a serious or extremely serious road safety problem (Beirness *et al*., 2002). A recent survey conducted by the INSPQ reveals that 93% of Quebeckers are in favour of a law regulating cell phone use while driving. Finally, these recommendations in no way detract from the advantages of cell phones, including the ability to contact emergency services in case of collision or to report crimes to police. Drivers would simply have to pull over to the side of the road to make a call.

Recommendation 2: Regulate the installation of in-vehicle telematics

While cell phones are the most widespread and frequently-used telematics device, automobile manufacturers are increasingly equipping their vehicles with other basic telematics such as driving aid systems – which, in fact, contain several other telematics such as global positioning system (GPS) and e-mail systems – and DVD players/televisions. Some high-end vehicles are even equipped with portable computers that sit in the glove compartment.

Since the cell phone is the most popular of the devices mentioned, virtually all the studies reviewed examine the effects of this device on performance and collision risk. However, devices that, like cell phones, draw on the cognitive and visual resources required to carry out primary tasks, are likely to distract drivers. This is the conclusion of a study by Lee *et al.* (2001) which demonstrates that using a speech-based e-mail system negatively affects driving performance. Again, the fact that the device allows the driver to keep his or her hands on the wheel does not diminish the effect of distraction.

The INSPQ recommends that installation of in-vehicle telematics devices that do not assist with driving be prohibited unless they are proven not to be a source of distraction. In support of such a measure, Transport Canada should compel automobile manufacturers to perform certain tests to ensure that new telematics devices do not interfere with driving. The burden of proof would be on manufacturers, in accordance with the principle that applies to pharmaceutical companies that want to market a medication. The INSPQ also encourages researchers to focus more attention on the distraction caused by other in-vehicle telematics and devices.

Recommendation 3: Modify collision reports

Currently, collision reports contain no checkbox to allow the presence of a cell phone to be systematically reported. Yet, there are standard entries for indicating whether someone was driving while impaired or speeding at the time of a collision. The INSPQ recommends that collision reports be modified to better measure the prevalence of collisions caused by cell phone use, and to allow for a better understanding of the circumstances surrounding collisions associated with cell phone use.

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