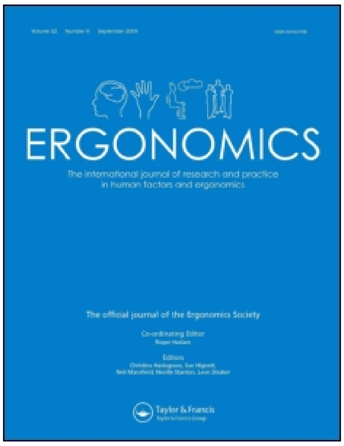

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Phoning while driving II: a review of driving conditions influence

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Phoning while driving II: a review of driving conditions influence

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The first paper examined how the variables related to driving performance were impacted by the management of holding a phone conversation. However, the conditions under which this dual task is carried out are dependent upon a set of factors that may particularly influence the risk of crash. These conditions are defined by several independent variables, classified into five main categories: i) legislation; ii) phone type (hands-free or hand-held); iii) drivers' features regarding age, gender, personal individual profile and driving experience; iv) conversation content (casual or professional) and its context (held with passengers or with a cell (mobile) phone); v) driving conditions (actual or simulated driving, road type, traffic density and weather). These independent variables determine the general conditions. The way in which these factors are combined and interact one with another thus determines the risk that drivers undergo when a cell phone is used while driving. Finally, this review defined the general conditions of driving for which managing a phone conversation is likely to elicit a high risk of car crash or, conversely, may provide a situation of lower risk, with sufficient acceptance to ensure safety.

Keywords: cell phone; distraction; driving; review; sharing attention

Introduction

The first paper described epidemiological, psychological, behavioural and physiological indicators influenced by the management of a dual task, e.g. holding a phone conversation while driving. These dependent variables gave a close evaluation about how driving performance was impacted by the secondary communication task. However, dependent variables are sensitive to general conditions of driving, which determine numerous factors or independent variables. Each may be studied either as a single factor or associated with others to provide particular sets of situations, which make the strain undergone by drivers vary and, consequently, may affect driving performance. The review of experimental results related to the management of this dual task provides a large amount of independent variables, which, however, may be pooled into five categories: i) legislation about phone use, which may differ according to each country; ii) phone type (hand-held or hands-free phone and its forthcoming evolution); iii) drivers' features with potential subgroups to be distinguished; iv) the conversation that can be held with a passenger (often considered the reference) or using a cell phone, and its content, which may elicit different levels of difficulty; v) driving conditions, depending on whether the experiment is simulated or performed under actual conditions. These are also related to the atmospheric disturbances that may contribute to make driving more or less easy to manage.

The aim of this second paper was thus to review these main independent variables, which are thought to strengthen or lessen the distractive effects of cell phone use. The review of the literature evidenced several factors included into one of the five categories described above and considered as sub-categories. All were studied among the amount of publications that were analysed, alone or combined one with another. First, the legislation related to phone use is likely to influence and to change habits that drivers have built up. Second, phone type was studied as even early on hand-held phones competed with hands-free kits. The drivers' features were studied through three main factors, gender, age and driving experience. The fourth group of independent variables was related to the conversation itself: the type (in-vehicle vs. remote) and the content of the conversation (high vs. low conversation strain) have been studied. The last group is made up of driving conditions, which may be under actual conditions or simulated. The driving conditions also depend upon traffic configuration or traffic density as well as the weather (e.g. cloudy, rainy or sunny). Although experimental designs may pool some of these

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factors, these will nevertheless be analysed separately in the following sections. In some interesting cases, how one factor may interact with another will be described. Finally, their whole interaction will then be explained with the aim to assess how some configurations may elicit high strain conditions.

Legislation

Epidemiological and experimental studies have often been cited as reference to bring arguments in favour of legislation on phone use. In turn, legislation is likely to make users' habits change and also highlight the potential danger associated with cell phone use while driving. Among the 29 nations belonging to the Organization for Economic Cooperation and Development, eight countries have enacted legislation prohibiting the use of hand-held phones while driving (Cohen and Graham 2003). New York became the first and only state of the United States to ban hand-held phone use on 1 November 2001 (McCartt and Geary 2004). Connecticut is an adjacent state with no such law. In 2003, 36 states in the United States considered restrictions on the use of a cell phone while driving (Cohen and Graham 2003). French legislation banned hand-held phones in April 2003, whereas the UK administration voted a similar law on 1 December 2003 (Luke *et al*. 2004, Tearle 2004, Johal *et al*. 2005). In all cases, the use of hands-free phones was allowed. The Japanese law was strengthened in November 2004, but remained applied to hand-held phones, thus still allowing hands-free systems (Kawano *et al*. 2005). The effect of legislation was specifically evaluated in New York State (McCartt and Geary 2004). The law elicited a significant decrease of phone use from a pre-law 2.3% to 1.1% after. The rate of talking on a hand-held phone among drivers in Washington DC declined in the same proportion, from 6.1% to 3.5% (McCartt *et al*. 2006). The same effect was observed in the UK, as overall use declined from 1.85 to 0.97% (Johal *et al*. 2005). However, McCartt and Geary (2004) underlined that 16 months after the law, the rate of hand-held phone use was back to the pre-law period rate. Despite the law banning hand-held phone use in early 2003, the rate of using a cell phone while driving remained at 3.1% in Finland (Rajalin *et al*. 2005) and increased to 5.8% 1 year after the law. This result may be related to the population's characteristics; Foss *et al*. (2009) found that cell phone restriction had little to no effect on teenage drivers shortly after the law took effect, 11.0% before the law took effect, 11.8% afterwards.

The evolution of the number of cell phone subscribers was shown to parallel that of traffic accidents by the Japanese Telecommunications Carriers Association (2004). This was attributed to cell phone use, with the exception of year 2000, the one following the law. After 1 year, these two factors were once again closely correlated. By analysing a sample of 10,594 men aged between 53 and 63 years and 3258 women aged from 48 to 63 years, Lagarde *et al*. (2004) provided evidence that 1.83% of drivers admitted using cell phones in a risky way while driving. They explained such behaviour with impunity.

As legislation banned hand-held phone use, the law contributed to reduce motor interference between the actions of driving and phoning (dialling or even holding the phone). The question should, however, be redefined with hands-free phones. Driving is generally a highly automated activity resulting from learning, although the degree of automation depends upon driving skill level. In routine driving situations, e.g. when external constraints are low, it remains possible to process two automated actions simultaneously. However, the two tasks might interfere when the main driving task and the secondary task might draw upon the same attentional resource. Studies of theories of attention postulate that it originates from multiple resource pools (Wickens 1984). Thus, a motor action may be performed well, while a cognitive activity might draw upon a separate resource of attention. Furthermore, the cognitive task might interfere with some other driving skills to which cognitive resources must be allocated. Hands-free kits are now provided with cell phones to be used in vehicles and are designed to limit motor interference with driving. However, investigating motor interference between driving and phone use would require considering all manual-processing demands that could interfere with the action of phoning. For example, distinguishing between manually geared and automatic-geared cars should be assessed to compare results from different experimental designs. Whereas the majority of research did not state which form of transmission was fitted in the test vehicle (with the exception of the paper by Brown *et al*. 1969), Haigney and Westerman (2001) stated that most experiments have been undertaken in automatic vehicles or by using driving simulators that closely mimic operating conditions within an automatic vehicle. This remains an important issue as manual transmission requires a higher level of manual interaction and there is a substantial bias towards manual transmission in Europe in comparison with the United States. This difference should now be lessened because legislation banned the use of hand-held phones and thus reduced potential motor interference. However, the question of cognitive interference remains relevant as, at this time, no country has banned the use of hands-free phones. The following is now asked in terms of additional load: carrying out two tasks simultaneously requires the allocation of the same mental resources and drivers must share attention over both the driving situation and the conversation contents.

Phone type

White *et al.* (2004) evaluated the perceived risk attached to phone use. Nearly half of drivers reported using a phone while driving. Among them, hand-held phone use was considered to be one of the riskiest activities to perform, whereas the risk of using a hands-free kit was perceived as smaller. Matthews *et al.* (2003) measured the effect of three types of cell phones on subjective workload, i.e. hand-held, hands-free with an external speaker and personal hands-free. As reported by drivers, the workload was significantly rated higher while using a cell phone than for the condition of no cell phone use. Additional knowledge was provided by the comparison of cell phone types. The perceived workload was the lowest for a personal hands-free phone and the highest for the hands-free speaker phone, while the intelligibility score (the way in which drivers understand how the materials work and should be used) was the highest for the personal hands-free cell phone and the lowest for the hands-free speaker phone. Intermediate scores were obtained with the hand-held phone. The authors concluded that the hands-free phone would interfere least with the cognitive demands of driving. Mazzae *et al.* (2004) also examined the phone interface-related preferences and contrasted these with phone use performance as a function of phone interface. In total, 54 participants drove a simulated freeway route with each of three phone interfaces: hand-held; headset hands-free (voice dialling and headset); voice dialling hands-free (voice dialling with cradle-mounted speaker phone). Results showed that participants considered the hand-held interface to be the most difficult to use, followed by the headset hands-free and voice dialling hands-free interfaces. In most cases, they overestimated the ease of use afforded by hands-free phone interfaces. However, significant differences among interfaces were evident with regard to dialling and hanging up. Although post-drive questionnaire results showed that participants rated the hand-held interface to be the most difficult to use, it was associated with the fewest dialling errors and significantly faster dialling times than the two hands-free interfaces. Drivers answered the phone more quickly when using the voice-dialling hands-free phone interface than when using the hand-held or headset hands-free interfaces. Unfortunately, data by Mazzae *et al.* (2004) were not set against driving performance and it would be interesting to know which offers the best guarantees from the safety view point, in addition to drivers' own perception of each phone's user friendliness. Subjective evaluation should, however, be confirmed by more objective data. Accordingly, Jenness *et al.* (2002) found fewer lane keeping errors (−22%) and fewer glances away from the road scene (−56%) under voice-activated dialling conditions as compared with manual dialling.

The comparison of phone types has often been considered with regard to motor interference. It is due to manipulating, dialling and holding the phone during the conversation and is lessened when using a hands-free phone. It seems obvious that this motor activity could disturb driving operations, e.g. turning the driving wheel or changing gears while keeping a hand-held phone in one's hand. Information processing may also be disturbed as motor actions on the cell phone may require glancing away from the road scene. Motor interference may occur early as drivers engage a hand-held phone conversation while driving, particularly on secondary and urban roads. Brookhuis *et al.* (1991) gave evidence of motor interference under actual driving conditions (light traffic on a quiet highway and heavy traffic on a four-lane bypass and city traffic). Drivers who operated hands-free phones showed better control over the test vehicle than those who operated hand-held phones, as measured by steering wheel movements (lateral deviation). Motor interference may particularly occur during dialling operations. When visual attention was divided, either looking at the car in front and continuously dialling a series of three random integers on a digital keypad, detection ability was impaired by about 0.5 s in terms of brake-reaction time and almost 1 s in terms of time to collision (Lamble *et al.* 1999). The same driving impairments were observed when drivers performed a memory and addition task, this being considered a non-visual attention task (Lamble *et al.* 1999). In this experiment, neither a hands-free option nor a voice-controlled interface removes the safety problems associated with the use of cell phones in cars. This shows evidence of a possible cognitive interference while motor interference is lessened by the use of a hands-free kit. Further experiments should investigate other aspects of phone-task performance, related to information processing and ocular behaviour.

Hands-free and voice-dialling systems may be hypothesised to more largely prevent glances away from the road scene than hand-held phones. This was partially investigated by Patten *et al.* (2004) in a peripheral detection task. Participants' reaction times increased significantly when conversing but, surprisingly, no benefit of hands-free units over hand-held units on rural roads and highways was found. In a simulated driving task, where participants were asked to release the accelerator pedal and depress the brake pedal as quickly as possible following the activation of a red brake lamp, Consiglio *et al.* (2003) found that a conversation, whether conducted person-to-person or using a cell phone (hand-held or hands-free) caused reaction times to slow down, whereas listening to music on the radio did not. The same results were found recently by Collet *et al.* (2009). If the use of a hands-free phone may offer a solution to motor interference, the problem of cognitive interference still exists. Cognitive interference supposes that mental resources are shared between two information sources that compete with each other. Attention resource allocation may thus be divided between the driving and the phoning tasks with a potential impact on either driving performance or conversation. Hendrick and Switzern (2007) confirmed that talking on a cell phone, regardless of its type, hands-free or hand-held, reduced the speed of information processing. Ranney *et al.* (2005) also confirmed that performing in-vehicle tasks required diversion of both peripheral (visual and manual) and attention (cognitive) resources from driving, although using a voice-based interface reduced the peripheral impairment but did not appreciably reduce attentional impairment. In a study by Strayer *et al.* (2005), the participants were requested to perform a pursuit-tracking task by using a joystick to manoeuvre the cursor on a computer display. The task consisted of keeping it aligned as closely as possible with a moving target, whose movement was unpredictable. At intervals ranging from 10 to 20 s, the target flashed red and participants were asked to press a button on top of the joystick as soon as they detected the red light. This single task was considered the control situation. The dual-task conditions requested participants to engage in a phone conversation while concurrently performing the tracking task. If reaction times increased significantly, as did the probability of missing the signal when participants were engaged in conversation on a cell phone, there was no reliable difference between hands-free and hand-held phone groups. Thus, hand-held and hands-free phones resulted in equivalent dual-task deficits and the authors concluded that the interference was not due to peripheral motor factors, e.g. holding the phone. Cellular-phone conversations disrupted performance by diverting attention from the driving situation to an engaging cognitive context. This conclusion confirmed previous results, which provided evidence that unconstrained conversation using either a hand-held or a hands-free cell phone resulted in a two-fold increase in failure to detect simulated traffic signals and a slower reaction time to those signals (Strayer and Johnston 2001).

What is generally observed under dual-task conditions is that the activities performed simultaneously require a high attention demand, which might affect attention resources usually allocated to driving, regardless of the type of phone use. The impact on performance mainly affects the operations of detecting and identifying events. This may explain why little difference is often found between the types of phone. In a review comparing the effects of hands-free vs. hand-held phones, Ishigami and Klein (2009) confirmed that the first type of phone was rarely found to be better than the latter. The authors mentioned studies in which drivers compensate for the harmful effects of phoning only when using a hand-held phone but neglect to do so when using a hands-free phone (e.g. Törnros and Bolling 2006). On the other hand, when motor interference was induced, the use of a hands-free phone might compensate for motor actions required by manipulation of the cell phone, as supposed earlier by Brookhuis *et al.* (1991). Thus, the conclusion by Patten *et al.* (2004) should be questioned as they did not find any difference between the two phone types, even when driving on rural roads. It may nevertheless be supposed that it is more difficult to monitor driving operations while holding a phone on a meandering road than on a straight one. To conclude, the evolution of phone technology now makes possible an integration of most phone devices to the communication system of the car (e.g. using a loudspeaker-operated cell phone). Thus, a remote conversation becomes close to a conversation with a passenger, just as if one talks with a back-seat passenger while keeping one's eyes on the road scene. Second, the interaction with other variables may then be considered. As a matter of fact, the conversation content may have a greater impact for drivers' distraction than the type of phone when driving on a highway or similar type of road (Consiglio *et al.* 2003).

Population

First, as cell phones have been put on the market recently, a difference between older and younger drivers may be hypothesised. Irrespective of drivers' features, however, Lorini *et al.* (2006) hypothesised that the personal trait of each individual may influence the occurrence of managing a secondary task while driving. As driving and phoning is considered a dual task, requiring allocation of more attentional resources, and as the main way to decrease dual-task load is to automate at least one of the two tasks, the effects of the driving experience must be studied concurrently. Finally, gender effects may also be supposed and must be investigated.

Individual features

Lorini *et al*. (2006) evidenced that cell phone use while driving is common among drivers who engage in other high-risk driving behaviours, particularly driving at high speed. Many drivers sincerely believe they have the ability to manage several things at the same time while they are not aware that distraction has deleterious effects on driving performance. Horrey *et al*. (2008) found that, in some cases, estimates of distraction were opposite of the observed effects, i.e. smaller estimates of distraction corresponded to larger performance deficits. Obviously, drivers believe that they do not need two hands on the steering wheel and two eyes on the road to drive well (Peters and Peters 2001). Furthermore, non-users of cell phones believed more strongly than users that cell phone use affects driving performance negatively and that talking on a cell phone may potentially cause an accident (Wogalter and Mayhorn 2005). This is confirmed by drivers themselves, as they reported being engaged in behaviours that place them at risk for a traffic crash (Beck *et al*. 2007). Finally, cell phone users reported that other drivers using a cell phone were more dangerous than themselves. This has already been found by White *et al*. (2004), who showed that the probability of a crash was estimated to be less for one than for others. Taken together, these results are somewhat questionable as, on the one hand, drivers do not seem aware of the danger and, on the other, they report that they are aware of a higher risk. Further research should probably be focused on the evaluation of personal traits. This remains quite a difficult challenge although risky behaviour has already been identified to be associated with phone users (Beck *et al*. 2007). The next step is to identify specific psychological profiles, e.g. extraverts who are likely to be engaged in risky behaviour, as hypothesised by Bianchi and Phillips (2005), (see also part I).

Drivers' age

According to Lam (2002), the age of drivers plays a crucial role in the relationship between distraction and car crashes. Young drivers represent 14% of authorised drivers, but 26% are involved in fatal crashes (Seo and Torabi 2004). Accordingly, Neyens and Boyle (2008) showed that teenage drivers are at a higher risk for crashes and have an increased likelihood of more severe injuries if distracted by a cell phone or by passengers. By contrast, most publications underline that senior drivers are more affected by the use of cell phones while driving than young drivers, perhaps with the exception of those described by Brookhuis *et al*. (1991), Lyda *et al*. (2002) and Strayer and Drews (2004). In a dual-task paradigm, in which the secondary task was to point to letters on a randomised or alphabetical letter matrix, Lyda *et al*. (2002) showed that phoning affected completion time, although without any age-related difference. The nature of the secondary task may explain such lack of difference. The earlier study by Brookhuis *et al*. (1991) did not evidence any difference related to age in driving performance. According to the authors themselves, this was probably due to the sample size (only 12 subjects, equally grouped into three age categories, 23–35, 35–50 and 50–65 years). However, laboratory-based studies showed large and strongly based age-related differences in dual-task processing (Kramer and Larish 1996). In the study by Strayer and Drews (2004), the absence of age-related differences between single- and dual-task performances thus appears to contradict such findings. The driving performance of younger (aged between 18 and 25 years, mean 20) and older (aged between 65 and 74 years, mean 70) adults was significantly impaired when conversing on a hands-free phone, but remained comparable one to another. Nevertheless, Strayer and Drews (2004) pointed out that the effect of having a younger driver converse on a cell phone was to approximate his/her reactions to those of older drivers not using a cell phone. In a simulated driving situation, the participants were asked to carry out a hands-free phone task close to real conversation (Shinar *et al*. 2005). Under such conditions, the interference effects between phoning and driving were greater when drivers were older. Results by Horberry *et al*. (2006) showed that drivers over the age of 60 years attempted to compensate for the distracting effect elicited by phone use by driving more cautiously than younger drivers.

These differences in favour of young drivers may not originate from factors that are directly related to phone use but from general decrements of physiological functions in the elderly. In ageing persons, the useful field of view is a measure that reflects a decline in visual sensory function, slows down visual processing and impairs visual attention skills. Reduction in the useful field of view thus increases the crash risk in older drivers (Owsley *et al*. 1998). The size of the useful field of view, a visual attention test, showed high sensitivity (89%) and specificity (81%) in predicting why older drivers had a history of crash problems (Ball *et al*. 1993). Older adults with substantial shrinkage in the useful field of view were six times more likely to have incurred one or more crashes in the previous 5-year period. Given the relatively extensive knowledge of visual-processing impairment among the elderly, visual dysfunction deserves further examination as causes of motor vehicle crashes and injury. It is nevertheless well known that age has a wide effect on task components that require speed of response to multiple and simultaneous demands (Hancock *et al.* 2003). Epidemiological investigations evidenced clearly that older drivers, on average, were more likely to be involved in fatal traffic accidents (Preusser *et al.* 1998, National Center for Statistics and Analysis 2001). Violanti (1997) showed increasing fatalities as age increased, with the exception of people under age 20 years who presented the highest rate. According to Alm and Nilsson (1995), the effect of a cell phone task has a more pronounced negative effect upon choice reaction time of elderly drivers. Data by McCarley *et al.* (2004) also reveal a tendency for conversation to impair orienting of attention in older adults. Finally, McKnight and McKnight (1993) evidenced that younger participants increased the rate of no detection cues to a lesser degree than older drivers, with the exception of those in intense conversation. From a motor control point of view, Mazzae *et al.* (2004) found that younger drivers answered the phone significantly more quickly than their elders.

The synthesis of the above data reveals that several factors may interact with age. Using a driving simulator may reduce differences between subjects as this situation may maintain a sense of novelty for people, whatever their age. Such an experiment involved a skill that the older adults have used for 50 years. It may thus be supposed that highly practised real-world skills such as driving are less sensitive to the dual-task impairments normally associated with ageing. Likewise, older people who voluntarily participated in the driving experiment were in better mental and physical shape than the average general population of older drivers. As stated by Strayer and Drews (2004), older drivers who run a greater risk of accidents are less likely to participate in driving-related research when they are asked to take part in an experiment voluntarily. If there is a tendency to acknowledge that older drivers are more likely to be involves in a car crash, this may not be due specifically to cell phone use. Finally, specific characteristics related to age lead to the conclusion that cell phone use may be detrimental, mainly in the youngest and the oldest populations of drivers.

Gender

Whether males are more or less efficient than females in managing the two tasks of phoning and driving simultaneously remains perhaps a more complex issue than the effect of age. As shown early on by McKnight and McKnight (1993), no gender effect was evidenced, i.e. men being as sensitive as women to distractors. More precisely, placing calls evidenced a marginal significance, with females showing the least distraction, whereas none of the other distractions approached significance, e.g. carrying on a casual cell phone conversation, carrying on an intense cell phone conversation and tuning a radio. The purpose of the study by Barkana *et al.* (2004) was to quantify the central attention-diverting effect of hands-free phone conversations on visual-field awareness. As described above, hands-free conversations caused some subjects to fail significantly on more points, to react more slowly to each stimulus and to perform with reduced accuracy, but there was no difference between males and females. Using data obtained from traffic accidents reported between 1992 and 1995 in the state of Oklahoma (USA), Violanti (1997) showed that males with phones had a significantly higher rate than females of being involved in a car crash for several driving actions, irrespective of safety (inattention, unsafe speed, driving on wrong side of road, striking a fixed object, etc.). Conversely, the experiment by Lesh and Hancock (2004) evidenced a gender difference in favour of male drivers; women's driving performance being more affected by the use of a cell phone. The participants were requested to rate their confidence in dealing with distractors while driving. Their ratings of both task performance and demand were compared with their actual driving performance in the presence of a cell phone task. While high confidence ratings were predictive of better driving performance on the part of male drivers (as confidence increased, the impact of the distraction effects decreased), this relationship did not hold for females. Furthermore, there was a strong interaction between gender and age, as for older females performance decreased while confidence increased. Additionally, when drivers were matched in terms of their confidence level, older females' braking responses were slowed down to a much greater extent (380 ms) than those of any other group (100 ms for younger males and females and 70 ms for older males). Finally, females also rated the driving task as less demanding than males, even though their performance was more greatly affected by distraction. The authors concluded that drivers, and older females in particular, were not aware of their dip in driving performance, and proposed to target educational campaigns on driver distraction toward senior female drivers.

Taking these data together does not provide a clear conclusion and it remains somewhat unclear whether driving performance impairment during a cell phone call may originate from gender differences. There is probably a combination of several factors, e.g. gender, age and perhaps driving experience, which, taken together, lead to driving impairments when phoning at the same time. There are certainly some differences between male and female driving styles. Considering that males may have a tendency to drive faster (Violanti 1997), it may be hypothesised that cell phone use raises the risk of being involved in a car crash for males more than for females. However, there is no strong evidence of some gender effect in favour of male drivers being distracted by a cell phone. Here again, new investigations are needed to bring additional data related to this independent variable.

Driving experience

There are several ways to consider driving experience. First, it may be the length of time in possession of a licence. The distance that subjects drive per year is also an index of driving experience. Lamble *et al.* (1999) considered subjects who had driven between 2000 and 125,000 km as experienced drivers. In this context, prior experience gained in using a cell phone may be taken into account (McKnight and McKnight 1993). Thus, motor automation of phone command manipulation and mental automation of procedures required to place a call should be integrated in to drivers' abilities. In the experiment by Matthews *et al.* (2003), drivers were selected as experienced in both driving and using cell phones. They had held a driving licence for at least 5 years, had driven at least 10,000 km per year and had owned a cell phone for more than 1 year (the group average was 3.7 years). The combined experience of driving and phoning resulted from automation of both tasks and the level of automation is known to influence the perceived load directly. In actual driving, drivers learn to time-share various tasks. They could pace their driving to accommodate the demands of a phone conversation and, in the same way, could pace the phone conversation to accommodate driving demands. Thus, the more automated the coordination of the two tasks, the lower the load perception and the risk associated. In this context, the senior population may be considered more experienced than young people, whereas young people may use a cell phone more easily than older people. Experience may also be acquired over a short period of time, irrespective of age. In the course of driving five sessions using the phone, Shinar *et al.* (2005) showed a learning effect on most of the driving measurements. In addition, the interference of the phone task on many of the driving tasks decreased over time. The learning effect was also shown as being highly selective and to depend upon conversation content. Hunton and Rose (2005) demonstrated that communication training may reduce the hazardous effects of cell phone conversations on driving performance. Thus, in accordance with Hancock *et al.* (2003), learning how cell phones work and training on procedures of in-vehicle phone interfaces may prevent diverted attention from the road scene. If taken into account, this function would be beneficial to driving schools. Finally, being experienced includes both the ability to manage several tasks simultaneously (these being automated by training) and the knowledge of such dual-tasks requirements with the potential risk encountered. Nevertheless, Cooper and Strayer (2008) concluded from their study that practice is unlikely to eliminate the disruptive effects of concurrent cell phone use on driving.

Conversation

The experiments designed to test the effects of conversation on driving have been mainly focused on the comparison of the cell phone vs. in-vehicle conversations (with a passenger). Such studies are quite recent and were usually devised to compare the nature of interference between two media of conversation. Second, conversation content could probably influence driving performance. Third, the 'quality' of the conversation must be taken into account as voices between two cell phones could be degraded, particularly in a moving car, thus making the demand in attention increase. To test the true impact of the communication task, experimental designs require a close evaluation of the additional load that is supposed as being elicited. Thus, the communication task is often made up of verbal, working memory tasks or mental calculation (Lin and Chen 2006), these not being conversations per se. A more ecological approach is the use of more natural conversations with different content, thus aiming to elicit different loads although these experimental designs are more difficult to control. Finally, few studies dealing with in-vehicle conversations were conducted with the aim to study the effect of driving upon conversation performance. This would suppose to take into consideration the potential degradation of voices between two cell phones. Most investigations have processed data related to the main driving task. However, providing evidence of conversation impairment may be useful to understand how attention is shared over the two tasks and to determine if such conditions are likely to elicit an overloaded situation. Thus, four main directions need to be investigated: i) the difference between in-vehicle vs. remote conversation; ii) the conversation content; iii) the effect of dual task on conversation performance; iv) the evaluation of message quality.

Consiglio *et al.* (2003) found little difference between the interference generated by the conversation with a passenger and that produced by a cell phone.

Reaction time in braking can be slowed down by paced conversation whatever the media involved, passenger or phone. Horrey and Wickens (2004) confirmed that talking on a phone was as harmful as talking to passengers. Laberge *et al.* (2004) and Amado and Ulupinar (2005) tested this hypothesis and found no difference in the driving performance between a passenger conversation and a conversation over a hands-free phone. Especially, conversation with a passenger or through a cell phone was not differentiated in terms of induced load, either by reaction time, attention and peripheral detection tasks (Amado and Ulupinar 2005) or by physiological indicators such as electrodermal activity or heart rate (Collet *et al.* 2009). The study by Golden *et al.* (2003) evaluated how much cell phone and just speaking interfered with visual attention skills. Licensed adult drivers were divided into three groups with all participants taking the Connors Continuous Performance Test II. Group 1 was the control group and performed the test without any distraction. Drivers in group 2 performed with someone in the same room talking to them and group 3 engaged in a cell phone conversation. Overall, there were substantial differences among groups on all variables, but primarily between the control and the two experimental groups. While the cell phone group had lower mean scores than the talking group overall, the difference was not significant. Thus, while cell phone use was distracting to visual attention functions on the Connors task, it was not more distracting than a similarly active conversation without a cell phone. Keeping in mind that this experiment did not involve a driving task, this experiment showed that phoning required the same mental resources as conversation to be carried out reliably. The cell phone was not more detrimental than conversing with a passenger or other distractions that drivers routinely face (Fix 2001). Amado and Ulupinar (2005) compared the conversation with a remote person using a hands-free phone and in-vehicle person with a passenger. The aim was to study the effect on attention in peripheral detection tasks. If conversation resulted in slower reactions and fewer correct responses, the conversation type (remote/in-person) did not make any significant difference.

However, Hunton and Rose (2005) indicated that cell phone conversations consume more attention and interfere more with driving than passenger conversations. Consiglio *et al.* (2003) underlined that, in real-world driving, there are often strong differences between conversing with a passenger and conversing with someone via a cell phone. Conversations with passengers are typically self-paced, in that they may be suspended or adapted at any time when driving demands require increased attention. Conversely, if phone conversations are also typically paced, there is greater expectation of continuous exchange from the person engaged in the conversation, regardless of driving demands. However, when talking on a cell phone, roadway situations cannot be shared and conversation cannot be stopped when the situation requires the driver's complete attention. Consiglio *et al.* (2003) underlined that the degree to which a driver is distracted by the conversation with a passenger may be to some extent offset by the added capacity for roadway observation offered by the passenger. Consequently, paced conversations on a cell phone would be expected to result in a higher cognitive demand experienced by the driver, than that elicited by conversation with a passenger. However, on the basis of electrodermal recordings, one study failed to demonstrate that cognitive demand was higher during a conversation on a cell phone than when talking with a passenger (Collet *et al.* 2009). Whereas the dual task elicited higher strain by comparison with the control condition (baseline driving), no difference emerged from the two types of conversation, thus suggesting that mental demands were equivalent. Finally, the findings by Consiglio *et al.* (2003) are consistent with those of Gugerty *et al.* (2004), who found that the amount of degradation in situation awareness during person-to-person and remote interactions did not differ significantly. However, the pace of the in-vehicle and remote verbal interactions differed, suggesting that remote verbal interactions may be more difficult for drivers. These conclusions may be biased if the conversation content is not controlled. In other words, in-vehicle vs. remote interaction differences may be counterbalanced by the complexity of the message.

Briem and Hedman (1995) reported that simple conversations did not negatively affect drivers' ability to maintain road position. On the other hand, several studies have found that working memory tasks (Alm and Nilsson 1995, Briem and Hedman 1995), mental arithmetic tasks (McKnight and McKnight 1993) and reasoning tasks (Brown *et al.* 1969) were sufficient to disrupt simulated driving performance. According to Horrey and Wickens (2004), when a conversation task is used, the cost is higher to driving performance than when an information-processing task is programmed. This is probably due to the greater personal involvement in conversations associated with a more or less emotional context. The information-processing task, although involving perceptual resources and working memory, does not share the same degree of commitment. This strain may be higher when the conversation is intense, i.e. when the emotional load is high. Amado and Ulupinar (2005) found that the difficulty of a verbal task affected the performance in peripheral detection, an important component of safe driving. The authors concluded that conversation has a negative effect on attention and peripheral detection and that this effect was greater with difficult conversations. A somewhat different finding was suggested by Shinar *et al.* (2005), who found that the interference effects were greater when the phone task was the often-used artificial maths operation task than when it was an emotionally involved conversation. Information-processing tasks do have a substantial influence on performance and, thus, should be able to simulate many aspects of the demands of a cell phone conversation. In the case of very hard problem-solving, the load elicited may deteriorate driving performance more drastically than in a simple conversation. Lin and Chen (2006) confirmed that the higher the cognitive load of the dialogue, the worse the driving performance. Thus, two features of the conversation content may be considered: the nature of the communication task (conversation vs. cognitive task) and its complexity. Aiming to remain close to actual driving conditions, other studies have investigated the effect of natural conversation content upon driving and conversation difficulty (Chapon 2004). The low level of difficulty was a conversation about the participants' latest vacations, whereas the high level required the participants to plan a business trip, using a hands-free phone in both conditions. Differences between the two levels were assessed by behavioural and physiological indices. Results showed a higher strain elicited by the high level of conversation difficulty likely to elicit driving performance impairment. The profile of higher strain was a significantly higher reaction time to visual stimuli and a higher rate of non-detection of stimuli. Physiological indices showed lower N2-P3 amplitude (an index of strain elicited by the task, extracted from electroencephalogram recordings – see part I) and higher heart rate, although the difference was close to the significant threshold. Thus, the conversation content may cause the load attached to it to evolve as a function of its complexity. If the harmful effects of conversing on the phone are very real initially, they may not be as severe when the conversation load is light. Under this condition, carrying out a cell phone conversation simultaneously while driving should impair driving performance to the same extent as a conversation with a passenger.

Studies usually examine the cognitive interference between conversation and driving with the aim to study whether driving performance is impacted. There are, however, fewer studies that reverse this question. Several experiments have provided evidence that driving can impact performance in a verbal task (Horswill and McKenna 1999), although such studies are not related to talking on a cell phone (Luke *et al.* 2004). Radeborg *et al.* (1999) examined the effect of a simulated driving sequence on a verbal memory task and showed that cognitive abilities were weakened when driving. Parkes (1991a) reported a decrease in different verbal performance tasks during a cell phone conversation while driving as compared with a driver–passenger conversation. Results were confirmed by an additional study using a natural negotiation situation through different media (Parkes 1991b). The author reported that a conversation conducted through a cell phone was of average efficiency although of more greatly perceived difficulty by participants. The tests used sentences that were not directly related to events of the participants' life. An example of a question asked, 'Felix is darker than Antoine. Who is the fairer of the two?' provides evidence that the resulting verbalisation was close to problem-solving and quite far from a natural conversation between two persons. A number of other measures may be taken to examine the quality of a conversation, e.g. mean number of sentences repeated correctly (when the task was to repeat sentences), mean response time to a question, mean number of pauses in a monologue and the mean rate of speech. The variables measuring conversation efficiency were more impaired under the phone condition than under control and even when compared with the passenger conversation. However, the response time was longer during conversation on a cell phone, but remained identical to a passenger conversation. The studies by Burns *et al.* (2002) and Luke *et al.* (2004) were aimed to test whether the information exchange was compromised during conversation on a cell phone. Both found impaired performance in conversation. Results by Gugerty *et al.* (2004) confirmed these findings as drivers talking with remote partners generated more long pauses than drivers talking with in-vehicle partners. Thus, being engaged in remote verbal interactions made the drivers modulating their verbalisations to maintain adequate driving performance. As stated by Charlton (2009), conversation modulation is a key factor in maintaining driving performance. In actual driving, conversation is probably impaired to compensate for attentional resources shared over the primary task of driving and the secondary task of talking. Pauses and decreased speech rates may thus be compensations to offset increasing load due to the dual task, although driving performance may also be impaired in such conditions.

Finally, Kawano *et al.* (2005) studied voice quality transmitted from cell phones in a car. Voices between two cell phones may be degraded in one of three types: spectral distortions; delay; interruptions. Consequently, more attention must be allocated to an auditory signal whose signification would become harder to understand when degraded. By using magneto-encephalographic recordings, Kawano *et al.* (2005) showed that auditory signal interruptions activated the temporal cortices bilaterally and the right parietal cortex; this latter activation being related to auditory attention. Resources in attention are already used even if voices through the phones are not degraded and thus further required when voices are degraded (Kramer and Spinks 1991). Consequently, much mental effort is needed to understand well with an increased risk to be less efficient in driving.

Driving conditions

Simulated and actual driving

To the present authors' knowledge, no experiment has been conducted with the aim of comparing simulated vs. actual driving while completing a cell phone communication task. Thus, this issue is rather a methodological procedure to test whether simulated and actual driving may bring comparable experimental conditions. The main advantage of using a driving simulator is to ensure safety in all situations, although, in some cases, this may generate sensorial conflicts between visual and vestibular information, often resulting in motion sickness (particularly with static simulators). Although there are no strong contradictory results between actual and driving simulator data, it may be hypothesised that, in a dual-task situation, the participants may encounter more difficulty in distinguishing between the main and the secondary task. Consequently, they may show a tendency to decrease driving performance to preserve a good performance level in the additional task, as they know implicitly that driving impairment will not have negative consequences on safety. This could be prevented if clear information, related to the hierarchy of the two tasks, is provided to the participants before starting the experiment. Under actual conditions, driving is obviously and unequivocally the main task that prevents the experimenter from giving information about the hierarchy in the dual task. This issue will not be developed extensively here as it is not related directly to the main concern of this paper. In addition, a very recent paper has reviewed simulator studies by distinguishing high-fidelity from low-fidelity simulators (for detailed information, see Drew and Strayer 2009).

Studying drivers' behaviour under actual conditions remains a more ecological way of assessing such complex operations and to guarantee reliability of the results although reliable data are also brought from driving simulator studies (Brookhuis *et al.* 1991, Lamble *et al.* 1999, Cooper *et al.* 2003, Hancock *et al.* 2003, Recarte and Nunes 2003, Patten *et al.* 2004). If real experiments are better suited, as they provide a hierarchy between the driving and the secondary task in a non-ambiguous way, variables are more difficult to control. Ethical and legal concerns should also be considered when the experiment takes place in the real world (Haigney and Westerman 2001). First, the experiment must be conducted with regard to the legal constraints of traffic legislation. Second, if the experimental design may cause changes in driving performance, the experimenter must ensure that the driving sequence will be safely performed and controlled. The use of driving simulators provides the most ethical way to conduct studies, during which some manipulated variables might affect safety (e.g. in conditions of dense traffic).

Easy and hard driving conditions

Although experiments conducted on a driving simulator offer the opportunity to vary driving conditions and to maintain a high safety level, only a few studies have investigated driving conditions. Brookhuis *et al.* (1991) studied the effect of phone use under three driving conditions, i.e. in light traffic on a quiet highway, in heavy traffic on a four-lane bypass and in city traffic. Interestingly, they found that swerving decreased during the phone task, but only in light traffic on a highway. Conversely, while phoning drivers checked the rear-view mirror considerably less often than on the quiet highway. Under such conditions, attention was probably split over both traffic ahead and the phone conversation, less attention being available to check out rear traffic. This behaviour occurred in heavy traffic, i.e. the minimum level of attention paid to rear traffic was reached and not further lowered by a subsidiary phone task. Liu and Lee (2006) studied the effects of driving conditions (urban roads and motorways) by using mathematical-addition tests relayed via cell phone. Mean response time was clearly increased (11.9%) for driving on urban roads as compared to motorways. In-vehicle distraction causing decreased driving performance was obtained in simple and complex highway environments by Horberry *et al.* (2006). However, they drew this conclusion on the basis of speed variation only.

Based on the assumption that driving at night is a riskier activity than driving during the day, Vivoda *et al.* (2008) evaluated the rate of drivers who used a cell phone while driving at night. This was similar to that found in previous daytime studies. While driving conditions are probably harder at night, cell phone use is probably facilitated by less traffic and competition for road space. In addition, phone conversations during the evening and at night may well be related to more social matters than business, thus providing conditions that may compensate for the decrease in

Table 1. Theoretical estimation of car crash or near-accident risk according to variables related to phone type, drivers' characteristics and driving constraints.

Factor	Maximal risk of using a cell phone while driving.	Commentary	Minimal risk of using a cell phone while driving
Phone type	Hand-held	Motor and cognitive interference elicited by hand-held phone. Cognitive interference elicited by hands-free phone.	Loudspeaker-operated cell phone
Drivers' age	Seniors	Older drivers' performance is impaired by irregular use of cell phone or by deterioration of cognitive abilities. Young drivers are more likely to take risks and be unaware of danger	Middle-age
Experience of driving	Low	The strain elicited by the dual task is reduced by automation of both tasks. Learning and automated skills decrease the resulting strain the drivers undergo.	Extensive
Traffic density	Heavy	External constraints add to general workload and make driving performance difficult to maintain at high levels.	Fluid
Driving place	Urban areas	High sensori-motor constraints in urban circuits due to the amount of information processing from the environment and driving actions to manage (e.g. changing gears or turning the steering wheel).	Highways
External conditions	Bad	Driving abilities are impaired by bad weather and driving operations require a high level of attention under detrimental conditions of weather.	Good
Conversation	Business	Business conversation content is a high attentional-resources consumer.	Routine

visual perception. Difficult traffic conditions are a further complication even if driving is a highly automated skill. As previously stated, automated driving behaviour may be impaired when external conditions became harder to manage. This was demonstrated experimentally by Cooper *et al*. (2003). Drivers' decision making was less efficient in the presence of phone messages and such a decline was exacerbated by adverse road surface conditions. These results confirmed those obtained previously by Cooper and Zheng (2002). Attention to a complex phone message while making decisions about turning through gaps in an on-coming vehicle stream was associated with significantly increased hazardous decision making by drivers. This was emphasised when an additional complexity in the form of a wet surface condition was introduced. Finally, as stated by Shinar *et al*. (2005), interference effects were greater when driving demands were higher.

Conclusion on the independent variable analysis

Results from independent variable analysis showed that numerous factors might interact to influence both driving efficiency and conversation quality. It still remains unclear how these factors may interact, and further experimental investigations are needed to propose a hierarchical list of variables impairing driving performance. At this time, and on the basis of the publications that were reviewed and analysed, the main deleterious factors are summarised in Table 1.

General conclusion

Cell phones are now often fitted into dashboards. There will be no return to the previous situation as the in-vehicle phone keeps one connected to the outside world while being inside a vehicle. A number of empirical studies were reviewed in the two papers, which often lead to the conclusion that cell phone use concurrently with driving may have a negative impact upon safety. The sub-tasks of entering a telephone number and having a demanding conversation are particularly likely to increase this risk, especially under heavy traffic conditions and if drivers are young and inexperienced. Experimental data, combined with epidemiological studies, will make it possible to have a broad view of the magnitude of this question. First, the risk of managing two tasks simultaneously has often been inferred from dual tasks that did not involve driving; distraction by phone was interpreted as impairing driving by using joy-stick manipulations (Strayer *et al*. 2005), psychological tests (Golden *et al*. 2003) or even pointing to letters (Lyda *et al*. 2002). Hendrick and Switzern (2007) tested a reaction time task in which participants had to lift their right foot from a pedal, but this was not in a driving scenario. Despite their heuristic function, such experimental situations remain nevertheless less like real driving conditions. Bowyer *et al.* (2007) stated that laboratory findings should not be interpreted as if real-world conversations are driver distractions without on-road validation and comparison to the effects of other in-vehicle tasks.

Second, it may be underlined that it remains possible to control two motor tasks simultaneously in many daily activities. However, the two tasks must be automated enough to be carried out under diffused attention and the environmental constraints must remain low enough to keep the resulting strain at a low level, compatible with safety. Under low task constraints, i.e. low motor interference, it could be possible to hold a very simple phone conversation while driving, without affecting safety, e.g. driving on a highway with very light traffic and fine weather. However, a motor skill although automated may require the allocation of mental resources when both external and internal constraints may involve its effectiveness, e.g. high time pressure, heavy external constraints, overloaded emotional conversation, congested traffic or bad weather. Thus, automated driving may require higher attentional resources, which remain incompatible with managing a secondary task.

Given the proliferation of in-vehicle technologies, it must be ensured that such devices do not produce unacceptable levels of distraction. As cell phone use is not the only distractor, there is an urgent need to develop a taxonomy of driver distractions, defining the different potential sources from within the vehicle and categorising these according to how distracting they are, both in absolute and relative terms (Regan *et al.* 2009). Loci and causes of distraction are represented as disturbances to various functional elements of a control loop involving driver intending (goal setting), sensing, deciding on control response, dynamics of the vehicle and human body activation (Sheridan 2004). Insofar as driving distractors are now focused on cell phone use, the following factors may be kept in mind:

- Until now, studies have been restricted to drivers and have not examined the potentially distracting effects of phone use (and other distractors) by pedestrians and other road users, especially in urban environments.
- Objective and standardised measurements of distraction should be developed. If reaction time, for example, remains a reliable index providing useful data to evaluate drivers' efficiency, driving must not be reduced to reaction to stimuli. Complementary variables, either behavioural or physiological, should thus be considered for a better understanding of distraction.
- Future research should explore in greater detail how individual difference factors such as age, gender and driving experience may influence drivers' distraction.
- Further research is also needed on alternative modes of input and output, such as tactile feedback and voice activation, to determine whether these interaction methods are safer and more viable than manual systems. Research has not yet clearly determined the real consequences of motor and cognitive interference during dual tasks. Although interference is often apparent, determining the implications of such findings for real-world driving remains difficult (Haigney and Westerman 2001). Technological improvements may bring some facilities (e.g. voice-activated recording systems) by removing associated tasks such as writing down phone numbers and address details on pieces of paper. Integrating new and additional technologies to the cell phone may emphasise the risk of mental overload, i.e. increase cognitive interference resulting from the will to decrease motor interference.
- Research must assess the costs and benefits provided by in-vehicle technologies before restricting or prohibiting drivers from engaging in distracting tasks while driving (Cohen and Graham 2003). For example, an in-vehicle cell phone does bring a time gain in calling assistance in the event of a road crash, whereas listening to the radio might be distracting for a truck driver. Conversely, using a cell phone may affect safety under loaded driving conditions, whereas listening to the radio might be beneficial in maintaining vigilance in a low-workload driving environment. Thus, costs and benefits must be determined by taking into account the driving context in which in-vehicle technologies are used. This requires that drivers are aware of such conditions and imply their education and training.
- Given the growing number of in-car technological innovations, it is important to make the motoring public aware that, under particular conditions, hands-free phones can be as distracting as hand-held phones. Drivers must be aware that using a cell phone requires learning and practice. They must learn how such systems work and how to use functionalities to ensure safety. These procedures may be included during practice for learner drivers. They should be told to pay attention to the potential risks associated with engaging in distracting activities within the vehicle. Thus, the graduated licensing system should be used to restrict probationary drivers from using cell phones while driving, until they

have a minimal driving experience, i.e. until the main driving skills have been automated. Everyone driving a car should remember at all times to keep one's hands on the wheel, one's eyes on the road and one's mind on the road (Hoey 2001).

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