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Is a hands-free phone safer than a handheld phone?☆

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ABSTRACT

Introduction: Although it is becoming more and more accepted that driving while talking on a cell phone can be hazardous, most jurisdictions are making handheld phone use illegal while allowing hands-free phone use. *Methods:* The scientific literature exploring the effects of these two types of cell phone use on driving and driving-related performance is reviewed here. *Results:* Our review shows that talking on the phone, regardless of phone type, has negative impacts on performance especially in detecting and identifying events. Performance while using a hands-free phone was rarely found to be better than when using a handheld phone. Some studies found that drivers compensate for the deleterious effects of cell phone use when using a handheld phone but neglect to do so when using a hands-free phone. *Impact on Industry:* Current research does not support the decision to allow hands-free phone use while driving.

1. Introduction

Today, there are more than 253 million cell phone subscribers in the United States (Cellular Telecommunications Industry Association), and more than 19.3 million cell phone subscribers in Canada (Canadian Wireless Telecommunications Association). These figures are more than half of the total population in both countries, suggesting that cell phones are becoming ubiquitous in our lives. It is not surprising, then, that there is an increase in the number of individuals who talk on their cell phones while driving. In fact, the percentage of drivers reporting using a cell phone "in the past days" rose from 20.5% in 2001 to 37% in 2006 (Vanlaar, Simpson, Mayhew, & Robertson, 2007). Although we use our hands and feet when we drive, driving is controlled by the mind. As William James (1890) noted, paying attention "...implies withdrawal from some things in order to deal effectively with others" (p. 403-404). Hence, using our mind to carry on a conversation or perform any other attention-demanding activity (e.g., eating, problem solving) will render it less available for processing the signals and performing the actions necessary to minimize accidents when driving.

If a cell phone conversation distracts the driver, then a cell phone conversation can be a possible safety hazard for driving. In fact, Goodman, Tijerina, Bents, and Wierwille (1999) noted a potential causal relation between the increasing number of cell phones and an increasing frequency of cell phone-related car accidents. Supporting this relation Laberge-Nadeau et al. (2003) found that the relative risk of being involved in accidents was 38% higher for cell phone users than for non-users and more than 100% greater for frequent cell phone users. Yet, in a survey of crashes reported to the police, Stutts, Reinfurt, Steplin, and Rodgman (2001) found that only 1.5% of self-reported distractions were linked to using or dialing a cell phone. For several reasons, this very low estimate from Stutts et al. (2001) must be regarded with caution. First, by definition, distraction means that the mind, which is needed to record things into memory, may be unavailable to do so; consequently, self-reported distraction should be particularly unreliable. Second, as noted by Stutts et al. (2001) in their conclusion, in post-crash situations drivers will be biased against reporting any self-imposed distractions, perhaps especially those involving cell phone use. Finally, and perhaps most importantly, Stutts and colleagues specifically note that "estimating the true percentage of crashes attributable to various distracting events was not the goal" of their study (p. 36).

Horrey and Wickens (2006) recently reported a 23 study meta-analysis of the costs associated with cell phone use while driving. Strongly supporting the proposal that talking on a cell phone can distract the driver in a way that increases response time to unexpected hazards, they found that using a cell phone while driving had substantial negative effects on driving-related performance in reaction time (RT), but not in lane maintenance. Moreover, evidence concerning the association between cell phone use and traffic accidents in the real world was found through epidemiological reports by Redelmeier and Tibshirani (1997) and McEvoy et al. (2005). In spite of the common understanding that a hands-free (HF) cell phone is a safer option than a handheld (HH) cell phone while talking and driving at the same time, Horrey and Wickens (2006) found that the deleterious effects of cell phone use were similar for the HH and HF phones. The purpose of their study was to provide a comprehensive picture of cell phone use in general, and consequently the difference between the two phone types, while mentioned, was neither emphasized nor covered in depth. The major purpose of the present review is to use the literature (Abdel-Aty, 2003;

☆ The data presented in this paper have been previously presented at the 18th Canadian Multidisciplinary Road Safety Conference and been published in the proceedings to this conference (for further reference, see Ishigami & Klein, 2008).

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Table 1
Methods of the studies examining the effects of phone type (HH and HF) on driving-related performance.

	Fidelity	Study	N	Phone task	Road complexity	Type of HF phone
Experimental	Non-driving	Consiglio et al.*	22	C	n/a	HFE
		Strayer & Johnston.*	48	C	n/a	?
	Simulated-driving	Haigney et al.	30	IP	Medium	HFE
		Strayer et al.*	40	C	Low/High	HFE
		Burns et al.*	20	IP	Mixed	HFE
		Törnros & Bolling*	48	IP	Low/High	HFS
		Abdel-Aty	20	C	Low/High	?
	Field-driving	Patten et al.*	40	IP	Low	HFS
Epidemiological		McEvoy et al.	456	n/a	?	?
		Redelmeier & Tibshirani	699	n/a	?	?

Note. *Attention was measured in a detection/identification task.
C = conversation, IP = information processing, HFE = HF phone with an earpiece/headset, HFS = HF phone with a speaker, n/a = not applicable, ? = information not available.

Burns, Parkes, Burton, Smith, & Burch, 2002; Consiglio, Driscoll, Witte, & Berg, 2003; Haigney, Taylor, & Westerman, 2000; McEvoy et al., 2005; Patten, Kircher, Östlund, & Nilsson, 2004; Redelmeier & Tibshirani, 1997; Strayer & Johnston, 2001; Strayer, Drews, & Crouch, 2006; Törnros & Bolling, 2005, 2006) to determine:

(1) whether talking on a HF cell phone while driving is safe, and
(2) whether there is a difference in safety between talking on a HH phone and talking on a HF phone while driving.

Across these studies of cell phone use, the degree to which the task performed resembles driving varies greatly. We will use the term “fidelity” to refer to variation along this dimension. Reed and Green (1999) suggested that driving-related performance suffered more from dialing a phone, in simulated driving, than in field driving tasks. It is possible that not only the manual operation of dialing (Reed & Green), but also the cognitive demands of conversing on a HH phone or a HF phone, may affect driving-related performance differently according to the fidelity of the driving situation being tested. Another purpose of this review is to examine this possibility.

We used the reference sections of papers (e.g., Horrey & Wickens, 2006) and online databases (e.g., PsycINFO, Web of Science Citation) to identify candidate papers for this review. The most important criterion for selection was that the relationship between driving-related performance and phone type (both HH and HF) was examined within a single study. We did not set any restrictions on the year of publication nor did we enforce any methodologically-based exclusions. Thus, there is variability in the methods used to simulate driving tasks, manipulate cell phone conversations, manipulate variables other than the telephone conversations, and measure effects of the cell phone conversation across the studies. Although this variability makes it difficult to combine the results across studies in a quantitative fashion, there is, nevertheless a significant benefit: when patterns of results are similar across studies with variable methods, the common pattern is consequently demonstrated to be robust and generalizable. In total we found 10 studies (eight experimental and two epidemiological[1] studies) that compared driving performance (experimental studies) and real accidents (epidemiological studies) while people were using HH and HF phones (Table 1).

[1] A third study that used epidemiological methods (Laberge-Nadeau, et al., 2003) surveyed respondents about cell phone ownership, type of cell phone, frequency of use and accidents. As described earlier (p. 1) this study drew conclusions about the increased risk of having an accident associated with cell phone ownership, usage and type. Because this study cannot support conclusions about the increased risk of accidents from talking on the phone while driving, it is not included in our review.

Experimental studies examine the effect of the phone type on the driving-related performance. The advantage of experimental studies is that cell phone use and the type of cell phone can be manipulated, which makes it possible to establish a causal relationship between the cell phone type and driving-related performance. However, there are different degrees of fidelity across the studies reviewed here. At low levels of fidelity, there are non-driving studies that do not involve actual driving, but instead require participants to perform tasks, whose component operations (e.g., tracking and RT tasks) are akin to driving operations (e.g., keeping the car on the road, braking to avoid a collision; Consiglio et al., 2003; Strayer & Johnston, 2001). Simulated driving studies have an intermediate degree of fidelity. In such studies, usually employing a driving simulator, participants drive on simulated roads (Abdel-Aty, 2003; Burns et al., 2002; Haigney et al., 2000; Strayer et al., 2006; Törnros & Bolling, 2005, 2006) while talking on a HH or a HF phone. Simulated driving studies, which are the most common among studies in general and also in this review, have advantages in terms of safety, cost, and experimental control (Reed & Green, 1999). Finally, a field driving study is the most realistic of all. In a field driving study, performance in an actual driving task is examined (Patten et al., 2004). Generally speaking, there is a tradeoff between fidelity and experimental control. Laboratory studies gain control while sacrificing fidelity; the reverse is true for field studies.

The general approach used in the experimental studies includes measuring driving-related variables while manipulating the phone type and other factors. Driving-related measures differ greatly across the studies. Most studies used the time to respond to targets or events as a measure of attention or degree of distraction (Young, Regan, & Lee, 2008). Because increases in the time to respond to a potential hazard by a braking or steering response can have disastrous consequences, great weight is placed on these data. With varying frequency the studies reviewed also included measures of vehicle control such as lane maintenance (lane deviation, collision, off-road excursion (OFF)) and vehicle speed. The focus here will be on these relevant variables from each study in which they were reported rather than upon all the (unique) variables reported in each study. In some studies drivers were instructed to maintain vehicle speed. In these cases, going too fast or too slow would be considered a failure to follow instructions. Because slowing down can be a compensatory strategy when driving becomes more difficult, and because going too fast increases the risk of accidents, our analysis of speed will focus on studies that allow us to determine the actual driving speed.

Epidemiological studies examine the relationship between cell phone conversation and motor-vehicle accidents in the real world. For example, Redelmeier and Tibshirani (1997) and McEvoy et al. (2005) evaluated cell phone records of individuals involved in motor-vehicle accidents. One advantage of an epidemiological approach is that there are fewer experimental artifacts that can contaminate the data (Goodman et al., 1997). Another advantage is that it is necessarily more realistic than the experimental studies. The main disadvantage is that, unlike experimental studies, epidemiological studies cannot firmly establish a causal relationship between the variables (e.g., cell phone use and occurrence of accidents).

2. Review of studies

2.1. Non-driving studies

Consiglio et al. (2003) examined the effects of cell phone conversations and other potential auditory/verbal sources of interference (control vs. listening to music on radio, conversing with a passenger, conversing with a HH phone, and conversing with a HF phone) as a within-subject factor[2] on RT in a braking response task.

[2] A within-subject factor is a variable for which each level of that variable is tested with all the participants in the experiment. A between-subject factor is a variable for which each level of that variable is tested with a different group of the participants in the experiment.

Table 2
Results of the experimental studies examining the effects of phone type [Control vs. HF (is the HF safe?), and HF vs. HH (is the HF safer than HH?)] on driving-related performance.

		HF minus Control			HF minus HH		
		Vehicle control		Attention	Vehicle control		Attention
		Speed	LM	RT	Speed	LM	RT
Non-driving	Consiglio et al.			+			ns
	Strayer & Johnston[a]			+			ns
Simulated-driving	Haigney et al.[b]	–	+/ns		ns	+	
	Strayer et al.[c]	ns	+	+	ns	ns	ns
	Burns et al.[d]	–	ns	+	+	ns	ns
	Törnros & Bolling[e]	ns	–	+	+	ns	ns
	Abdel-Aty[f]	?	?		?	ns	
Field-driving	Patten et al.	ns		+	+		ns

Note.
'+' represents cost (i.e., faster speed, more lane maintenance (LM) errors, and slower RT).
'–' represents benefit (i.e., slower speed, less LM errors, and faster RT).
[a] The difference between the HF and the control conditions in RT is implied in the study.
[b] The control condition in this study is calculated by taking a mean of the pre-call and the post-call conditions. The difference between the HF and the control conditions in speed is implied in the study. The "+/ns" signifies that there was a significant difference in off-road excursions while there was no difference in the number of collisions.
[c] The differences between the HF and the control conditions in LM and RT are implied in the study.
[d] The results are from the curved road condition (one of the four traffic environments). Only in this condition are both vehicle speed and RT to warning signals measured.
[e] LM is better in the HF phone than in the control conditions. This difference is implied in the study, as was the difference between the HF and the control conditions in RT.
[f] For HF vs. control, '?' indicates that the results were not reported. For HF vs HH "disobeying the speed limit" occurred more frequently in HH than HF. When contacted by us the author of this paper did not know whether these extra errors were due to participants "going too slow" or "going too fast."

Twenty-two participants performed a braking response task, in which they were asked to release the accelerator and depress the brake pedal as quickly as possible following activation of a red brake lamp located in front of them. In the three conversation conditions, participants answered straightforward scripted questions. When talking to the passenger in the passenger conversation condition, the participants were asked to look at the lamp rather than the passenger. Results indicated that RT was slower in the phone conditions, regardless of the phone type, than in the control condition. Importantly, there was no significant difference between the HH and the HF phone conditions. In addition, there was no difference in performance between the passenger and the phone conditions. The lack of a difference between the passenger and the phone conversation conditions will be discussed later in this review.

Strayer and Johnston (2001, Experiment 1) examined the effects of phone conversation (single and dual tasks) as a within-subject factor and the effects of the phone type (control, HH, and HF) as a between-subject factor[2] on performance of a pursuit-tracking task. Forty-eight participants performed the tracking task on a computer display. They were instructed to continue the task if the light on the screen was green but make a braking response when the light turned red. In the control group, the participants performed the pursuit-tracking task while listening to a radio. In the phone groups, the participants discussed current events (e.g., the then-ongoing Clinton presidential impeachment) on the phone while performing the pursuit-tracking task. RT and probability of missing the red lights were measured. Unfortunately, in Experiment 1 in which the HH and the HF phone conditions were compared, tracking error was not reported. Results indicated that RT was longer and probability of missing the red lights was higher in the phone groups than the control group. There was no significant difference between the two phone groups.

These non-driving studies show that talking on the phone while "driving" impairs RT in detection and does so equally in the HH and the HF phone conditions (Table 2).

2.2. Simulated driving studies

By far the most common type of study used some sort of simulated driving task, a method that enables objective measurement of vehicle control and attention.

Haigney et al. (2000) examined the effects of phone type (HH and HF) manipulated within-subject during different periods in relation to a 150 second phone call (pre-call, during call, and post-call) on driving performance. Thirty participants drove a simulated road four times, populated with vehicles on either side of the highway. Each simulated driving episode included three phone calls, each lasting 150 seconds. During a call, participants verbally responded to a reasoning test. Number of collisions, number of off-road OFFs, and vehicle speed were measured. The number of collisions and OFFs did not differ as a function of the period of a call. However, vehicle speed was slower during the call period than during the other periods. These patterns suggest a process of risk compensation when talking on a phone (i.e., slowing down to avoid a collision or an OFF). While the number of collisions and speed did not differ as a function of the phone type, there were significantly more OFFs with a HH phone than with a HF phone.

Strayer et al. (2006) examined the effects of the phone type (control, HH, and HF) as a within-subject factor[3] on driving performance. Forty participants drove a simulated highway (38.6 km long). Their task was to follow a pace car that was intermittently braking. Naturalistic conversation (15 minutes long) was used to simulate the demands of conversation over the phone. Topics were identified on the first day as being of interest to the participant. The total number of accidents, vehicle speed, following distance, and braking RT were measured. Results indicated that there were more accidents in the phone conditions, irrespective of the phone type, than in the control condition. Moreover, braking RT was slower, and following distance was more variable in the phone conditions, irrespective of the phone type, than in the control condition. There was no significant difference in vehicle speed between the control and the phone conditions though there was a slight tendency for slowing down during phone use (89.3 vs. 86.6 km/h). There were no significant differences between the two types of phone in any of these measures, but unfortunately for our purposes, the actual performance levels were not reported separately for the two different phone types.

Burns et al. (2002) examined the cell phone conversation (control, HH, and HF),[3] and traffic environment (motor way, 3-lane motor way, curved road, and 2-lane road) as within-subject factors on simulated-driving performance. Twenty participants were asked to: (a) follow a pace car, driving between 80-113 km/h, on a motorway for 15 km; (b) drive as they normally did on a 3-lane motorway with a speed limit of 113 km/h for 4.7 km; (c) drive a section of a curved road maintaining a

[3] There was an additional condition in which the participants consumed alcohol. This will be discussed later.

speed of 96.6 km/h for 3.6 km; and (d) respond to target warning signs by flashing their headlights while driving on a 2-lane road for 3.3 km. A sentence memory task and a verbal puzzle task included in casual conversation were used to simulate the demands of conversation over the phone. Lane deviation, vehicle speed, RT to the target signs, probability of missing the target signs, and false alarms to the target signs were measured. Lane deviation was unaffected by the phone conversation, regardless of the phone type. Vehicle speed was not different among the three phone conversation conditions on the motorway. However, vehicle speed was slower in the HH and HF conditions than in the control condition on the curves and on the two-lane roads. This tendency to slow down was significantly greater in the HH than in the HF conditions. As noted in the introduction, slowing down can be a compensatory behavior (see also Patten et al., 2004; Törnros & Bolling, 2005) to maintain safety in the face of factors challenging it. Drivers may have slowed down more when talking on a HH phone because they were more aware of the mental and physical load imposed on them. In the detection task (which was performed only on the curves), RT was slower, probability of missing target signs higher, and probability of false alarms higher in both phone conditions than in the control condition. Note that compensation behavior of slowing down did not help the participants to detect the target signs quickly in the phone conditions. Although RT was numerically slower with the HH than with the HF phones, this difference was not significant. Moreover, this trend was very likely attributable to structural interference rather than distraction; the manual tasks of handling a steering wheel while holding a cell phone likely interfered with the manual detection task response of flashing the headlights. There were no significant differences between the HH and the HF phones in either false alarms or misses.[4]

Törnros and Bolling (2005, 2006)[5] examined the effects of phone use (phone and control) and environmental complexity as within-subject factors and phone type (HH and HF) as a between-subject factor. There were two types of environment, rural and urban. The rural environment had two levels, differing in speed limit. The urban environment had three levels, differing in complexity. There were 48 participants in the study whose task was to drive, as they normally would, on the simulated roads (total of 70 km long) that led through the urban and rural environments. Participants also performed a peripheral detection task (PDT) while they were driving. In the phone conditions, participants verbally responded to a paced serial addition task. Vehicle speed and lane deviation in the driving task, and RT and accuracy in the PDT task were measured. Results indicated that vehicle speed was slower in the phone conditions than the control condition, but this pattern was due mainly to slower speed in the HH than in the control conditions. This suggests that conversing with the HH phone is accompanied by a larger compensatory effect than conversing with the HF phone; in other words, drivers may underestimate risks associated with conversing with the HF phone (see also Burns et al., 2002; Patten et al., 2004). When environmental complexity was taken into consideration, the speed reduction was observed only in the rural environment with higher speed limit and in the most complex urban environment (Törnros & Bolling, 2006). In addition, in these environments, a speed reduction was observed with the HF phones. These patterns show the compensatory effect when the driving environment is relatively challenging. Unexpectedly, lane deviation was greater in the control than in the phone conditions. Perhaps this difference was a direct consequence of the compensatory slowing of the vehicle in the phone conditions. This pattern, however, is inconsistent with Strayer et al. (2006), who showed impairments in lane maintenance in the phone condition. There was no significant difference between the HH and HF phone conditions for this variable. In the PDT, RT was longer and accuracy was worse in the phone conditions, irrespective of the phone type and environmental complexity, than in the control condition.

Abdel-Aty (2003) examined the effects of the phone type (HH and HF) and the period of a call (pre-call, during call, and post-call) as within-subject factors as well as the effects of traffic density (low and high) as a between-subject factor on the number of driving-related errors during a simulated driving task. Unlike other studies, the author did not report counterbalancing order for the phone type. Unfortunately, a failure to counterbalance would challenge any conclusions drawn from the findings about differences (or lack of differences) between the HH and the HF conditions. This study also differs from the other simulated studies by being the only one that focused on frequency of errors. There were 20 participants in this experiment, 10 in each density condition. They sat in front of the driving apparatus and were asked to drive, while following all traffic rules, to explore a simulated city that included vehicles and pedestrians. During the phone calls, some personal information (e.g., name, ages) was requested to simulate the demands of conversation over the phone. The number of errors the participants made such as lane deviation, leaving the road, crossing the median, crashing, disobeying the speed limit, failing to stop, and other errors were measured. The total number of errors across the error categories was greater during the call than before the call and there was no difference between the HH and HF conditions. However, there was one exception. The participants tended to violate the speed limit more frequently when using the HH phones than the HF phones. Whereas it might be reasonable to infer that "violate the speed limit" means "drive faster" it is also possible that driving too slowly resulted in the recording of a speed error.[6] Surprisingly, the number of errors was greater for the low traffic than high traffic conditions in the post-call condition. From these patterns the authors suggested that the negative effect of using a cell phone may be carried over for a while after conversation is terminated and that this pattern is prominent for the environment with low density. It is possible that lack of alertness in the low density condition encouraged the participants to 'think' about the conversation they had just completed.

The simulated driving studies generally show that talking on the phone while driving impairs performance on a secondary task (Table 2). In addition, from studies that actually reported vehicle speed it is apparent that participants have a tendency to compensate for the safety risk of phone use by slowing down and that this compensatory response is greater when using a HH phone. There was little effect of phone conversation on lane maintenance, perhaps because of the compensatory response of slowing down. There was also little effect of phone type on lane maintenance and RT.

2.3. Field driving study

There is only one experimental study comparing HH and HF phone use while participants were actually driving in the real world. Patten et al. (2004) examined the effects of phone type (HH and HF) and conversation complexity (control, simple, and complex) as within-subject factors on driving and PDT performance. There were 40 participants whose task was to drive, as they normally would, while following traffic rules. They drove a section of a highway with relatively low levels of road complexity and interactions with other vehicles. The speed limit was 110 km/h on this highway. The participants drove 37 km and came back the same way (total 74 km). It took about one hour to complete the return trip. Participants

[4] This false alarm finding is based on a personal communication with one of the authors.

[5] One experiment was conducted with the results presented in different papers with an emphasis on the type of road in the 2006 paper. In the 2005 paper,the participants performed two experiments, one measuring effects of conversation and the other measuring effects of dialing. We report only the results from the former experiment for our review purpose.

[6] Personal communication with the author failed to resolve this ambiguity.

were tested with one type of phone on the way and the other type on the way back. There were four phone calls in each direction, two at each level of complexity. They also performed a PDT, in which they responded by depressing a small switch attached to the left index finger to a light stimulus appearing in their periphery, while they were driving. To simulate simple and complex demands of conversation, a digit shadowing task and a memory-addition task were used, respectively. Vehicle speed in the driving task and RT and accuracy in the PDT were measured. Vehicle speed was slower in the HH conditions than in the control condition. Speed in the HF condition was not significantly different from the control condition. The authors suggest that a HH phone might remind the participants of their "*self*-imposed impediment," resulting in a compensatory speed reduction (see also Burns et al., 2002; Törnros & Bolling, 2005). In the detection task, RT was longer and accuracy was worse in the phone conditions than in the control condition, and there was no significant difference between the two phone types in either RT or accuracy on this task. RT was longest in the complex conversation condition, followed by the simple and the control conversation conditions. This pattern was the same with the HH and the HF phones, suggesting that the conversational complexity was a more important factor affecting driver distraction than phone type.

This field driving study shows that talking on the phone while driving impairs RT regardless of the phone type (Table 2). As in most of the other studies reviewed here, participants slowed down when using a HH phone, a behavior that might be an appropriate adaptation to the dual task demands.

2.4. Epidemiological studies

Redelmeier and Tibshirani (1997) and McEvoy et al. (2005) evaluated the cell phone records of individuals involved in motor-vehicle accidents resulting in damage to property and resulting in hospitalization, respectively. Both studies show that cell phone use was associated with about a four-fold increase in the likelihood of getting into an accident, linking cell phone use and traffic accidents in the real world. One common finding from these studies is that there was no safety advantage to the HF as compared with the HH phones. Thus, the HH and HF phones seem to be equally dangerous in real world settings. As mentioned earlier, accidents in the real world could be caused by poor vehicle control and/or attention being distracted from the task of driving. The results from the experimental studies summarized in Table 2 strongly suggest that the major safety risk from carrying on a cell phone conversation while driving is the withdrawal of cognitive resources from the driving task.

2.5. Summary of the studies

A summary of the results from the experimental studies discussed is presented in Table 2. The results for the measures of speed, lane maintenance, and attention (RT) are presented separately for HF phone vs. control groups, and HF vs. HH phone groups.

Based on the examination of each study and Table 2, it can be concluded that conversation with HF phones is distracting because, compared to the control condition, it consistently impairs detection RT. All of the studies that examine the difference show this pattern. Using the four studies (Burns et al., 2002; Consiglio et al.; 2003, Patten et al., 2004; Törnros & Bolling, 2005, 2006) that reported detection RT for the control and HF conditions, this was quantified by a t-test, $t(3) = -4.157$, $p = 0.02531$. Importantly, none of the studies show a significant difference between the HF and the HH phones on the detection task, suggesting no attention advantage for the HF over the HH phones (see also Fig. 1A); in other words, carrying on a conversation on a HF phone is just as distracting as carrying on a conversation on a HH phone. Using the same four studies that reported detection RT for the two phone types, this was quantified by a t-test, $t(3) = -1.0018$, ns.

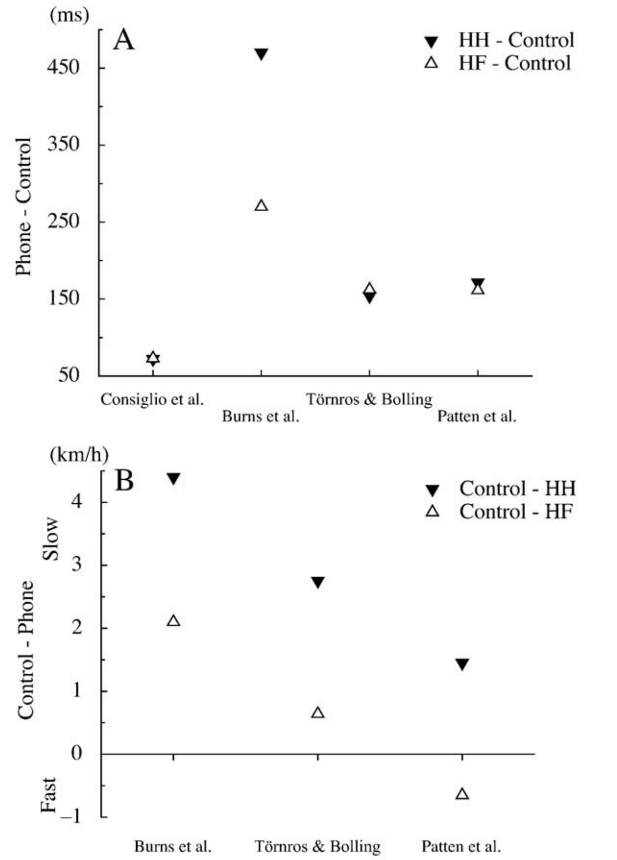

Fig. 1. (A) Difference between the control and HF phone (HF minus control), and the control and HH phone (HH minus control) conditions in detection RT in ms, and (B) difference between the control and the HF phone (control minus HF), and the control and the HH phone (control minus HH) conditions in speed control in km/h for the studies whose data are available. The results of Burns et al. (2000) in A and B are from the curved road condition (one of the four traffic environments in their study). Only in this condition were both vehicle speed and RT to warning signals measured.

However, one study (Burns et al., 2002) showed a non-significant trend for reaction time to targets to be slower in the HH condition than in the HF condition. In this study, the participants flashed the headlight by pulling the stalk to the left of the steering column when detecting the events.[7] As noted above, it is possible that the manual tasks of handling a steering wheel and holding a cell phone might have interfered with this additional manual task of flashing headlight. There are three other studies in which the participants' RT was measured from their manual responses (Patten et al., 2004; Strayer & Johnston, 2001: Törnros & Bolling, 2005, 2006) and one study in which the participants' RT was measured from their braking responses (Consiglio et al. (2003), none of which found an HF phone advantage. The responses in these manual response studies included pressing a micro switch attached to the finger (Patten et al., 2004; Törnros & Bolling, 2005, 2006) or pressing a button located in the thumb position on top of the joystick (Strayer & Johnston, 2001). The responses in the braking study required depressing the brake pedal by the right foot. None of these responses would entail the same degree of structural interference (Kahneman, 1973) that would have been present in the Burns study.

As for vehicle speed, there was a general tendency for drivers to slow down when using a cell phone, but, as we will show, this trend was stronger for the HH than for the HF conditions. First, only two out of five experimental studies found that conversation in the HF

[7] This information is based on a personal communication with one of the authors.

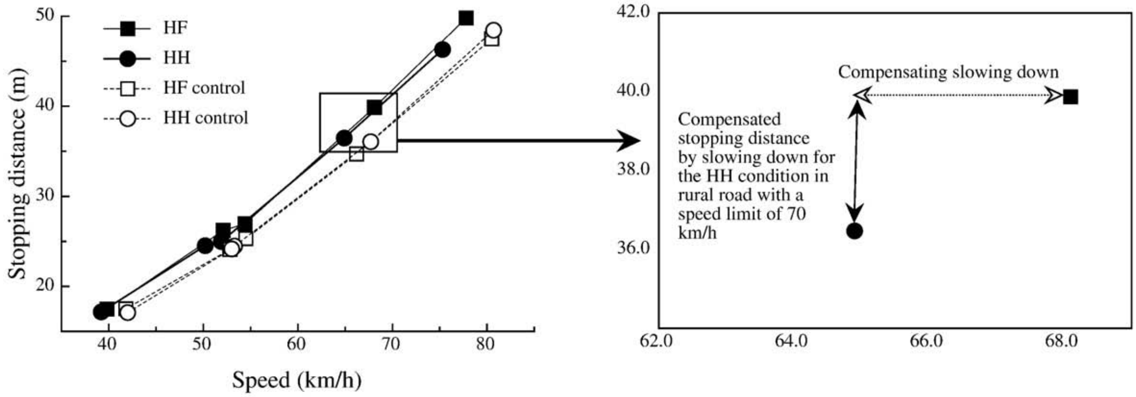

Fig. 2. Stopping distance as a function of vehicle speed is plotted based on data from Törnros & Bolling (2006, Fig. 6). Stopping distance is the distance which a car travels while the driver perceives an event and reacts to it plus the distance a car travels while braking. There were two types of environment, urban (speed limit of 50 km/h) and rural. The urban environment had three levels, differing in complexity. Further, the rural environment had two levels, differing in speed limit (speed limit of 70 and 90 km/h). The rural road condition with a speed limit of 70 km/h is emphasized for the HH and the HF conditions to illustrate compensation behavior of the HH conversation.

condition resulted in slower vehicle speed compared with the control condition. Three out of five experimental studies found that conversation in the HH condition resulted in slower vehicle speed compared with the HF condition. Using the three studies (Burns et al., 2002; Patten et al., 2004; Törnros & Bolling, 2005, 2006) that reported the actual speeds (or speed differences vs. control) for the two phone conditions, speed difference between the HF and the HH conditions was quantified by a t-test, t (2) = 33.6353, p<.001. This consistent trend is illustrated in Fig. 1B.

Looking at RT and vehicle speed findings together (see Fig. 1 and Table 2), it can be seen that the drivers with the HH and the HF phones are equally slow to react to events around them, and yet the drivers using a HF phone do not slow down as much as the drivers using a HH phone. The assumption that the distraction-mediated delay in reaction time to targets in the experiments reviewed here would generalize to reactions, such as braking or steering in response to real-world hazards, allows us to illustrate the effect of cell phone distraction upon driving safety graphically by plotting stopping distance (distance the car travels between perceiving an event and reacting to it, including the distance the car travels while braking) as a function of vehicle speed. All other things being equal, an increase in stopping distance represents a challenge to safety. This is illustrated in Fig. 2 using the relatively rich data set provided by Törnros and Bolling (2006). Especially in the conditions with a higher speed limit (e.g., 70 km/h), talking on a HF phone does not show as much compensatory slowing down as does talking on a HH phone, resulting in a longer stopping distance. In every comparison, save for the slowest one, the stopping distance for the HF condition was greater than for its corresponding control condition. In contrast, the greater compensatory slowing by drivers in the HH condition was sufficient to overcome the reaction time delay and, consequently, roughly equate stopping distance with its corresponding control condition. This pattern, which was also reported in Burns et al. (2002) and Patten et al. (2004), suggests that HF phone could be more dangerous than HH phones in some situations.

One out of three studies shows that conversation with HF phones impairs lane maintenance, and only one study out of five clearly shows a difference between the HF and the HH phones on the same measure. These patterns suggest little safety advantage of the HF over the HH phones. This pattern is, at first, surprising because drivers using a HH phone should be at a disadvantage in stable lane maintenance with only one hand controlling the steering wheel. However, it seems likely that participants are more aware of interference imposed by the phone when the phone is HH (i.e., when there is a structural limitation). Indeed, it is probably this awareness that leads to the compensatory behavior of slowing down (see above). Perhaps at the slower speeds maintained in the HH phone condition, drivers are able to maintain lane position at the same level as in the HF phone condition where a higher speed (due to less, or no, compensation) is maintained (Burns et al., 2002; Törnros & Bolling, 2005, 2006). Although slowing down when asked to maintain speed in a certain range might be considered poor vehicle control, we believe that in the context of a cell phone conversation it represents an adaptive strategy to improve safety.

One purpose of this review paper has been to evaluate the effects of phone conversation and phone type on driving performance across different levels of driving fidelity. Table 2 shows that there are clear patterns in the measure of attention across the different fidelities within the experimental studies; phone conversation regardless of the phone type impairs detection/identification RT. On the other hand, there is not a clear pattern in the measure of vehicle control. These patterns are consistent with the conclusions of Horrey and Wickens (2006), who show costs of using phones while driving regardless of the phone type with clear costs for RT tasks but little costs for tracking tasks (i.e., lane maintenance). Even though the HH phone condition in this review is restricted to HH phone use for conversation and not for dialing, a similarity between Horrey and Wickens's meta-analysis and the patterns found in this review is revealed. Talking on the phone impairs attention and there is little difference between the HH and HF phones. Moreover, meta-awareness of the possibly deleterious effects of HH phone use seems to result in a compensatory speed decrease thereby maintaining performance in keeping the car in the lane. These patterns can be interpreted as consistent with the results from the epidemiological studies, which show a greater likelihood of getting into an accident when talking on the phone regardless of the phone type. We assume that accidents could happen because of poor vehicle control and distracted attention. Given the experimental studies described here we believe that it is likely that accidents associated with cell phone use in the epidemiological studies were more often due to distracted attention than to poor vehicle control (Regan, Lee, & Young, 2008).

3. Other Issues

3.1. Comparison of cell phone conversation and passenger conversation

As mentioned above, a difference between the phone conversation and the passenger conversation was not found by Consiglio et al. (2003) who compared: control, radio listening, conversation with passenger, conversation using HH phone, and conversation using HF phone. In the three conversation conditions, the participants answered straightforward scripted questions. Although they reported that performance on the detection task was not necessarily better in the passenger than in the phone conditions, the naturalness of the passenger condition was seriously challenged: participants answered scripted questions while focusing on the red lamp in front of them. This unnatural conversation might be cognitively demanding and as such might offset the advantage of natural conversation with a passenger. In fact, in other studies when natural interaction was involved between the passenger and the driver, there was a safety advantage for the passenger conversation over the phone conversation (Drews, Pasupathi, & Strayer, 2008; Hunton & Rose, 2005). When natural interaction is involved, the driver and the passenger can develop the same situational awareness (Drews et al., 2008) making it less likely that the passenger will initiate a conversation that might distract the driver's attention. Conversely, because of this shared situational awareness, there is less social pressure to remain engaged with a passenger than with a phone conversant: The passenger will realize that the demands of driving have caused a cessation of the conversation, while the phone conversant will perceive such a cessation as rude.

3.2. Comparison of cell phone use with alcohol intoxication

A clear pattern found in this review is that driving-related performance, especially detection/identification of events, is poorer when driving while talking on the phone (irrespective of the phone type) than in the control condition. It might be argued that worse than normal driving does not necessarily mean dangerous driving (Burns et al., 2002). Of course, the 4-fold increase in the risk of an accident that is associated with cell phone use while driving provides one cogent response to this argument. Another response is provided by two studies (Burns et al., 2002; Strayer et al., 2006) that compared drunk and cell phone drivers. Both studies found that the participants in the phone condition, regardless of the phone type, were as slow as, if not slower than, drunk drivers, to respond to signals. Driving drunk is illegal in many jurisdictions. Perhaps similar restrictions regarding use of a cell phone while driving should be considered.

4. Suggestions for future research

Our review sought to uncover what was the “true” danger (relative to control) of using a HF phone and whether this danger differed from that of using a HH phone. Whereas we could report the outcome of the statistical comparisons made in all of the studies (Table 2) conducted so far, and this review leads to some very clear conclusions about distraction, we had difficulty analyzing the studies quantitatively (Fig. 1) because often data were not reported when there was no significant difference between the two phone types. We recommend that researchers studying driving and cell phone use consistently report the data for type of cell phone, whether or not the differences are significant.

In this review, we focused on the manipulation of the phone type (especially for the experimental studies) and its effects on driving performance according to the different fidelities. However, there were considerable variations in factors other than the phone type, which make firm conclusions about these factors difficult to draw. These manipulations include type of conversation, environment complexity, and type of HF cell phone receiver (e.g., HF phone with an earpiece/headset vs. HF phone with a speaker). These factors were found or suggested to influence driving performance (type of conversation: e.g., Briem & Hedman, 1995; McKnight & McKnight, 1993; Shinar, Tractinsky, & Compton, 2005; Liu, 2003; environmental complexity: e.g., Strayer, Drews, & Johnston, 2003; Liu & Lee, 2006; and type of receiver: Matthews, Legg, & Charlton, 2003). Among the studies reviewed, the study by Törnros and Bolling (2006) can be put forward as a model study. Their manipulation of environmental complexity was realistic and variable, including five levels of environmental complexity. Their complete reporting of the data allowed us to represent their findings to reveal an important relationship between type of cell phone and safety-related compensation.

5. Conclusion

The epidemiological and the experimental studies show a similar pattern: talking on the phone while driving impairs driving performance for both HH and HF phones. Experimental studies across a wide range of driving fidelity demonstrate that talking on a phone, regardless of the phone type, has negative impacts on detecting and identifying events. In the real world, such detection failures might mean failing to notice pedestrians crossing streets or missing traffic signals, resulting in critical accidents. Whereas, when talking on a HH phone drivers tend to slow down, they do so much less if at all when talking on a HF phone. The combination of a slow response and a relatively high speed implies a longer distance between any hazard and the driver's maneuver to avoid the hazard (Fig. 2). In the real world, failing to react quickly might mean hitting pedestrians or failing to avoid an out-of-control vehicle. These examples, together with the findings reported here, suggest that because of the absence of a compensatory response, talking on a HF phone may actually be more dangerous than talking on a HH phone.

We posed two questions at the beginning of this review: Is talking on a HF cell phone while driving safe, and is there a difference in safety between talking on a HH phone and talking on a HF phone. Based on accident rates linked to cell phone use in the real world, and based on objective measures of distraction in experimental studies, we have shown, in this review, that the answer to both questions is “No.”

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