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# Cell Phones and Driving: Review of Research

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***Objective.*** *The research literature on drivers' use of cell phones was reviewed to identify trends in drivers' phone use and to determine the state of knowledge about the safety consequences of such use.*

***Methods.*** *Approximately 125 studies were reviewed with regard to the research questions, type and rigor of the methods, and findings. Reviewed studies included surveys of drivers, experiments, naturalistic studies (continuous recording of everyday driving by drivers in instrumented vehicles), studies of crash risk, and evaluations of laws limiting drivers' phone use.*

***Results.*** *Observational surveys indicate drivers commonly use cell phones and that such use is increasing. Drivers report they usually use hand-held phones. Experimental studies have found that simulated or instrumented driving tasks, or driving while being observed, are compromised by tasks intended to replicate phone conversations, whether using hand-held or hands-free phones, and may be further compromised by the physical distraction of handling phones. Effects of phone use on driving performance when drivers are in their own vehicles are unknown. With representative samples of adequate size, naturalistic studies in the future may provide the means to document the patterns and circumstances of drivers' phone use and their effects on real-world driving. Currently, the best studies of crash risk used cell phone company billing records to verify phone use by crash-involved drivers. Two such studies found a fourfold increase in the risk of a property-damage-only crash and the risk of an injury crash associated with phone use; increased risk was similar for males and females, younger and older drivers, and hands-free and hand-held phones. A number of jurisdictions in the United States and around the world have made it illegal for drivers to use hand-held phones. Studies of these laws show only limited compliance and unclear effects on safety.*

***Conclusions.*** *Even if total compliance with bans on drivers' hand-held cell phone use can be achieved, crash risk will remain to the extent that drivers continue to use or switch to hands-free phones. Although the enactment of laws limiting drivers' use of all phones is consistent with research findings, it is unclear how such laws could be enforced. At least in the short term, it appears that drivers' phone use will continue to increase, despite the growing evidence of the risk it creates. More effective countermeasures are needed but are not known at this time.*

**Keywords** Motor Vehicle Crashes; Cellular Phones; Hand-Held Cellular Phones; Hands-Free Cellular Phones

In December 2004, there were more than 180 million subscribers of wireless or cellular telephones (hereafter referred to as cell phones) in the United States, more than double the number in December 1999 (Cellular Telecommunications and Internet Association, 2005). Cell phone ownership has increased for every age, educational, income, and regional sector of the population (Insurance Research Council [IRC], 2000).

The proliferation of cell phones has led to concerns about implications for highway safety. Drivers' use of hand-held phones is illegal in most countries throughout the European Union, in all Australian states, and in the Canadian province of Newfoundland and Labrador. In Japan, it is illegal for drivers to use any kind of phone, but enforcement can occur only if drivers have committed another traffic violation and pose a danger to others. In the United States, it is illegal for drivers to use hand-held phones in Connecticut, New Jersey, New York, and Washington, D.C. In some states, phone use is restricted among certain drivers (e.g., young drivers with provisional licenses, school bus drivers) or in selected jurisdictions by local ordinance (Insurance Institute for Highway Safety, 2005).

The National Highway Traffic Safety Administration estimates that about 25 percent of all highway crashes involve some form of driver inattention (Wang et al., 1996). However, the exact percentage is unknown because it is nearly impossible to determine accurately whether driver inattention was a factor in a crash. Although concern about driver distraction is not new, many regard cell phones as qualitatively different and potentially more dangerous than other long-standing distractions such as eating, drinking, or tuning the radio. Heightened attention to driver distraction also is fueled by the emergence of other potentially distracting in-vehicle technologies (e.g., wireless messaging, navigation systems, DVD players) that are available as standard or optional features on new vehicles or through aftermarket vendors.

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Early experimental studies of the effects of cell phone use on driving tasks used models of divided attention, resource allocation, and information processing developed by human factors researchers (Brookhuis et al., 1991; Fairclough et al., 1990; Green et al., 1993; Kames, 1978; McKnight & McKnight, 1993; Parkes, 1991; Stein et al., 1987; Zwahlen et al., 1988). The number and types of studies have increased dramatically during the past few years. A search of the literature found more than 125 published scientific papers and technical reports examining some aspect of cell phones and driving.

This literature was reviewed to gather information about trends in drivers' cell phone use and to determine the state of knowledge about the safety consequences of such use. The goal was to determine the extent to which the following questions have been addressed: How does phone use compromise safe driving? What is the risk of crashes of various severities associated with phone use? What are the relative risks of hand-held versus hands-free phones? What types of drivers and driving situations are at highest risk? Are countermeasures to reduce drivers' phone use warranted?

## METHODS

Studies were identified through online searches (Google, Nexis, Factiva), backwards referencing, proceedings of scientific conferences, news clippings, and the National Academy of Science's Transportation Research Information Services (TRIS) database. Earlier literature reviews also were consulted (Cain & Burris, 1999; Goodman et al., 1999; Hahn & Dudley, 2002; Haigney & Westerman, 2001; Royal Society for the Prevention of Accidents, 2002; Young et al., 2003). Included studies were those written in English, involving passenger vehicle drivers, and with relevance to highway safety in the United States. Almost all were government technical reports or papers in scientific journals.

Approximately 125 studies of the following types were reviewed with regard to the research questions, type and rigor of the methods, and findings:

- Surveys that measured the prevalence and patterns of drivers' cell phone use and the characteristics of phone users.
- Experimental studies that examined the effects of well-defined phone tasks on well-defined simulated or instrumented driving tasks under controlled conditions.
- Naturalistic studies that recorded the behavior of drivers engaged in everyday driving over an extended period of time.
- Crash studies that examined the role of phone use in crashes.
- Evaluations of the costs and benefits or the effects of laws limiting drivers' phone use.

### Patterns and Trends in Drivers' Phone Use

The review encompassed 30 survey studies. Surveys may have a limited "shelf life," given the continuing increase in cell phone ownership, increased availability of phones with hands-free features, and rapid advancements in phone technologies. Thus, the following summary emphasizes the most recent U.S. studies.

*Observational Surveys.* Well-designed observational surveys can provide reliable estimates of the rates of drivers' hand-held cell phone use. National U.S. surveys indicate that at any given time during daylight hours in 2005, six percent of passenger vehicle drivers were talking on hand-held phones, up from three percent in 2000, four percent in 2002, and five percent in 2004 (Glassbrenner, 2004, 2005a, 2005b; Utter, 2001). Similar use rates were estimated in statewide surveys (Eby & Vivoda, 2003; Reinfurt et al., 2001; Salzberg, 2002). Observed use rates were higher in some areas; for example, six percent of drivers were observed talking on hand-held phones in Washington, D.C., in spring 2004 (McCartt et al., 2006), when estimated use nationwide was five percent (Glassbrenner, 2005a). Observed phone use rates were higher than national use rates on highways in Dallas during afternoon peak travel periods (Crawford, 2002), but lower on the New Jersey Turnpike during all hours of the day (Johnson et al., 2004).

Three surveys estimated daytime rates of passenger vehicle drivers using phone headsets or earpieces. In the 2004 and 2005 national surveys, 0.4 and 0.8 percent of drivers, respectively, were talking with headsets (Glassbrenner, 2005a, 2005b). In New York, annual statewide observations commenced after it became illegal in November 2001 for drivers to talk on hand-held phones (Dowling, 2005). In spring 2005, nearly three percent of drivers were illegally holding phones to their ears; 0.4 percent were using hands-free adapters/devices, and 0.3 percent were dialing, activities permitted by law. Among drivers observed using hand-held phones in the Washington, D.C., metropolitan area in spring 2004, about six percent were talking on phones and 0.6 percent were dialing (McCartt et al., 2006). In the 2005 national survey, an estimated 0.2 percent of drivers were dialing phones, checking personal digital assistants (PDAs), or otherwise manipulating some hand-held device while driving.

Some U.S. surveys examined differences in rates of hand-held phone use by driver characteristics. Although these surveys found no gender differences (Eby & Vivoda, 2003; Glassbrenner, 2005a, 2005b; Johnson et al., 2004; McCartt & Geary, 2004; Reinfurt et al., 2001), significant differences by drivers' estimated ages were observed. Use rates were significantly lower among drivers estimated to be 70 and older (Glassbrenner, 2005a, 2005b) and 60 and older (McCartt & Geary, 2004) than among younger drivers. Use rates were higher among drivers estimated to be ages 16–45 (Johnson et al., 2004) or 16–24 (Glassbrenner, 2005a, 2005b) than among older drivers, and were higher among drivers of estimated ages 25–44 than among younger or older drivers (Reinfurt et al., 2001). In the 2005 national survey, the rates of hand-held phone use were 10 percent for ages 16–24, 6 percent for ages 25–69, and one percent for ages 70 and older (Glassbrenner, 2005b).

Use rates were lower in the Northeastern United States (Glassbrenner, 2005a, 2005b), among drivers carrying at least one passenger (Glassbrenner, 2005a, 2005b; Johnson et al., 2004; Reinfurt et al., 2001), and among drivers exceeding the speed limit on the New Jersey Turnpike (Johnson et al., 2004). Reinfurt et al. (2001) found higher seat belt use among phone users, but Eby and Vivoda (2003) reported lower belt use among phone users. Based on observations conducted between 5:00 p.m. and 6:00 p.m. at intersections with four-way stop signs in residential areas, the likelihood of drivers coming to a complete stop was significantly lower among drivers talking on hand-held phones than among drivers without phones (Strayer & Drews, in press).

Observed daytime rates of hand-held phone use in other countries generally have been lower than in the United States. In Perth, Western Australia, the use rate was 1.5 percent in 1998–99, prior to a ban on drivers' hand-held phone use (Horberry et al., 2001), and two percent in 2002–04 after the ban (McEvoy et al., 2005). In Melbourne, Victoria, where drivers' hand-held phone use has been illegal since 1988, the use rate was two percent in 2002 (Taylor et al., 2003). Observed hand-held phone use in the United Kingdom was nearly two percent 10 weeks before a ban on such use, and one percent 10 weeks after (Johal et al., 2005). Observed use in four of the largest cities in Finland increased from about three percent in spring 2003, shortly after a law banning drivers' hand-held phone use took effect, to about six percent in spring 2004 (Rajalin et al., 2005).

*Telephone Interviews.* Observational surveys provide estimates of drivers' cell phone use at a given point in time. Although subject to reporting biases, telephone surveys are a means to study general patterns of phone use among drivers. In 2003, about 6,000 U.S. drivers were interviewed about their phone use while driving (Boyle, 2005). About two-thirds of drivers reported they usually have cell phones in their vehicles when they drive, and more than half of drivers said they talk on phones while driving at least occasionally. The reported frequency of phone calls varied widely. Among drivers who said they usually carry cell phones, about a quarter said they never talk on their phones while driving, but 13 percent said they did so on most or all of their trips. About a third of all drivers said they had used cell phones to report emergencies while driving or riding in motor vehicles; most commonly they had called to report highway crashes.

Other national surveys reported similar (Harris, 2001) or somewhat lower (IRC, 2000) rates of phone use among drivers, but more than half of North Carolina drivers surveyed said they had used phones while driving (Stutts, Hunter, et al., 2003). Most drivers who used phones report using hand-held devices (Boyle, 2005; IRC, 2000; Stutts, Hunter et al., 2003). Most drivers with hands-free devices said they used headsets or earpieces rather than speaker phones, and more than half said they do not always use the hands-free features (Stutts, Hunter et al., 2003; Boyle, 2005). Among New York drivers using phones, the proportion with hands-free devices increased from 50 percent in fall 2001, shortly before hand-held phone use became illegal, to 64 percent in 2003; however, only about half said they always used the hands-free features. About three-quarters of hands-free features were headset/earpiece adapters rather than speaker phones (Dowling & Hammer, 2003).

Of drivers who reported talking on phones while driving at least occasionally, about a third said they tend to dial phones while driving, 41 percent tend to dial during temporary stops, and 23 percent tend to pull over and stop before dialing (Boyle, 2005). Most drivers reported phone use affects their ability to drive safely (Dowling, 2003, 2005; Royal, 2003). In New York surveys, the majority of respondents said dialing is more distracting than conversing or answering incoming calls (Dowling, 2005; Dowling & Hammer, 2003). The degree of support for laws limiting drivers' phone use has varied among surveys. In the most recent national survey, 57 percent of respondents supported a ban on all phone use while driving, and 71 percent supported a ban on hand-held phone use (Royal, 2003).

The reported prevalence of phone use while driving is substantial in other countries. One-fifth of Canadian drivers reported using phones while driving during the previous week (Beirness et al., 2002). In surveys of Finnish drivers, reported phone use while driving increased from 56 percent in 1998 to 68 percent in 1999 (Lamble et al., 2002) and to 81 percent in 2002 (Pöysti et al., 2005). After a ban on drivers' hand-held phone use took effect in spring 2003, reported use declined, especially among drivers with hand-held phones, but increased substantially about a year after the law (Rajalin et al., 2005). Despite high rates of reported phone use, about half of Canadian drivers surveyed strongly favored a ban on phone use while driving (Beirness et al., 2002). Before Finland instituted its law limiting hand-held phone use, about half of drivers surveyed favored a hand-held phone ban, and 27 percent supported a ban on all phones (Lamble et al., 2002).

*Mail or Handout Surveys.* In conducting mail or handout surveys, it is difficult to obtain representative samples of drivers, and low participation rates may substantially bias the results. Few such surveys were identified. Mailed surveys conducted in Quebec (Laberge-Nadeau et al., 2003) and Sweden (Thulin & Gustafsson, 2004) and a survey with postage-paid envelopes handed out at gas stations in New Zealand (Sullman & Baas, 2004) produced findings that generally were consistent with those from telephone surveys. Many drivers reported using phones while driving. Use of hands-free phones was far less common than use of hand-held devices. Half of Swedish respondents supported a ban on drivers' use of hand-held phones, and 31 percent supported a ban on all types of phones. In the United States, a questionnaire was distributed to college students enrolled in health-related courses in four midwestern and southern states (Seo & Torabi, 2004). Three-quarters of cell phone owners reported they used their phones at least occasionally while driving.

*Summary.* Observational and telephone surveys in the United States indicate many drivers talk on cell phones and that drivers' phone use is increasing. Observed rates of hand-held phone use were higher among some driver groups and in some geographical areas. Some of these differences may be attributable to sampling differences. Observed rates of drivers' hand-held phone use in other countries have been lower. Internationally, drivers typically report using hand-held phones, and hands-free devices most often incorporate headsets/earpieces. Drivers also generally support laws limiting hand-held phone use, although there is less support for limitations on all types of phones.

### *Effects of Phone Use on Simulated or Instrumented Driving Tasks*

More than one-third (54) of the studies reviewed were experiments testing volunteer drivers on simulators or in instrumented vehicles on test tracks or public roads. In these studies, participants' performance of various driving tasks was monitored, with driving with phone tasks compared with driving with no distraction tasks (control) or other nonphone distraction tasks. However, synthesizing these studies and assessing their relevance to real-world driving is problematic (e.g., Goodman et al., 1999; Haigney & Westerman, 2001) for the reasons noted below.

The strength of experimental studies is that driving tasks and phone tasks are well-defined, and effects of various distractions on driving tasks can be tested rigorously. But the rigor has a downside; changes in performance of experimental tasks have uncertain implications for real-world driving. Driving simulators and test tracks vary widely in their attributes and how realistically they depict real-world driving (e.g., Goodman et al., 1999). Because there are no serious consequences of subjects' driving errors, it is unknown whether drivers would make the same decisions when driving their own vehicles. Even subjects tested on public roads or test tracks are never exposed to potentially dangerous driving situations. Phone and driving tasks are paced by experimenters, but in the real world drivers decide when and where to use their phones and may adapt their phone use to varying traffic conditions. Although the measures of driving performance (e.g., lane deviation, speed, reaction time) appear related to crash risk, the extent to which this is the case is unclear. Some studies examined the effects of a phone task on drivers' performance of a peripheral detection task (e.g., reacting to peripheral light stimulus) to gauge mental workload. Other study limitations include that subjects may be influenced by the knowledge that their behavior is being monitored or by the presence of a researcher passenger, that samples typically are small groups of volunteer subjects (limiting generalization of findings to all drivers), and that learning effects (i.e., improved performance with more experience on a task) rarely are accounted for.

A wide range of variables are relevant to experimental studies of drivers' phone use (Table I). Many studies did not provide important details about these variables. For example, early studies often did not describe the phone equipment used or subjects' prior experience with cell phones. There is no taxonomy of phone technologies, and experimental tasks, measures, and methods are not standardized. This lack of "operational clarity" results in concerns about the ecological validity and reliability of the studies' findings (Haigney & Westerman, 2001), hampers replication by other researchers, and inhibits cross-study synthesis and comparison.

Especially in early studies, the phone equipment or the conversation task often was unrealistic. Even in studies that examined the physical distraction from handling phones, an actual phone may not have been used. Only a few studies used the full range of tasks that may be encompassed by hand-held phone use including accessing, opening, dialing, and holding a phone (e.g., Greenberg et al., 2003; Ranney et al., 2005). A driver sometimes does not interact with another person; a task such as counting backwards may simulate phone conversations. The conversation tasks often are unrealistic, having little emotional content and consisting of simple or complex vocabulary, computational, or recall tasks. Some recent simulator studies have used "naturalistic" conversation tasks that better represent actual phone conversations. For example, Shinar et al. (2005)

**Table I** Experimental study variables

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|---|
| Setting |
| • Driving simulator (35 studies with 44 experiments) or instrumented vehicle on test track (7 studies with 8 experiments) or public roadway (12 studies). |
| Characteristics of driving environment |
| • *Simulator:* Quality of visual scene, motion base, interactive, whether actual vehicle body, etc. |
| • *Closed course:* Length and difficulty, presence of other vehicles. |
| • *On the road:* Type of roadway, traffic flow. |
| Vehicle transmission |
| • Automatic or manual; often not specified. |
| Driving task |
| • May include stopping, turning, following lead car, etc.; varies widely in difficulty. |
| Subjects |
| • *Sampling method*: Volunteers; suboptimal driver populations (e.g., professional drivers, college students) sometimes used. |
| • *Sample size:* Range 8 to 350; simulator experiments: mean 46, median 30; closed course: mean 30, median 37; on road: mean 27, median 21. |
| • *Characteristics:* Data on age and gender generally provided, but data on driving experience, driving record, experience with cell phones often missing. |
| Experimental condition: phone task |
| • *Actual or simulated phone:* Simulated phone may include touch screen or audio input. |
| • *If actual phone, type and features:* No taxonomy; types range from fully hand held to fully hands free with voice activation; size, weight, location, mounted/portable, cordless/corded, flip/non-flip phone, type and size of keypad, type of display, speed dialing, and other features often not provided. |
| • *Scope of task:* May include retrieving, opening, finding number, dialing, answering, talking, listening, etc.; dialing and conversing are primary components modeled; associated tasks (e.g., taking notes) not included. |
| • *Nature of conversation:* Pertains to content, difficulty, length, method of delivery; simple topical conversation or cognitive/information processing task; computational or vocabulary exercises of varying difficulty are common; conversation generally lacks emotional content |
| Control or comparison conditions |
| • Driving without distraction tasks (control) or driving with other nonphone distraction tasks (e.g., tuning radio, conversation with passenger) |
| Independent variables |
| • May include phone use vs. control, hands free vs. hand held, dialing vs. conversing, types of phone dials, complex vs. simple phone task, complex vs. simple driving task, age or experience of driver. |
| Dependent variables |
| • Eye movements, subjective workload, ability to recall, heart rate, hands on wheel, vehicle movements (e.g., lane keeping or tracking, response time to event/stimulus, lateral vehicle displacement, braking, time to complete route, speed, distance to lead car, checking rear view mirror, time to collision, gap acceptance). |

gathered information from subjects about work, school, social habits, hobbies, and interests to generate discussions with researchers that would be emotionally challenging. Similarly, Strayer and colleagues (Strayer & Drews, 2004; Strayer, Drews, & Crouch, 2003; Strayer, Drews, & Johnston, 2003) based cell phone conversations on topics that subjects had identified as being of interest.

*On-Road Studies.* Studies conducted in instrumented vehicles on public roads would be expected to have more validity than those conducted in simulators or on test tracks. Eleven on-road studies were conducted in the United States (one study), Europe (eight studies), Canada (one study), and New Zealand (one study).

Two on-road studies examined hands-free phone conversations. Although an apparent novelty effect made it difficult to separate the effects of higher mental workload and technology, negotiation tasks (e.g., booking a vacation) using hands-free phones decreased average speeds and increased heart rates and subjective mental workload/stress compared with control (no distraction). Heart rates also were higher for negotiation tasks conducted by phone than for negotiation tasks conducted with a passenger (Fairclough et al., 1990). Computational conversation tasks using hands-free phones degraded inspection of the visual field and increased hard braking incidents and subjective workload/distraction; effects generally increased with more difficult phone tasks (Harbluk et al., 2002).

Several studies examined hands-free and hand-held phone tasks. Using a difficult memory/computational task, Brookhuis et al. (1991) found that both phone types adversely affected some driving performance measures and perceived workload, but reduced swerving. Hands-free users showed slightly more vehicle control. Subjects were unfamiliar with cell phones, and there were clear learning effects for some measures. Matthews et al. (2003) examined subjective workload for a rhyming task using phones that were hand-held, hands-free speaker, or hands-free earbud/microphone. All phone types were associated with increased subjective workload; hands-free earbud/microphone interfered the least and hands-free speaker interfered the most. Hand-held phones were rated more physically demanding, but physical demand was not a high contributor to perceived workload.

Patten et al. (2004) studied cab drivers and couriers driving on low-complexity expressways and performing a peripheral detection task. Drivers pushed a button to begin complex arithmetic and memory phone tasks or simple phone tasks (repeating single digit numbers). Reaction times on the peripheral detection task increased and correct responses declined for phone tasks versus control and for complex phone tasks versus simple phone tasks. Phone type (hands free versus hand held) did not affect performance on the peripheral detection task, but mean vehicle speed was higher for hands-free phones than for hand-held phones or control.

Several studies compared the effects of phone tasks with other distraction tasks. Green et al. (1993) found small effects on driving performance with hand-held phone tasks (dialing, listening, conversing) and navigation system tasks compared with control, but no difference in driving performance and eye location with phone tasks compared with navigation system tasks. Olsson and Burns (2000) found that counting backwards (intended to simulate phone conversation) produced slower reaction times on a peripheral detection task than did tuning a radio or operating a CD player. Parkes (1991) reported lower memory and information processing scores from conversing with the office by phone while driving than from conversing with passengers, conversing with the office by phone in the laboratory, or talking face-to-face in the laboratory. In contrast, Fairclough et al. (1990) found almost no differences in driving performance between negotiation tasks conducted either using hands-free phones or with a passenger. Crundall et al. (2005) reported that in demanding simulated driving situations versus easy ones (e.g., busy urban roads with traffic lights and roundabouts versus rural roads with little traffic), conversations with passengers but not phone conversations were suppressed.

Three studies examined the effects of phone dialing. Lamble et al. (1999) found that dialing on a mounted keyboard versus performing memory/addition tasks (simulating phone conversation) similarly impaired brake reaction time and time to collision. Wikman et al. (1998) reported longer glances away from the roadway for dialing than for changing a cassette or manipulating the radio when driving on local roads, but shorter glances for dialing when driving on expressways. Experienced drivers (ages 29–44) allocated visual attention better than novice drivers (ages 18–24). Green et al. (1993) found greater deviations in steering wheel angle for dialing than for conversing with a passenger, but throttle position varied more with conversing.

In a different type of on-road study, Lerner & Boyd (2005) studied the willingness and perceived risk of engaging in technology tasks using cell phones, navigation systems, and PDAs and in nontechnology tasks (e.g., drinking a hot beverage). The tasks were described by a researcher riding with the driver. In general, male drivers reported greater willingness than female drivers to use in-vehicle technologies, and teenage drivers (ages 16–17) and younger drivers (ages 18–24) expressed more willingness than middle age (ages 25–59) or older (60 and older) drivers. Males and teenage/younger drivers also perceived this use as less risky than did females and middle/older drivers. Across all participants, drivers were more willing to use cell phones than PDAs or navigational systems while driving and were more willing to have conversations on cell phones than to answer or dial phones.

*Test-Track Studies.* Seven studies used instrumented vehicles on test tracks. An early study by Kames (1978) found that different designs or locations of dials within the reach and sight of drivers similarly affected driving control. Zwahlen et al. (1988) found that dialing increased lane deviations to levels described as potentially dangerous. Not being permitted to look at the roadway was most disruptive; low-mounted phones were more disruptive than high-mounted ones.

Hancock et al. (2003) found that a phone task (memory exercise on mounted touch screen) increased nonresponses to stoplights by 15 percent. Among drivers who stopped, responses were slower for phone tasks than for control; drivers braked more intensely but still stopped 50 percent closer to stoplights. Distraction effects on all performance measures were greater for older drivers (ages 55–65) than for younger drivers (25–36). Deleterious effects on brake response time and stop light compliance were greater for female drivers.

Cooper et al. (2003) and Cooper and Zheng (2002) found that complex hands-free phone conversation tasks degraded driving performance on the relatively demanding tasks of weaving through targets and gauging gap space for left turns, but increased the likelihood of stopping at red lights. When comparing phone conversation tasks with control, drivers on wet pavement had a twofold increase in the number of potential collisions, and older drivers (ages 45–70) had slower braking reaction times. The speed at which younger drivers (ages 19–24) chose to run red lights also went down substantially.

Ishida and Matsuura (2001) compared the effects of distraction tasks (receiving a call and performing cognitive addition exercises using hand-held or hands-free phones versus inserting and listening to a cassette) while following a lead car. Compared with the cassette task or control, hand-held phone tasks led to delayed brake reaction time, reduced speed, longer distance from lead vehicle, longer glances at apparatus, and more steering wheel movements. Performance generally was better with hands-free phones than with hand-held phones. Mean glance duration was longer when answering hand-held phones than when answering hands-free phones or inserting a cassette.

Schreiner et al. (2004) examined voice-recognition dialing versus manual dialing among older (mean age 57) and younger (mean age 23) drivers. Compared with baseline, the duration of glances at the forward roadway increased with voice dialing and decreased with manual dialing. The duration of glances at the speedometer decreased for both dialing modes compared with baseline, but more so for manual dialing. Voice dialing took longer than manual dialing, especially among older drivers. Reaction time (i.e., pressing brake when lights appeared) was longer for manual dialing than for voice dialing or control among younger drivers and longer for both dialing modes than for control among older drivers.

*Driving Simulator Studies.* Of the 35 studies conducted in driving simulators, virtually all found that conversations on hand-held or hands-free phones (or tasks simulating conversations) caused some degree of impairment on at least some simulated driving tasks. Measures of simulated driving performance included reaction time, maintaining lane position, stopping distance or time, following distance, maintaining appropriate speed, complying with traffic signals, appropriate steering, and perceived workload. Examples of phone tasks ranged from determining whether or not sentences were sensible (Nilsson & Alm, 1991) or performing complex mathematical computations (Shinar et al., 2005) to discussing where one lives (Liu, 2003), child prostitution in Thailand or U.S. economic policy (Briem & Hedman, 1995), or topics that subjects had identified as being of interest (e.g., Strayer & Drews, 2004).

The most frequently reported effect from phone tasks was slowed reaction time (Alm & Nilsson, 1994, 1995; Burnes et al., 2002; Consiglio et al., 2003; Kircher et al., 2003; Laberge et al., 2004; Liu, 2003; McKnight & McKnight, 1993; McPhee et al., 2004; Nilsson & Alm, 1991; Parkes & Hooijmeijer, 2000; Strayer & Drews, 2004; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001; Strayer et al., 2005; Woo & Lin, 2001). Some studies found that drivers performing phone tasks tried to compensate for slowed reaction times by increasing following distance (Strayer & Drews, 2004; Strayer, Drews, & Crouch, 2003; Strayer, Drews, & Johnston, 2003; Strayer et al., 2005) or slowing down (Pachiaudi & Chapon, 1994; Rakauskas et al., 2004). Some studies found an increase in simulated crash risk among drivers using hands-free phones compared with control (Abdel-Aty, 2003; Briem & Hedman, 1995; Strayer, Drews, & Johnston, 2003). The following summaries identify other key findings.

*Difficulty of Phone or Driving Tasks.* Performance on driving tasks generally was worse with difficult versus easier phone tasks (Briem & Hedman, 1995; Laberge et al., 2004; McKnight & McKnight, 1993; Shinar et al., 2002) and with difficult versus easier simulated driving situations (Alm & Nilsson, 1994; Liu, 2003, Shinar et al., 2005). For example, Shinar et al. (2005) found that compared with controls, driving performance worsened with hands-free phone tasks when drivers were instructed to maintain a 65 versus 55 mph speed and with complex mathematical tasks versus conversations about personally relevant topics such as a favorite sports team.

*Learning Effects.* Few simulator studies systematically considered learning effects (Shinar et al., 2002, 2005). Shinar et al. (2005) tested across multiple sessions and found substantial learning effects. Initial deleterious effects of hands-free phone conversations on many driving tasks were reduced or eliminated with continued practice, albeit at a faster rate for younger drivers (ages 18–33) than for older drivers (ages 60–71).

*Hand-Held Versus Hands-free Phone Conversations.* Findings regarding the relative effects on driving performance of conversations using hand-held versus hands-free phones were mixed. Several studies found no significant differences in simulated driving performance measures by phone type (Abdel-Aty, 2003; Consiglio et al., 2003; Kircher et al., 2003; Shinar et al., 2002; Strayer, Drews, & Crouch, 2003; Strayer & Johnston, 2001; Strayer et al., 2005). Other studies reported phone tasks were more impairing with hand-held than with hands-free phones with regard to simulated lane keeping (Haigney et al., 2000; Stein et al., 1987), reaction time (Burnes et al., 2002), and steering and lane position (Mazzae et al., 2005). Törnros & Bolling (2005) found that performance on a peripheral detection task while driving was impaired by conversations using hand-held or hands-free phones compared with control. Conversations using either phone type decreased lane deviations compared with control (no phone task), but speed decreased only with hand-held phones.

*Dialing.* Several studies found degradations in driving performance associated with phone dialing, and there is limited research suggesting that voice-activated dialing is less impairing than manual dialing. An early study by Stein et al. (1987) reported that manual dialing increased lane deviation compared with speed dialing, voice-activation dialing, radio tuning, or control. Similarly, Reed and Green (1999) reported that manual dialing reduced precision in speed maintenance and lane keeping compared with control. Törnros and Bolling (2005) found that dialing either hand-held or hands-free phones with loudspeakers degraded performance on a peripheral detection task and increased lane deviations compared with control. Speed decreased when dialing, especially for hands-free phones. Greenberg et al. (2003) found that dialing and entering voice mail prompts using hand-held phones increased lane deviations compared with other distraction tasks (tuning radio, adjusting climate control, voice-recognition hands-free dialing and voice mail prompts, receiving calls with hands-free and hand-held phones). Ranney et al. (2005) reported that manual dialing interfered with lane maintenance more than voice dialing with headset or cradle-mounted phone. Although subjects rated manual dialing more difficult than voice dialing, manual dialing was faster and resulted in fewer errors. McKnight and McKnight (1993) compared responses to traffic situations (e.g., changing speed or direction) for manual dialing versus tuning the radio, casual hands-free conversation, and intense hands-free conversation (problem-solving exercises). All distraction tasks degraded driving performance compared with control, but dialing and casual conversation led to fewer failed responses than tuning the radio and intense conversation. Older drivers (ages 50–80) exhibited worse performance with dialing and simple conversation tasks than did younger drivers (ages 26–49).

*Phone Tasks Versus Other Distractions or Drinking Alcohol.* Several studies found greater effects from hand-held or hands-free phone conversations than from listening to the radio (Consiglio et al., 2003; Strayer et al., 2005). However, Briem and Hedman (1995) found radio listening led to greater degradations in simulated driving on slippery roads than did hands-free phone conversation. Findings from three other studies were inconsistent, depending on the types of phone task, radio task (listening versus tuning), and driving task (Greenberg et al., 2003; Liu, 2003; McKnight and McKnight, 1993; Stein et al., 1987). For example, Liu (2003) found that radio listening increased lane variation compared with "simple" hands-free conversations (e.g., "Where do you live?") but not "complex" conversations (e.g., mathematical calculations, logic puzzles). Strayer and Johnston (2001) reported that hands-free phone conversation tasks disrupted driving performance, whereas listening to books on tape did not.

Consiglio et al. (2003) found similar reaction times on driving tasks for conversing on the phone (hand held or hands free) and for conversing with a passenger. However, Drews et al. (2004) found that subjects talking on phones, of a type not described, were four times more likely to miss their exits compared with those talking with a passenger. In a study comparing hands-free phone conversation with conversation with a passenger, Laberge et al. (2004) reported no differences in speech rate or word complexity for easy (residential) or difficult (urban) simulated driving tasks.

Two studies compared the effects of phone conversation with being dosed with alcohol on simulated driving performance. In both studies, the cell phone and alcohol conditions differed significantly on some measures from baseline driving (without alcohol or phone task), and the cell phone and alcohol conditions differed significantly from each other. In the Burnes et al. (2002) study, performance among drivers when dosed to 0.08-percent blood alcohol concentrations (BACs) was compared with performance among the same drivers when conducting challenging phone conversation tasks (e.g., recall or judgment tasks) on hand-held or hands-free phones. Drivers noticed fewer roadside warning signs and were slower to respond to signs when using phones than when dosed by alcohol. Travel speeds were slower and more varied on curved roadways when drivers used phones than when dosed with alcohol, although lane-keeping measures were worse for drivers when dosed with alcohol. In the Strayer, Drews, and Crouch (2003) study, performance among drivers when engaged in natural conversations using hand-held or hands-free phones was compared with performance among the same drivers when dosed to 0.08-percent BACs. Drivers had more simulated rear-end collisions, greater following distances, and took longer to recover speed lost during braking when using phones than when dosed with alcohol. However, drivers applied greater braking pressure when dosed with alcohol, perhaps due to their shorter following distances.

*Gender.* Most studies included male and female participants, but few examined gender differences. Briem and Hedman (1995) found that males exhibited slightly better vehicle control than females on simulated slippery roads during both radio and hands-free phone conversation tasks. Woo and Lin (2001) found no significant gender differences in the effects of a hand-held phone conversation task on reaction times.

*Age.* Definitions of older and younger drivers varied. For example, older drivers were defined as ages 40–50 (Ranney et al., 2005), 50–80 (McKnight & McKnight, 1993), and 65–74 (Strayer & Drews, 2004), and younger drivers were defined as ages 16–18 (Greenberg et al., 2003) and 18–25 (Strayer & Drews, 2004). More than a third of the simulator experiments included only drivers 35 and younger, and less than a third included drivers older than 60.

Several studies found that the effects of phone conversation tasks on reaction times were greater among older drivers (Alm & Nilsson, 1995, McKnight & McKnight, 1993; McPhee et al., 2004; Nilsson & Alm, 1991; Woo & Lin, 2001). Other types of degradations that were exaggerated among older drivers were detection time (McKnight & McKnight, 1993), visual scanning (McCarley et al., 2004), lane keeping and driving speed (Nilsson & Alm, 1991), visual fixation and recognition memory (McPhee et al., 2004), and time to dial and answer phone (Ranney et al., 2005). One study found no age differences; effects of hands-free phone conversation tasks on reaction time, following distance, and speed recovery after braking did not differ between drivers ages 18–25 and those ages 65–74 (Strayer & Drews, 2004). Shinar et al. (2005) observed that on most driving-performance measures with hands-free phone tasks, drivers ages 60–71 performed worse than drivers ages 18–33 at baseline, and improved at slower rates on repeated tasks. However, by the fifth day of testing older drivers performed similarly to younger drivers on most measures.

Few studies included participants younger than 18 or explicitly examined the effects of phone use among teenagers. Greenberg et al. (2003) reported that, when compared with adult drivers (ages 25–66), teenager drivers (ages 16–18) detected far fewer events in front of vehicles when dialing hand-held phones and had more lane deviations during hand-held voicemail tasks. Shinar et al. (2005) observed similar performances on driving measures (e.g., speed, lane keeping) for younger drivers (ages 18–22) and intermediate drivers (ages 30–33), and both groups performed better than older drivers (ages 60–71). In another study, Ranney et al. (2005) found that younger drivers (ages 18–25) were faster than older drivers (ages 50–60) at dialing and answering hand-held and hands-free phones.

*Divided Attention.* The limited ability of humans to divide attention among multiple tasks helps explain why distractions may degrade simulated or instrumented driving performance. It is well established that people have a limited amount of attentional resources, and focusing attention on one task (e.g., the cognitive load of a phone conversation) reduces the capacity to process information needed to perform other tasks (e.g., driving). Performance degradations may result even when two tasks use different senses. A study on cortical activity during shifts of attention between visual and auditory stimuli suggests that when attention is focused on listening, the ability to process visual stimuli may be hindered (Shomstein & Yantis, 2004). In experiments conducted in simulators and in instrumented vehicles driven in real traffic, Engström et al. (2005) found that a visual task (examining matrices of arrows on an LCD screen to determine whether an upward arrow was present) and an auditory cognitive task (counting several different target sounds, presented in sequence among non-target sounds) affected driving performance differently. Visual demand led to reduced speed and increased lane-keeping variation. The auditory cognitive task did not affect speed but reduced lane-keeping variation and increased gaze concentration toward the middle of the road. Results generally were consistent between experiments conducted in simulators and those conducted on real roads. Strayer, Drews, and Johnston (2003) hypothesized that "attentional blindness" explained why a hands-free phone conversation reduced a driver's ability to recall billboards they had visually focused on. Another study found that a hands-free conversational task reduced visual attention, as measured by the useful field of view (Atchley & Dressel, 2004).

*Meta-Analysis of Experimental Studies.* One meta-analysis of experimental study findings was identified. Horrey & Wickens (2004) derived single estimates of the effects of phone use versus control on lane-keeping ability and response time, based on 16 studies (representing 37 analysis entries) that included three on-road, one test-track, and 12 simulator studies. The analyses included five moderator variables hypothesized to influence effects of phone use: measure of driving performance (lane keeping versus response time), hand-held versus hands-free phone, naturalistic conversation versus information processing tasks, passenger versus remote conversation, and simulator versus field study. Studies were excluded that did not meet the requirements of meta-analysis (e.g., single degree-of-freedom main effects not derived), compare phone use with a single-task baseline condition, examine lane tracking or response time measures, or focus on effects of phone conversations.

Significant decrements in driving performance were associated with phone use while driving, manifested primarily in increased response time. Unweighted effect size (product moment correction [r]) for response time was 0.60 overall, 0.56 for hands-free phones, and 0.68 for hand-held phones. This means that talking on a cell phone, whether hand held or hands free, explained more than a third of the differences in response times among subjects. The effect size for lane keeping/tracking was smaller and not significant ($r = 0.22$ overall, $r = 0.17$ for hands-free phones, $r = 0.27$ for hand-held phones). The authors hypothesized that lane keeping and response to hazards depend on ambient and focal vision, respectively, which may be affected differently by phone conversation. Estimated effects did not differ significantly for hands-free and hand-held phones, for phone and passenger conversations, or for simulator and field experiments. However, there were greater effects for conversation (e.g., discussion of current events) versus information processing (e.g., word game) tasks, although both were significant.

Studies that examined other driving measures were excluded, and only the conversational component of phone use was examined. Because the researchers failed to account for potential publication bias, it is possible the reported effects may overestimate the actual effects. In addition, correlations between the moderator variables were not provided, so it is possible the results were affected by high inter-correlations.

*Summary.* Experimental studies have found that simulated or instrumented driving tasks are compromised by tasks that are intended to replicate phone conversation, whether using hands-free or hand-held phones, and may be further compromised by the physical distraction of handling phones. Slowed reaction time was the effect most commonly found. Studies have found greater effects among older drivers (e.g., ages 50–80) than among younger drivers and with more difficult phone or driving tasks. There is mixed evidence regarding whether effects also may be greater among young adults or teenagers than among drivers of other ages. No clear gender differences have been identified. Experimental findings on the relative effects of phone use and other types of distractions while driving are mixed, but there is some evidence that phone conversations are more disruptive than conversations with passengers or manipulating a radio, CD, or cassette player. Two simulator studies suggest that either talking on cell phones or being dosed to 0.08-percent BACs affects simulated driving performance, but the effects are different. For example, one study found that drivers on cell phones tended to have greater following distances and slower reaction times when braking, whereas drivers dosed to 0.08-percent BACs tended to have shorter following distances and to brake faster and with greater force.

Although the preponderance of experimental evidence indicates that phone use can be distracting, the implications for real-world driving are unclear because experimental studies do not take into account how and when drivers use phones in their own vehicles and may not accurately reflect the effects of phone use on real-world driving performance. There is some experimental evidence that drivers may compensate for distraction by driving more slowly and allowing greater following distance.

### *Effects of Phone Use on Real-World Driving*

Using video cameras and other in-vehicle technologies, naturalistic studies record drivers' behaviors during a period of everyday driving. These studies are costly, and volunteer subjects' driving may be affected by the knowledge that they are being monitored. However, naturalistic studies provide a way to gather detailed real-world data on the patterns, contextual circumstances, and effects of drivers' phone use. With large representative driver samples and longer monitoring periods, there is the potential to examine the effects of phone use on crashes and near crashes.

A small-scale Swedish study observed seven drivers who drove as part of their job responsibilities and used a variety of phone systems (Esbjörnsson & Juhlin, 2003). Data were collected by in-vehicle video cameras, audio recorders, and research observers. Phone calls served many purposes, and business calls generated a variety of associated tasks such as taking notes. Drivers generally self-regulated phone use according to the demands of the driving situation, and there were instances when drivers made the other conversant aware of the driving situation so that the conversation could be suitably adapted. The authors concluded that driver adaptation may play an important role in mitigating potential crash risks of phone use.

A U.S. study documented the behavior of 70 drivers, including seven males and seven females in each of five age groups ranging from 18–29 to 60 and older, during approximately one week of everyday driving (Stutts, Feaganes, Rodgman, Hamlett, Meadows, et al., 2003; Stutts, Feaganes, Rodgman, Hamlett, Reinfurt, et al., 2003). Subjects were audiotaped, and cameras continuously filmed the driver's face, vehicle interior, and the roadway immediately ahead of the vehicle. Based on three hours of randomly selected data for each subject, drivers engaged in some form of distracting activity for 16 percent of the total time and used cell phones for about one percent of the time. About one-third of drivers used cell phones at least once, and these drivers used phones for four percent of their driving time. Dialing and talking/listening, but not answering, were more likely to occur when a vehicle was stopped. The small sample size limited the detection of significant associations between distractions and driving-performance measures. When compared with driving when not using a phone, dialing/answering a phone and talking/listening were associated with more frequent driving without both hands on the steering wheel; dialing/answering was associated with more frequent occasions of eyes turned inward. There were more adverse vehicle events (e.g., lane wanderings) when dialing/answering a phone, but not significantly so. When debriefed after the data were collected, 15 of the 70 subjects said that being monitored had changed their driving, most commonly by driving more safely.

In the "100-Car Naturalistic Driving Study" (Neale et al., 2002; Neale et al., 2005; Virginia Tech Transportation Institute, 2005), drivers were monitored in a major metropolitan area for 12–13 months. The majority of drivers drove their own vehicles, and data were collected for 109 primary drivers and 132 secondary drivers. To achieve a goal of recording crashes and near crashes, the sample was biased toward drivers younger than 25 and drivers with relatively high annual mileage. Video cameras and a variety of other in-vehicle technologies (e.g., global positioning system, speed and brake sensors) continuously recorded case vehicle behavior (e.g., following distance, unplanned lane deviation), other vehicle behaviors, roadway characteristics, and driver behaviors. "Trigger events" precipitated review of data leading up to and following "events," which included 69 crashes (defined as any contact between a case vehicle and another vehicle or object, including 15 police-reported crashes), 761 near crashes (rapid, severe evasive maneuvers required to avoid crashing), and 8,295 incidents (evasive maneuvers of lesser magnitude than near crashes). Some form of driver inattention was present in most crashes and near crashes, and almost all rear-end crashes. Drivers were using wireless devices in seven percent of all types of events, and this occurred far more often than talking with passengers, eating and drinking, or engaging in other secondary tasks. Wireless devices were usually cell phones and involved conversations more often than dialing. Measures of exposure and relative risks for cell phones and other distractions were not reported.

Mazzae et al. (2005) examined the frequency and duration of phone use while driving and driving performance as a function of phone type (hand-held, hands-free headset, hands-free with voice dialing). Ten subjects drove instrumented vehicles for six weeks, using each phone type for two weeks. Among the findings were that hand-held phones were associated with more calls and longer calls, and that drivers made fewer calls in heavy traffic than in light traffic, especially when using hands-free phones. Driving performance measures did not differ significantly by phone type or for phone use compared with baseline. Although hands-free phones enabled drivers to keep both hands on the wheel more often than did hand-held phones, drivers infrequently steered with both hands during baseline. Phone use did alter eye glance behaviors.

*Summary.* Naturalistic studies have documented that phone use and other distractions are common among drivers and often are present when a crash, near crash, or other driving event occurs. One study found that drivers using phones were less likely to drive with both hands on the wheel and that dialing/answering affected visual attention measures, and another study concluded that drivers self-regulated phone use in response to driving demands. With adequate and representative samples of drivers and study designs that incorporate exposure data or appropriate control groups, these studies may provide useful data on the patterns and circumstances of phone use, the types and extent of problematic driving behaviors caused by phone use, and the risk of crashes and near crashes associated with phone use.

***Cell Phones and Crash Risk***

Mounting evidence from experimental and naturalistic studies indicates that phone use degrades driving performance. However, only studies of crash-involved drivers can quantify the crash risk associated with phone use. Twenty-one such studies were reviewed. The strength of these studies was assessed in terms of the study design and the reliability of data on crash-involved drivers' phone use.

Most states do not provide data elements for drivers' phone use on their police crash report forms (Governor's Highway Safety Association, 2004), and researchers, highway safety organizations, and others have called for fuller, more standardized reporting by states (Goodman et al., 1999; Governor's Highway Safety Association, 2004; Huang et al., 2003). However, even with standardized reporting requirements, police reports will not be useful in assessing the role of phone use in crashes because the data on phone use are unreliable. Absent witnesses to a crash or a driver's admission, a police officer cannot discern whether a crash-involved driver was using a phone. Trend analyses of police crash report data are even more problematic because reporting practices likely have changed as attention to the potential risks of phone use has increased. Studies that relate crash severity to drivers' phone use may result in spurious findings because more severe crashes are investigated more thoroughly. For these reasons, it is important that researchers establish crash-involved drivers' phone use independent of police reports. It also is necessary to use research designs that incorporate appropriate measures of exposure (i.e., prevalence of phone use) or comparison driver groups. Based on these criteria, there are few methodologically sound studies of crash risk.

*Studies of Police Crash Reports or Insurer Reports.* Of the reviewed studies, about half used police crash report data to estimate the proportion of crashes attributable to phone use. In the United States, researchers examined national crash databases including the Fatality Analysis Reporting System (Goodman et al., 1999) and Crashworthiness Data System (Goodman et al., 1999; Stutts et al., 2001; Wang et al., 1996), or state crash reports (California Highway Patrol, 2002; Glaze & Ellis, 2003; Goodman et al., 1999; Huang et al., 2003). These studies analyzed computerized files of coded data, and some also reviewed police narrative reports (Goodman et al., 1999; Huang et al., 2003; Reinfurt et al., 2001) or case files from in-depth crash studies (Goodman et al., 1999). Stevens and Minton (2001) coded and analyzed in-depth police reports of fatal crashes during 1985–95 in the United Kingdom. All of the above studies reported that less than one percent of crashes were related to phone use. Based on crash reports from three Taiwanese cities for four months, drivers in four percent of crashes were using phones (Woo & Lin, 2001). As noted above, all these estimates were unreliable because of the limitations of police crash report data. Characteristics of cell-phone-related crashes were examined in some of these analyses (e.g., Goodman et al. 1999; Huang et al., 2003). However, these results also were subject to reporting biases and were based on very small samples of reported cell-phone-related crashes.

A few studies applied case-control methods to police-reported crash data by comparing drivers reportedly using phones (cases) to those reportedly not using phones (controls). In New Zealand, Lam (2002) examined the relative risk of driver death/injury associated with phone use. Violanti (1997, 1998) used Oklahoma police crash reports to estimate the relative risk of death associated with phone use or presence. However, epidemiologic approaches in these studies could not compensate for the data limitations, which included not only unreliable police-reported information on phone use but also extremely small samples of cell-phone-related crashes (0.3 percent or less of crashes). With regard to Violanti (1997, 1998), researchers noted additional methodological limitations (Cher et al., 1999; McEvoy & Stevenson, 2003) and problems in the coding of cell phone presence/use in Oklahoma crash reports (Goodman et al., 1999). Violanti and Marshall (1996) reported increased crash risk for drivers talking on cell phones at least 50 minutes per month (not necessarily while driving), based on mail surveys of 100 drivers involved in reportable collisions in New York State and 100 noncrash-involved drivers randomly drawn from driver's license files. Study limitations included poor participation rates (rendering the samples of controls and subjects nonrandom), very small sample sizes, and failure to control for or match controls on driver age, gender, or miles driven.

Using files from two large insurance companies in Norway, Sagberg (2001) sent a mail survey to a random sample of drivers who recently had submitted crash claims. Drivers were classified according to whether or not they were assessed as culpable by the insurer. Less than one percent of drivers reported using phones when the crash occurred. An induced exposure approach, in which nonculpable drivers were assumed to provide a measure of driving exposure, found a twofold increase in crash risk with phone use. Study limitations included a low participation rate (31 percent), small samples of reported drivers using phones, reliance on drivers' self-reports to determine phone use, and reliance on insurer records to assess driver culpability.

*Other Study Approaches.* Several approaches have been used to verify crash-involved drivers' phone use. Young (2001) used data from OnStar, an in-vehicle embedded phone system that permits drivers to receive various services by calling a travel advisor or automatically dials an advisor in the event of an airbag deployment. Of the eight million calls to OnStar advisors between October 1996 and May 2001, eight calls were followed in less than 10 minutes by an airbag call. This suggests an extremely low prevalence of crashes occurring during or shortly after calls. However, the study had numerous limitations including that other phone calls made by drivers were not examined, vehicles with OnStar were not a representative sample of the vehicle fleet, some crashes did not result in airbag deployment, and calls to advisors likely were atypical of other cell phone calls.

Wilson et al. (2003) identified drivers using phones from a single set of roadside observations in Vancouver, and records of insurance claims and police-reported crashes were obtained for about half the observed drivers. Compared with nonusers, observed phone users more often were male, ages 25–44, and had higher counts of prior alcohol and traffic violations. After adjusting for estimated age, gender, alcohol offenses, exposure (represented by not-at-fault crash claims), and aggressive driving offenses, the relative risk (RR) of at least one at-fault crash claim was significantly higher for phone users than for nonusers overall (RR = 1.2), and particularly for female users (RR = 1.3) than for male users (RR = 1.1). Phone users had a higher proportion of rear-end collisions. The authors noted they may have "over-controlled" for potential confounding variables, particularly other risky driving behaviors, thereby masking the effects of phone use.

Four studies used cell phone company billing records to establish phone use. In a study of near-field radio frequency exposure from phone use, Dreyer et al. (1999) obtained billing records for subscribers of two large U.S. cell phone carriers serving several metropolitan areas, and information on deaths among these persons came from the National Death Index. It was reported that standardized motor vehicle crash deaths per 100,000 person-years in 1994 increased as cell phone minutes per day during November–December 1993 increased. Useful conclusions relative to crash risk could not be drawn; however, as phone use while driving was not documented, data on driving exposure were not obtained, and the statistical significance of differences was not reported.

Cell phone company billing records have not been available for crash-involved drivers in the United States. However, studies conducted in Toronto (Redelmeier & Tibshirani, 1997a) and in Perth, Western Australia (McEvoy et al., 2005), used billing records to verify phone use at the time of a crash. Both studies used a case-crossover design, which is a variation of the case-control design that is appropriate when a brief exposure (drivers' phone use) causes a transient rise in the risk of a rare outcome (crash). In these studies, a driver's phone use at the estimated time of a crash (hazard period) was compared with the same driver's phone use during control periods at the same time of day during the week prior to the crash. By using drivers as their own controls, the design controls for driver characteristics, including risk-taking propensity, that may affect crash risk but do not change over a short period of time.

Redelmeier and Tibshirani (1997a) studied about 700 Canadian drivers who were involved in collisions during July 1994–August 1995 and resulting in property damage but no personal injury. A driver's use of a cell phone up to 10 minutes before a crash was associated with a fourfold increased likelihood of crashing. Relative crash risk associated with phone use was not significantly different for various driver characteristics such as age and gender. Hands-free phones appeared to offer no safety advantage over hand-held phones, but these analyses were hampered by the small proportion of drivers with hands-free phones.

In Perth, McEvoy et al. (2005) studied about 500 drivers who were involved in crashes during April 2002–July 2004 and necessitating hospital attendance. A driver's use of a cell phone up to 10 minutes before a crash was associated with a fourfold increased likelihood of a serious crash. Increased crash risk did not differ significantly according to whether the phone was hand held or hands free, and increased risk was similar among male and female drivers and among drivers 30 and older and those younger than 30. Although it has been illegal since July 2001 for drivers to use hand-held phones in Western Australia, a third of calls before crashes and on trips during the previous week reportedly were on hand-held phones. The sample size was not large enough to assess whether certain types of hands-free devices were safer; only six percent of drivers reported having phones with voice-activation features.

Laberge-Nadeau et al. (2003) surveyed drivers in Quebec by mail, and driver records and cell phone company billing records were obtained for cell phone owners who granted permission. Based on self-reported survey data, the relative risk (RR) of a crash, but not an injury crash, was slightly but significantly higher among cell phone users than among nonusers for both male drivers (RR = 1.1) and female drivers (RR = 1.2), after adjusting for age, miles driven, and other driver characteristics. Based on phone billing records, the adjusted relative risk of at least one crash per month doubled for heavy phone users compared with those who made minimal use of cell phones or nonusers. Cell phone records were not linked with times of driving in these analyses, and there were low participation rates for the mail survey and cell phone billing records. Crash rates were higher for survey nonrespondents than for respondents, especially for males, suggesting a volunteer bias.

Min and Redelmeier (1998) studied whether the frequency of motor vehicle collisions was correlated with increases in cell phone use (derived from activity of cell phone towers), but concluded the effects of cell phone use on collisions were small relative to biases in ecologic analysis.

*Summary.* It is important that studies of crash risk verify the phone use of crash-involved drivers independent of police crash reports. One source for verifying phone use is cell phone company billing records. Such records have been unavailable in the United States, but two studies conducted elsewhere found a fourfold increase in the risk of a property-damage-only crash associated with cell phone use, and a fourfold increase in the risk of a crash serious enough to injure the driver. Relative crash risks did not differ significantly between male and female drivers or between younger and older drivers, and the risks were similar for hand-held and hands-free phones. No reliable estimates of the proportion of crashes in which phone use was a factor have been reported.

***Evaluations of Laws and Other Policy Studies***

Several studies have examined the effects of laws prohibiting drivers' use of hand-held cell phones on such use. Observational studies conducted in New York state (McCartt et al., 2003), Washington, D.C. (McCartt et al., 2006), and the United Kingdom (Johal et al., 2005) found that drivers' hand-held phone use fell by about 50 percent a few months after the laws took effect. In New York state, phone use measured about 18 months after the law had increased to a level not significantly different from that before the law (McCartt & Geary, 2004). Although a spate of publicity surrounded the passage and initial implementation of the law, it dissipated soon thereafter. Cell phone citations represented about two percent of all citations issued for traffic violations during the first 15 months of the law; there was no statewide publicized enforcement campaign. Thus, it appeared that a drop-off in publicity and the lack of a publicized enforcement campaign may have led to the erosion in compliance over time. Similarly in Finland, observations of hand-held cell phone use conducted after a hand-held ban took effect found that phone use was about three percent shortly after the ban and about six percent one year later (Rajalin et al., 2005). However, a recent study of the Washington, D.C., law found a more lasting effect. The 50 percent decline in drivers' hand-held phone use measured a few months after the law took effect had endured when use was measured about a year later (Insurance Institute for Highway Safety, 2006). It was not clear why the results in New York state and Washington, D.C., differed, but the researchers noted that D.C. is widely known for strict enforcement of traffic laws. Citations for cell phone violations represented eight percent of all moving violations in D.C. compared with four percent in New York. Another factor may have been the continung media attention in D.C. about the dangers of phoning while driving.

The expectation is that some drivers in jurisdictions with hand-held cell phone bans will switch to phones with hands-free features. In Washington, D.C., courts may waive the fine for a first offense if drivers provide evidence that a hands-free device has been obtained. Telephone survey research in New York showed that the proportion of drivers using phones who reporting having hands-free features/adapters increased from 50 percent immediately before the law to 64 percent about 18 months after; however, about half these drivers said they did not always use the hands-free features when driving (Dowling & Hammer, 2003). Telephone surveys of Finnish drivers found that among drivers who owned cell phones, the percentage owning hands-free devices was 34 percent before the law, 52 percent shortly after, and 48 percent one year later (Rajalin et al., 2005).

Several economic analyses have sought to estimate the costs and benefits of laws limiting drivers' cell phone use (Cohen & Graham, 2003; Hahn & Tetlock, 1999; Lissy et al., 2000; Redelmeier & Weinstein, 1999). These studies combined estimates of the amount of driving time, the amount of time drivers spend using phones, the increased crash risk associated with phone use, the incremental impact of cell phones on crash rates, the increased economic value of drivers' phone use, and the estimated social costs associated with crashes due to phone use. A recent study measured benefits in terms of quality adjusted life years potentially saved and health care and other services averted from crashes (Cohen & Graham, 2003). Costs included enforcement costs and consumers' foregone willingness to pay for phone use (i.e., the amount of money consumers are willing to spend for phone use while driving), apart from whether calls were placed for business, personal, or other purposes. The study concluded that there is a net benefit of zero for a ban on cell phone use while driving; this differs from earlier findings that the costs of a ban would outweigh the benefits (Hahn & Tetlock, 1999; Redelmeier & Weinstein, 1999). All the economic studies acknowledged the substantial uncertainties associated with the parameters and wide ranges in estimated costs and benefits.

## *DISCUSSION*

The extent to which drivers' cell phone use represents a safety concern depends on the degree of risk associated with phone use and the prevalence of use. It is clear from observational surveys that drivers in the United States and elsewhere commonly use cell phones while driving and that use has increased. There are no indications that use has peaked; the availability of text messaging, Internet access, cameras, and other features on cell phones likely will push use even higher. Although observed phone use is higher among certain types of drivers and in certain geographical areas, phone use apparently has penetrated all groups of drivers to some extent. Drivers report they most often use hand-held phones; hands-free phones, when used, usually are of the headset/earpiece type rather than fully hands-free voice-activation phones.

It is important that studies of crash risk verify the phone use of crash-involved drivers independent of police crash reports. One source for verifying phone use is cell phone company billing records. Two studies using these records had remarkably similar findings: phone use was associated with a fourfold increase in the risk of a property-damage-only crash or a crash serious enough to injure the driver. There were no significant differences in increased crash risk by driver age or gender, and hands-free phones offered no safety benefit over hand-held devices.

Thus, the elevated crash risk associated with phone use and the high prevalence of use make phone use while driving a legitimate highway-safety concern. Most studies of cell phones and driving are experimental, and their findings help explain the elevated crash risk from phone use. The preponderance of experimental evidence is that phone conversations, whether conducted using hand-held or hands-free devices, affect some measures of driving performance to some degree. Various types of driving performance measures have been examined. The evidence is strongest for slowed reaction times, but studies also have documented that drivers conversing on phones are less likely to absorb information on traffic signs and more likely to miss traffic signals and increase lane deviations. Effects are greater for more difficult phone tasks, more difficult driving tasks, and among older drivers versus younger or middle-age drivers. There is mixed evidence regarding whether effects also may be greater among younger drivers. In addition to the cognitive distraction of phone conversations, experimental studies suggest there may be added effects from the physical distraction of handling phones, particularly dialing.

There are no reliable estimates of the proportion of crashes attributable to phone use. Police crash reports are not helpful in this regard. The cause of a crash often cannot be determined, and crashes often involve multiple contributing factors. In addition, police crash reports do not provide reliable information on crash-involved drivers' phone use. Studies have established a driver's increased risk of crash involvement when using a phone. However, to estimate the proportion of crashes attributable to phone risk, this increased risk must be combined with other information including the total amount of driving time among all drivers, the total time drivers spend on phones, and the crash risk due to all causes. Some of this information can only be estimated.

Importantly, the risk of a crash varies widely among drivers and driving situations. In some experimental studies, drivers compensated for the added workload from cell phone conversations by slowing down or leaving more following distance. In addition, in a study with multiple trials there were strong learning effects (i.e., improved performance with practice) for hands-free phone conversations such that initial effects were reduced or eliminated with continued practice. Similarly, a small naturalistic study of drivers using phones for work found that drivers self-regulated phone use according to the demands of the driving situation, and a larger naturalistic study found that drivers were more likely to dial or converse on phones when the vehicle was stopped rather than moving. Such behaviors would not eliminate the risk from phone use but might reduce it.

Discussions about appropriate policy on drivers' cell phone use have often focused on the risk of phone use relative to other important crash risks such as alcohol impairment or speeding, or the risk of phone use relative to other distractions. In a study of the effects of phone use on the risk of a property-damage-only crash, Redelmeier & Tibshirani (1997a) concluded the relative risk of phone use was similar to that associated with driving with a BAC at the illegal threshold. However, in a subsequent paper the authors clarified why driving with a BAC at the illegal threshold is not equivalent to using a cell phone (Redelmeier & Tibshirani, 1997b). This primarily is because the risks associated with alcohol impairment accumulate over the entire duration of a trip and thus usually are much greater than the risks associated with phone use, which typically lasts for only a small portion of a trip. In addition, crash risks are much greater for very high BACs typically found among drivers arrested for impaired driving or involved in crashes. Of the two experiments examining the relative effects of phone use and alcohol, drivers were dosed to 0.08-percent BACs, and the effects of higher BACs were not examined. No research has examined the relative risks of phone use and other crash risk factors such as speeding. Thus, at this point, there is no credible evidence that the magnitude of the crash problem associated with cell phone use is comparable with that associated with alcohol impairment or speeding. Nonetheless, phone use represents a significant driving hazard.

This report summarized experimental findings comparing cell phone use with other distractions. In general, greater effects were found with phone use. It appears, for example, that conversations with passengers can have a protective as well as distractive effect. However, there is no reliable evidence of the relative crash risks associated with various sources of distraction other than cell phone use. The fact that phone use may encompass various types of distraction (cognitive, auditory, visual, etc.), may involve a relatively extended period of exposure, and is interactive would seem to make phone use potentially more impairing than many other common distractions such as eating, drinking, or tuning the radio.

Many jurisdictions around the world have laws prohibiting the use of hand-held cell phones while driving. Studies of such laws found substantial reductions in phone use immediately after the laws took effect. In New York state, phone use subsequently returned to levels seen before the law, but in Washington, D.C., substantial declines in phone use were sustained after one year. Although it is not clear why the results in these jurisdictions differed, the more lasting effect in Washington, D.C., may have been due to more rigorous enforcement coupled with ongoing media attention to the dangers of phoning while driving. Laws banning drivers' hand-held phone use may be beneficial to the extent that not all drivers would make the switch to hands-free phones. However, even full compliance will not eliminate the risk of crashes to the extent that drivers continue using or switch to the types of hands-free devices commonly used. Hand-held phone laws also may convey a message to drivers that hands-free phones are safe, which is counter to the preponderance of scientific evidence.

Laws limiting all phone use while driving would be difficult to enforce. Some drivers would comply with such laws, but experience with other highway safety laws indicates publicized enforcement is needed to achieve widespread long-term compliance. A possible solution in the future is to change cell phone technology so phones cannot be used except for emergency calls when vehicles are in motion, but it is unlikely the industry would embrace such an approach or that tamper-proof systems could be developed. New vehicles increasingly are being equipped with Bluetooth technology, facilitating voice activation and thus fully hands-free phone use. At least one jurisdiction, the Australian state of Queensland, is examining the merits of a regulation to require all new cars to be equipped with Bluetooth (Queensland Transport and Main Roads, 2005). Fully hands-free phones may eliminate the physical distraction of handling phones, but the distraction from phone conversations would remain. The relative risks associated with different types of hands-free phones have not been established, but experimental evidence strongly suggests that conversations—even if conducted using fully hands-free voice-activation phones—are distracting.

There is growing interest among U.S. states in curbing phone use among teenage drivers. Observation surveys have not estimated the extent of phone use among teenage drivers. However, the 2005 observation survey of U.S. drivers reported that one in 10 drivers estimated to be ages 16–24 were using a hand-held cell phone at any given daylight moment. This was significantly higher than the use rate for drivers estimated to be ages 25–69 (six percent) or 70 and older (one percent) (Glassbrenner, 2005b). Ten U.S. states and the District of Columbia have laws restricting the use of cell phones while driving for teenagers in graduated licensing systems. In September 2005, the National Transportation Safety Board (2005) placed restrictions on wireless communication devices among teenage learning drivers on its "most wanted" list of transportation safety improvements. Increased crash risk associated with phone use among teenage drivers has not been estimated; the best studies of crash risk had very small samples of teenage drivers. Experimental research suggests that young drivers are not as efficient as more experienced drivers in processing the visual information needed to drive safely while attending to nondriving tasks (Mourant & Rockwell, 1972; Summala, 1996).

There also is experimental research suggesting the effects of phone use on some driving performance measures may be greater among teenage drivers than among adult drivers, and greater among novice drivers than among experienced drivers. One experimental study reported greater deleterious effects from phone use on simulated driving performance among teenagers (ages 16–18) than among adults (ages 25–66) (Greenberg et al., 2003). An experimental on-road study found that experienced drivers (ages 29–44) allocated visual attention better than novice drivers (ages 18–24) (Wikman et al., 1998). Another on-road study reported that drivers ages 16–17 and drivers ages 18–24 were more likely than older drivers to express willingness to use cell phones and other in-vehicle technologies in various driving situations (Lerner & Boyd, 2005). Thus, there is evidence that cell phone use among young novice drivers may be particularly problematic, although enforcement of a ban on such use would be challenging.

In sum, there is a growing body of evidence, including methodologically sound studies of crash risks, that drivers' cell phone use substantially increases crash risk. Crash risk increases for men and women, young and old, and for hands-free as well as hand-held phones. Laws restricting hand-held phone use have had only limited compliance, and their effect on safety is unclear. More effective countermeasures are needed but are not known at this time.

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